MZO-09

Vardhman Mahaveer Open University, Kota

Entomology II

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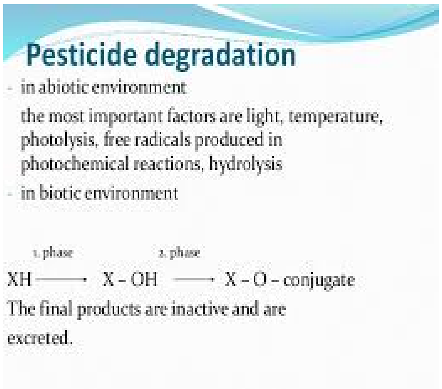
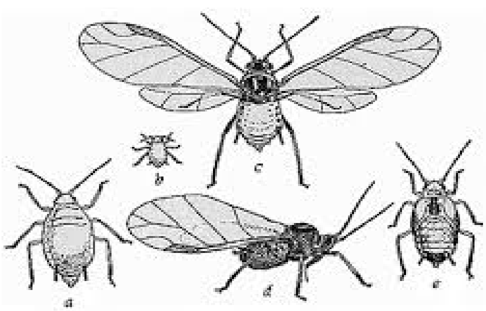
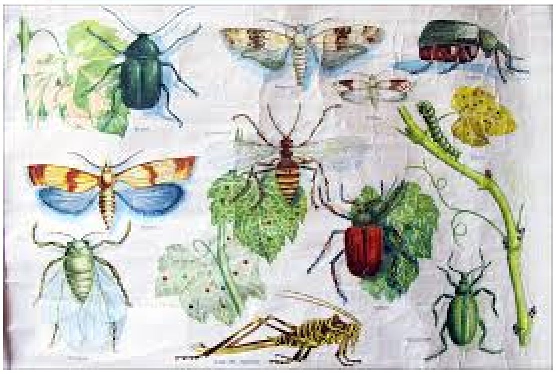




Aphids: a, wingless; b, newborn nymph; c and d, winged; e, nymph



Entomology II

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Preface

The present book entitled "**Entomology II**" has been designed so as to cover the unit-wise syllabus of MZO-09 course for M.Sc. Zoology (Final) students of Vardhman Mahaveer Open University, Kota. The basic principles and theory have been explained in simple, concise and lucid manner. Adequate examples, diagrammes, photographs and self-learning exercises have also been included to enable the students to grasp the subject easily. List of books suggested for further study will be a great help the students. The unit writers have consulted various standard books and internet as their reference on the subject and they are thankful to the authors of these reference books. Suggestions for the further improvement of the book will be thankfully acknowledged and incorporated in further editions.

Unit -1

Definition and Classification of Insecticides

Structure of the Unit

1.1 Objective

After going through this unit you will be able to answer the following question

- What are pesticides?
- How the chemical control started long years back?
- How pesticides are classified?
- What are the importance of pesticides in trophic level of food chain?
- What are I, II and III generation pesticides?

1.2 Introduction

Pests are organisms that damages human resources and compete for his food supplies. These are small or large organism which directly or indirectly related to human beings. The examples of pest are like rat, grasshoppers, moths, stored grain insects and many more. They damage agricultural crops, causes diseases in human or animals, furniture, or any article. The FAO defines pesticide that any chemical substance that prevent, destroy, attract, repel or control any pest including unwanted species of plants or animals. Pesticide is a general term used to kill any pest.

Specific terms such as insecticide to kill insect, acaricide for ticks and mites, fungicide for fungal control, herbicide to remove herbs, rodenticide to kill rats, nematodicide to harm nematodes, bactericide to kill bacteria, etc. are used to indicate precisely the target pest. In India consumption of chemical pesticides are more as compared to the World consumption. The insecticides are classified on the basis of mode of entry, chemical nature and mode of action. Insecticides are categorized into I,II and III generation.

1.3 Definition and scope of insecticide toxicology

Toxicity

The toxicity of a substance is its capacity to cause injury to a living system as human body or parts of the body (such as the lungs or the respiratory system); a system like a pond, a forest and those creatures that live in direct contact. Toxicity represents the kind and extent of damage that can be done by a chemical.

Dose-Time Relationship

The effect of a pesticide depends on a number of factors; dose-time relationship is the most important factor of all. Dose/dosage is the quantity of a substance used against a surface, plant, or animal to control pest. Time means how long will the exposure occurs. This relationship gives rise to two different types of toxicity acute and chronic toxicity that should be considered at the time of using and handling pesticide.

Kinds of Toxicity

Acute **toxicity** refers to how much toxic is a pesticide to a human, animal, or plant after a single short-term exposure. Acute toxicity is used to describe effects which appear very soon, or within 24 hours of exposure. A pesticide having a high acute toxicity is deadly even when it is absorbed in very small amount. Acute toxicity levels are used to compare how poisonous pesticides are and for the warning statements on the label. Acute toxicity may be measured as acute oral toxicity, acute dermal toxicity, and acute inhalation toxicity.

- **Acute oral toxicity:** Chemicals are given to pest with food and mortality or sub-lethal effects are noted in a short period of time. It is measured in mg/kg body weight. Pesticides enter the body through the mouth by a normal process called ingestion. This can occur when hands are not properly washed before eating or smoking pesticides may be swallowed by mistake. Improper storage of pesticide in food containers can also ingested anywhere along the gastrointestinal tract mainly the small intestine. Once absorbed, they enter the blood stream and circulate throughout the body.
- **Acute dermal toxicity**: Chemicals may be of wet, dry or gaseous are applied to external body parts or surface or may be eye because it is the most sensitive part of the body. Oil or paste forms allow greater absorption through the skin as compared to water-based pesticides. Some pesticides do not pass through the skin very readily while others absorbed quickly through the skin. Skin capacity varies in every pest to act as a barrier to pesticide absorption. The eyes, ear drums, scalp and groin area absorbs pesticides more quickly than other areas. If the skin is damaged or injured penetration by pesticide will be easier. Once they get absorbed through skin, pesticides enter the blood stream and are transported throughout the body.
- **Acute Inhalation toxicity:** Chemicals are in the form of dust or vapor that is inhaled by the pest and toxicity tested. Whether as dust, spray, mist, or fumes, pesticides can be drawn into your lungs as you breathe. Inhalation of pesticides can occur when wettable powders are mixed with water or other solvent in dust form or granule form. Poisoning can also occur while fumigation or spraying without applying breathing apparatus The largest particles that are inhaled stick to the surface of the throat and nasal passages but smaller particles can be inhaled directly into the lungs. Once they are absorbed through the surfaces of the lungs, chemicals enter the blood stream and are distributed to the rest of the body.

***Chronic* toxicity** refers to the delayed poisonous effect after exposure to a substance. Chronic toxicity of pesticides concerns the general public health, as well as those people handling directly with pesticides because of continuous exposure to pesticides in food products, water and the air. It is measured in experimental conditions after three months of either continuous or occasional exposure and at least two generation of test insect is examined for changes in liver tissues, carcinogenic effects and teratogenic properties.

It is not necessary for a material having high acute toxicity, does have high chronic toxicity or with low acute toxicity will have low chronic toxicity. For many pesticides, the toxic effects of single acute exposures are quite different from those produced by chronic exposure. For example, when large amounts of the pesticide cryolite are eaten by rats at one time, little or no harmful effects will be observed as it quickly passes through the intestinal tract and eliminated without harmful effects as it is insoluble. But, if the rats are fed by small amounts of cryolite every day in their food, they become ill and die. Small amount of chemical absorbed from a one-time exposure is not sufficient to cause illness, but absorption of the same small amount every day, can cause chronic illness and death. The effects of both acute toxicity and chronic toxicity depends upon dose; the greater the dose, the greater will be the effect.

We cannot change the inherent toxicity of pesticides, but we can limit the possibility of poisoning by preventing and limiting the exposure rate. In other words, the risk of pesticide exposure is equal to toxicity and route of exposure to the pesticide.

RISK = Toxicity X Exposure

Toxicity in human may vary with the health condition in pregnancy cases, age as child are more sensitive, gender, body size and habits like smoking, drug inhaler or alcohol taker. Effect may of immediate action or delayed, reversible or irreversible, permanent or temporary, mutagenic or suppressant. Toxicity can be measured in terms of LD 50, LC 50, LT 50.

1.4 History of chemical control

The use of chemical control started 1200 BC when Chinese used chalk and wood ash to control insects and botanicals for treating seeds. Pyrethrum was used in mid eighteenth century. A number of insecticides which are synthetic inorganic Paris green, lead arsenate and botanical like rotenone, nicotine started developing in the end of 18^{th} and starting of 19^{th} century. Introduction of chemical pesticides started replacing cultural and ecological control. Age of pesticide began with the discovery of DDT since the period started from 1940. It is divided into three phases as era of optimism, era of doubt and era of IPM.

- **Era of optimism (from 1946 to 1962)**

  As the DDT discover and its insecticidal properties were known other synthetic organic insecticides like HCH, aldrin, dieldrin, parathion, allethrin were discovered, manufactured and applied on field. The organophosphates and carbamates ensure immediate killing of insects and easy to apply. The use of pesticide offers cheap, easier method to yield more production with large profitable amount and hence universally accepted to minimize the pest damage. This is the age of pesticide evolution with dominance of chemical control.

- **Era of doubt (from 1964-1976)**

  Aucante observed the arsenic poisoning, mercury and its health hazards and France banned the use of arsenic products. Due to health hazards of inorganic compounds, organic compounds were extensively used and misused. The problem occurred when these insecticides killed natural enemies, non target species, and beneficial insects and resulted in pest resurgence and outbreak of secondary pest. Rachel Carson mentioned in his book Silent Spring about health hazards due to pesticide misuse. In this era doubt occurred about magic power of chemical insecticides and control measure turn their way to non chemical ways to develop. As the profit is large in using chemical pesticides more chemicals like monocrotophos, fonofos, aldicarb, permethrin and other organophosphates and carbamates develop. One more problem developed with all these as resistance occurred in insect species from one or more insecticides and upto the year 1975; 364 species become resistant. Out of these 70 species showed multiple resistances and 7 developed resistances to all major groups of insecticides. The other problems also generated with contamination of food chain and environment toxicology.

- **Era of IPM (1976 onwards**)

  Forbes enumerated the principles of IPM even before a century. Stern *et a*l. in 1959 gave concept of economic injury level (EIL) and economic threshold level (ETL) and emphasize on the integrated use of selective chemical use and biological control. Pest Management term was first given by Geier in 1970. Then IPM Integrated pest management come in role where the use of all control methods cultural, ecological, biological etc are used to control pest and chemical control only use when the pest population reaches the EIL.

Even today with advances in agricultural technologies losses due to pests and diseases range from 10-90%, with an average of 35 to 40%, for all potential food and fibre crops. As there was no chemical industry, any products used had to be either of plant or animal derivation or, if of mineral nature, easily obtainable. Research into pesticides continued; in 1970s and 1980s the introduction of the world's greatest selling herbicide, glyphosphate there was the synthesis of a 3^{rd} generation of pyrethroids, the introduction of avermectins, benzoylureas and B_t (Bacillus thuringiensis) as a spray treatment. This period also saw the introduction of the triazole, morpholine, imidazole, pyrimidine and dicarboxamide families of fungicides. In the 1990s research activities concentrated on finding new members of existing families which have greater selectivity and better environmental and toxicological profiles. Today the pest management has expanded to include use of genetically modified crops designed to produce their own insecticides or exhibit resistance to broad spectrum herbicide products or pests. These include herbicide tolerant crops like soybeans, corn, canola and cotton and varieties of corn and cotton resistant to corn borer and bollworm respectively. In addition ,the use of Integrated Pest Management (IPM) systems which discourage the development of pest populations and reduce the use of agrochemicals have also become more widespread. These changes have altered the nature of pest control and have the potential to reduce and/or change the nature of agrochemicals used.

1.5 Pesticide use

Reasons for Use of Pesticides

1) Pesticides are used to ensure better protection at standing crop harvest stage against unpredictable losses caused by plant diseases and pests.
2) Pesticides are used to improve both quality and quantity of food crop.
3) Pesticides are used to decrease the vector born and other diseases in humans and animals.

Ideal Pesticide: The ideal pesticide should have the following properties:

1) It should have a broad spectrum to kill the pests.
2) It should not be toxic to mammals.
3) It should not cause harm to plants.
4) It should not be costly, have low production cost.
5) It should be easily formulated and manufactured.
6) It should have optimal residue persistence, without longer residual effect.

7) It should have low toxicity to beneficial insects or non target species.
8) It should be compatible with other pesticides.
9) It should not produce bad odor on vegetables on which it is sprayed.
10) It should be non inflammable and should have non corrosive action on spraying and dusting equipments.
11) It should spread uniformly and quickly degradable.

1.6 Pesticide industry in India

The state-wise utilization of pesticides in India vary, out of the 28 states and 7 union territories of India, above 80% of total pesticide consumption are from five states viz., Andhra Pradesh, Karnataka, Gujarat, Punjab and Maharashtra (FIG 1.2). Rest of the states consumes only 20% of the total pesticides used in whole of the country. Per hectare farmland or cropland usage of pesticides in India is too small as compared to other advanced countries. The available statistics show it to be presently 400-500 g/ha (different sources) in India as against up to about 3000 g/ ha in the USA, Europe and West Germany, and 11800 g/ha in Japan. We share only 3-5% world annual production of pesticides which is about to be 2 million tonnes, against 45% shared by Europe and 24% by the USA (FIG 1.1). In spite of this, the fast growth of pesticide industry in India played a very important role in maintaining Indian Green Revolution free of pests and participating in providing food security to our ever increasing population during the last decade, in particular. Maximum pesticide use in g/ha against crops of cotton, fruits, and plantation crops as compared to rice, cereals, pulses, sugarcane and other crops.

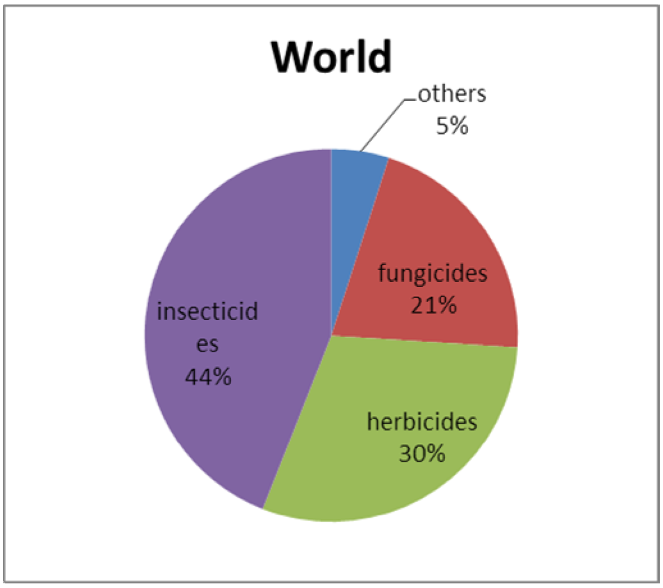


FIG 1.1: Pie chart showing consumption of insecticide throughout world

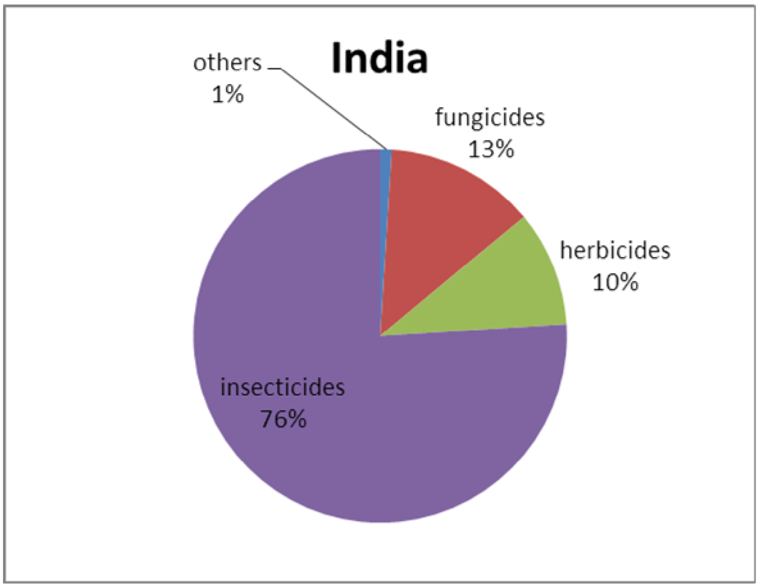


FIG 1.2: Pie chart showing consumption of insecticide throughout India

Pesticide Names: There are three names associated with every pesticide:

1) **Chemical Name**: The systematic name of a chemical compound according to the rules of nomenclature of the International Union of Pure and Applied Chemistry as adapted for indexing in chemical abstracts. For example 3,5,6-trichloro-2-pyridinyloxyacetic acid is a chemical name.
2) **Common Name:** A generic name for a chemical compound (see the Weed Science Society of America list of herbicide nomenclature). For example: The common name for 3,5,6-trichloro-2-pyridinoxyacetic acid is triclopyr. The common name is the name generally used in discussing pesticide toxicology and environmental behavior and fate.
3) **Product Name:** The trade name of a pesticide is referred to the name on the container you purchase. It is also the name to which the EPA registration number is applied at the time of registration. Triclopyr alone is sold as Garlon 3A or Garlon 4.

There are several steps involved in Commercial preparation of Pesticide starting from;

1) Laboratory synthesis of pesticides
2) The preliminary screening of pesticide
3) Formulation
4) Toxicity studies (acute toxicity, oral toxicity, dermal toxicity etc.)
5) Metabolism affecting studies

6) Residual studies
7) Registration of pesticide manufactured
8) Promotion of pesticide
9) Pilot plant studies
10) Commercial Development in factory on large scale

Table 1: Insecticides Registered in India u/s 9(3) of the Insecticides Act 1968 (Personal Communication DPPQ&S, Faridabad (Haryana), (As on 7th March, 2005)

Chlorfenvinphos	Chlorpyriphos
Chlorpyriphas methyl	Cyfluthrin
Cypermethrin	Cyphenothrin
Decamethrin (=deltamethrin)	Diazinon
Dichloro-Diphenyl Trichloroethane (DDT)	Dichlorvos (DDVP)
Dicofol (acaricide)	Difenthiuron
Diflubenzuron	Dimethomorph
Dimethoate	D-trans Allethrin
Endosulfan	Ethion (Acaricide)
Ethofenprox (=etofenprox)	Fenazaquin (acaricide)
Fenitrothion	Fenobucarb (BPMC)
Fenpropathrin	Fenthion
Fenvalerate	Fipronil
Flufenoxuron (acaricide)	Fluvalinate
Formothion	Hydrogen Cyanamid (fumigant)
Imidacloprid	Imiprothrin
Indoxacarb	Lambdacyhalothrin
Lindane (=gamma HCH)	Malathion (also fumigant)

Methomyl	Methyl bromide (fumigant)
Milbemectin	Methyl Parathion
Monocrotophos	Oxydemeton methyl (= metasystox)
Paradichlorobenzene (PDCB)	Permethrin
Phenthoate	Phorate (also nematicide)
Phosalone	Phosphamidon
Prallethrin	Pirimiphos-methyl
Profenofos	Propargite (acaricide)
Propetamphos	Propoxur
Pyrethrins (Pyrethrum) (botanical)	Quinalphos
S- bio-allethrin	Spinosad (microbial)
Tebuconazole	Temephos (= abate)
Thiodicarb	Thiomethoxain
Thiometon	Triazophos
Transfluthrin	Trichlorofon

Remarks: The total number of registered pesticides in India is 186, which is lowest among the top seven pesticide using countries, with USA having highest number of 755 registered pesticides. The neighboring country Pakistan has registered so far 495 pesticides

India produces 90,000 metric tons of pesticides every year and it is the largest producer in Asia and the 12th largest in the world. Overall about 400 million acres area under cultivation 60% approximately of the country's population are dependent on agriculture.

India loses nearly 30% of its potential crop due to damage by weeds, pests, insects and fungus, both before and after harvest. Pesticide helps to increase crop yields with cultivable land is shrinking. The industry manufactures two main types of products the one of which are technical grade pesticides (the basic concentrated chemical compound) and the other is formulations from these technical grade pesticides.

1.7 Classification of insecticides and acaricides

Pesticides have been classified on various basis as follows:

On the basis of effect on target organism

- **Ovicidal** – if kills eggs
- **Larvicidal**- if kills larval stage
- **Adulticidal**- if kills adult stage

1.7.1- Mode of entry (On the basis of route of entry): In the insects there are different routes of entry by which pesticides get inside and cause their effects.

Repper has given the following classification of systemic (FIG 1.3):

- **Stomach poison**: These chemicals enter insect body through gut when the insecticides feed or clean their body parts. Example, inorganic chemicals, arsenicals, boric acid.
- **Systemic poison:** These chemicals are taken up by plants and translocated within the plants or animals when treated with insecticides. When piercing and sucking insects like bugs sucks the juices they are killed. Example, DNOC.
- **Stable systemic**: Insecticides which don't metabolize in the system e.g. sodium fluorpsilicate, sellinum.
- **Endolytic systemics**: Systemic insecticides in which the toxic compound is present in 98% in its original form and taken up by the insects e.g. Schradan.
- **Endometatoxic:** Systemic insecticides in which the toxic compounds gets converted into more toxic form after ingestion, e.g. systox, metasystox.
- **Contact poison:** These chemicals enter the body through cuticle when come in contact and absorbed through integument, example botanicals.
- **Fumigants:** These are highly volatile and enter through the tracheal system through the openings called spiracles and absorbed by the tissues, example respiratory poison – DD, PDV, Naphthalene, CS2.

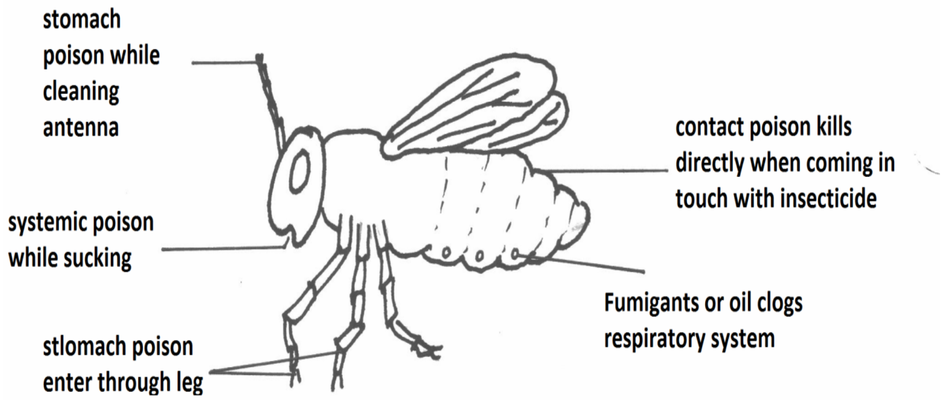


FIG 1.3: General insect showing mode of entry of insecticides

1.7.2- Mode of action

- **Physical poisons:** These compounds exert a physical effect rather than a biochemical effect and these actually kill the insects by suffocation.
  - **i) Asphyxiation:**These may exert a purely asphyxiation effect killing scale insects slowly by exclusion of air. Example heavy mineral oil or emulsion.
  - **ii) Mechanical injury:** These chemical causes abrasion of cuticle leading to the desiccation and death of insect like Aluminium oxide, boric acid.
- **Inert dusts:** They affect loss of body moisture from insects by two types of action. Abrasive dusts e.g. aluminum oxide cause water loss by lacerating the epicuticle and water adsorbents e.g. charcoal remove water as a consequence of their hygroscopic properties.
- **Protoplasmic poisons:** The action of these poisons appears to be associated primarily with the precipitation of proteins e.g. Heavy-metals/ nitrophenols, nitro cresols.
- **Respiratory poisons:** They combine with cytochrome oxidase and other oxidases containing Fe and thus inhibit their catalytic action e.g. HCN, H_2S, CO.
- **Nerve Poisons:** The action of these poisons is associated primarily with their solubility in the tissue lipids. e.g. chlorinated hydrocarbons, organophosphates, botanical insecticides.

i) **Nacrotics**: It induces unconsciousness in insects; they are fat soluble and stores in fatty tissue, nerve sheaths, and lipoproteins. For example, Chlorine, Bromine, Flourine.

ii) **Axonic poison:** It interrupts normal axonic transmission from one cell to another and causes them to stay in permanently depolarized state, example chlorinated hydrocarbon, pyrethroids.

iii) **Synaptic poison:** Nerve poison interferes with acetylcholinesterase that breaks the acetylcholine into acetate and choline, example organophosphate, carbamates.

Acetylcholine-----------→ Acetate + choline
aectylcholinesterase

- **Muscular poison:** These chemical disrupt excitable membrane muscles which results in three fold increase in oxygen consumption and cause paralysis and death. Example, Ryanodine, Rotenone.
- **Molt/chitin inhibitor:** It does not allow the insect to form chitin, example Dimilin.

1.7.3-On the basis of chemical nature

- **Inorganic:** Molecules that do not contain carbon, example: heavy metals like lead and arsenic compounds, Copper products, Sulfur products.
- **Organic:** Molecules contain carbon and may be chain or ring compound hydrocarbons. It can be further divided into different groups as

i) plant originated biochemicals as pyrethrum, nicotine
ii) animal originated chemicals nereistoxin
iii) synthetic organic compounds
iv) Hydrocarbons such as petroleum, oil

Inorganic pesticides

1. **Arsenicals:** made of arsenic compounds

i) **Lead arsenate-** They are weak poison, insoluble in water, stable, have better degree of adherence quality, safer to plants, can be sprayed or dust. Example: acid orthoarsenate, basic orthoarsenate used against *Epilachna*, lemon butterfly.

ii) **Calcium arsenate-** One third more toxic than lead arsenate, incompatible with benzene but compatible with soap, sulphur, used as dust. Example:tricalcium arsenate against cut worms, grasshopper, ants.

iii) **Paris green-** It is green in color, completely soluble in ammonia, used as dust or spray. Example: copper acetoarsenate (Paris green) against Colorado patato beetle.

iv) **Arsenic trioxide-** it is cheaper, active poison, used as baits. Example,grasshoppers, armyworm, ants.

v) **Sodium trioxide-** it is highly soluble in water, highly phytotoxic, used as baits. Example, weedicides, locust control.

2. **Fluorine compounds**: it is relatively safer to plants as compared to arsenicals, less toxic to mammals but it is not obtained in fine powder form so coverage is poor .

   i) **Sodium fluoride**- It is white in color so care must be taken not to be mixed with flour, used as dust. Example:earwigs, locust.

   ii) **Sodium fluosilicate**- It is cheaper, safe and used as baits. Example, moths, cutworms.

   iii) **Borium fluosilicate-** It has less compatibility and corrosive to appliances, used as spray and dust. For example: used against fleas and blister beetle.

   iv) **Cryolite/ sodium fluoaluminate-** It is found as mineral in Greensland as deposits, more toxic to human beings, used against chewing insects. Example: flea beetle.

3. **Sulphur compounds:** It has greater residual effect, strong foul smell; container becomes black so used rarely. Example: lime sulphur.
4. **Phosphorous compound:** It is made of sulphur constituent used as poison baits against rats, crickets, moles.
5. **Mercury compounds:** Mercuric chloride used as repellent against cabbage maggots, ants, termites, cockroaches.
6. **Thallium compounds:** As thallium sulphate used as poison baits against ants.
7. **Boron compounds:** Borax or boric acids against mosquito maggots, houseflies.
8. **Sodium compounds:** Sodium selecate absorbed as systemic poison against aphids, mites.
9. **Antimony compounds:** potassium antimonyl tartarate against thrips, fruit flies.

Organic compounds

i) **Plant originated biochemical-** These are called **botanicals** as they are the components of plants and used as biochemical against pest as they have toxicity effect.

- **Nicotine-** It is a byproduct of tobacco plant *Nicotina tabaccum* and *Nicotina rustica.* It is an alkaloid, colorless, odorless, fast acting and nerve poison. It darkens in light and nicotine content is higher in leaves and stalk of the plant. Example, Nicotine benconite contains 14% nicotine used against codling moth on apple plant; nicotine sulphate is banned in India.
- **Pyrethrum-** It is the first botanical preferred in all botanicals. Flowers come from Yugoslavia and Japan but Kenya supplies most of them. It is obtained from plant *Chrysanthemum coccineum, C. cinerariaefolium, C. cameum.* The active component is pyrethrin I, pyrethrin II and cinerins I, cinerins II affects Peripheral Nervous System (PNS). After coming in exposure to air, heat, sunlight, UV looses its toxic properties therefore stored at 0ºC. It is used as dust or spray and has no residual effect. Can be mixed with other compounds (PBO) to use as synergist against silver fish, bedbugs, flies.
- **Rotenone-** It is the second most widely used botanical, found in leguminous plant *Derris elliptica, D malaccensis* (containing 5-9% rotenone), *Tephrosia, Lonchocarpus utilis, L. uruca* (8-11%) in South America. It attacks nervous system causes paralysis in insects. It is a metabolic inhibitor inhibits respiratory chain by oxidation of NADH-linked substrate. It is used against pest of horticulture crops.
- **Ryaniodine-** It is obtained from the plant *Ryania speciosa.* It is an alkaloid acting as contact or stomach poison, less toxic to mammals than rotenone, longer residual action, most effective in hot weather. It is used against codling moth (*Cydia pomonella*) on apple plant.
- **Sabadilla and Hellebore-** It is product of *Schoenocaulon officinale, Veratrum album* containing alkaloid cevadine, veratridine used as contact or stomach poison. It is least toxic of

all botanicals but highly toxic to honeybees. Used against hemipterous insect, human lice.

- **Azadiracta indica-** Commonly called as neem contains component nimbidine, nimbindiol, azadiractin affects moulting, metamorphosis, oviposition and feeding deterrence. Used against stored grain pest, armyworms, patato beetle, leafhopper, grasshopper.
- **Sweat flag-** It is a constituent of rhizome of aquatic plant *Acorus calmus* found in Western ghats and Nilgiri. Used against stored grain pest.
- **Labelia excelsa-** This plant is found in Western Ghats of South India and used against aphids on snake gourd, tingid bug, mites on castor.
- **Volatile oil plants**- Oils obtained from plants and used as repellent (oil of cedar, citrenella) and attractants (eugenol, geraniol).

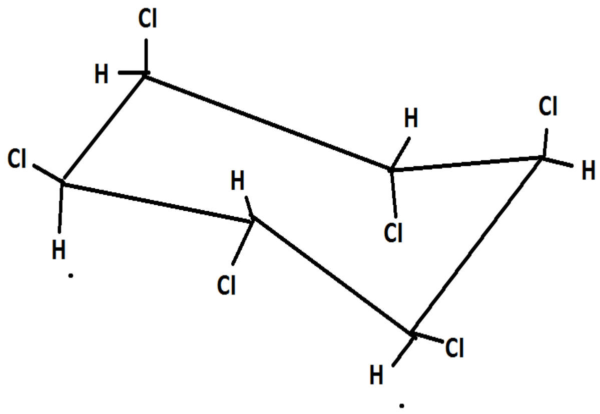
ii) **Animal originated chemicals**- Nereistoxin is a toxic component possess insecticidal properties obtained from marine annelid *Lumbrinereis heteropoda* and *Lumbrinereis brevicirra.*

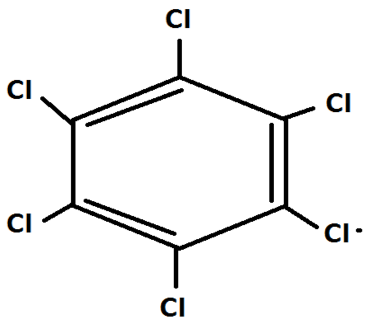
iii) **Synthetic organic compounds-**

- **Dinitrophenols-** They are the derivatives of 4,6-dinitro-2-alkylphenols and their salts or ester. They can be fungicides, insecticides or herbicides.
  - ➢ **DNOC (4,6-dinitro-o-cresol, syntox)-** They are yellow, odorless, solid, highly toxic to plants. It kills all plants in an area.
  - ➢ **DNOCHP (4,6-dinitro-o-cyclohexylphenol)-** yellowish white, odorless, used against red spider mite.
  - ➢ **DNOSBP** (4,6-dinitro-o-butylphenol)- orange color crystalline solid.
  - ➢ **DINOCAP**-trade name is karathane and crotothane used as acaricide and fungicide.
  - ➢ **Binapacryl**- trade name is Endosan, Acricid against all stages of mites

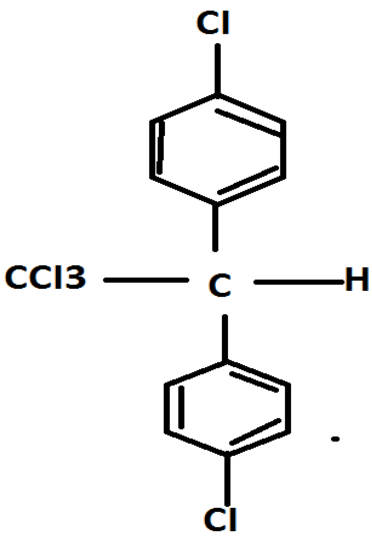
- **Organic thiocyanites**- Trade name is Loro against aphids, spider mites, thrips and Lethane A-70 as cattle sprayer, household insecticide.
- **Organochlorine compounds**- It is the oldest chlorinated hydrocarbon used against pest. They were commonly used in the past, but many have been removed from the market due to their health and environmental effects and their persistence (e.g. DDT and chlordane). They operate by disrupting the sodium/potassium balance of the nerve fiber, forcing the nerve to transmit continuously. Their toxicities vary greatly, but they have been phased out because of their persistence and potential to bioaccumulate (FIG 1.4).
  - **DDT** (dichlorodiphenyltrichoroethane)- It is the first synthetic organic compound and synthesized by German scientist Othner Zeidler in 1874 and the insecticidal properties of DDT is found in 1939 by Paul Muller. It is banned in India and used against wide variety of insect's lice, fleas, mosquito, housefly, cockroaches. Methoxychlor contains 80% pp isomer of DDT used against housefly. Other are DDD, DMC and Decofol.
  - **BHC** (benzenehexachloride)/HCH(hexachlorocyclohexane)- It is more toxic than DDT and stable in light and heat**.** Lindane is **99%** gamma isomer of BHC and discovered by Vander Lindane and do not accumulate in fat safer than BHC but more toxic to insects.
- **Chlorinated terpenes**- It is obtained by chlorination of terpenes.
  - **Toxaphene**-It is used extensively in agriculture and most widely used insecticide but toxic to cucurbits plants and fishes. It is less toxic to man than DDT. Used against grasshopper, thrips, Lepidoptera larva.
  - **Strobane**- It is a chlorinated mixture of camphene and pinene consisting of 66% chlorine.
- **Cyclodiene insecticides**- It is highly chlorinated cyclic hydrocarbon with endomethylene bridged structure prepared by Diels Alderdiene reaction. It is more toxic to DDT act upon nerves ganglion and causes convulsion, hyperactivity and prostration.

- **Eldrin/octalene**- It is white crystalline solid, insoluble in water and converts into dieldrin in animal and plant tissue. It is most effective poison used as dust against grasshoppers and locust.
- **Dieldrin-** It is the epoxy derivative of aldrin having long residual effect, most toxic and most persistant chemical used to control cotton pest, household pest, flies, fleas, termites but restricted to locust.
- **Endrin-** It is less stable than dieldrin, most toxic hydrocarbon insecticide having high residual activity used to control grasshopper, lepidopterous larva, coleopteran larva.
- **Chlordane/octachlor**- It is unstable in presence of alkali, lime which destroys its toxicity to insects. It is used against wireworm, termite, white, grubs, lice, ticks, fleas, ants.
- **Heptachlor**- It is derivative of chlordane and stable compound. It is a nervous poison and four five times more toxic than chlordane. Used to treat soil dwelling insect, termites.
- **Isobenzan/Telodrin-** highly toxic contact insecticides.
- **Thiodon/endosulphan-** Control noxious insects like cucurbits, aphids, pod borer, bugs caterpillar and do not harm beneficial insects. It is non toxic, leave no residues, safe insecticides.





LINDANE **BHC**

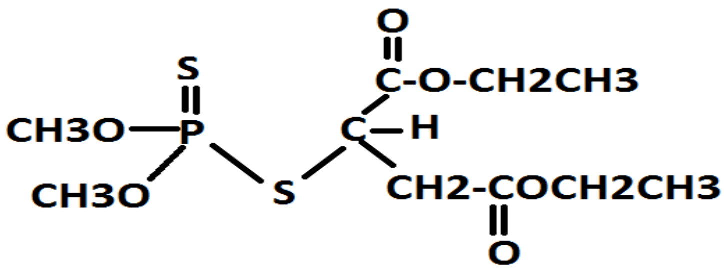


DDT

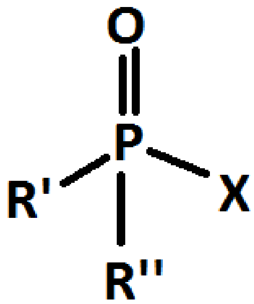
FIG 1.4: Chemical formula of organochlorine insecticides

- **Organophosphorous insecticides-** It is most romantic group of insecticide as it shows systemic and non systemic action both. It breakdown in presence of light into non toxic compound therefore it has replaced chlorinated compounds. It is derived from phosphoric acid with different alcohol group discovered by Schrader. The phosphorous esters inhibit enzyme acetylcholinesterase and most widely used insecticides. They were developed during the early 19th century, but their effects on insects, which are similar to their effects on humans, were discovered in 1932. Some are very poisonous (they were used in World War II as nerve agents). However, they usually are not persistent in the environment (FIG 1.5).

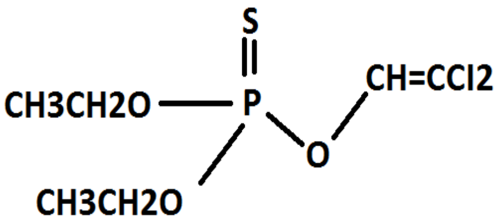
- **Dichlorovos/ DDVP** (Trade name- Nuvan, Dedevap, Noges,Vapona)- It is highly toxic to bees and fishes, having good penetrating power, rapid knock down effect, safe insecticide, do not leave residues.
- **Malathion** (Trade name- cythion, Malathion**)-** It is an aliphatic derivative of organophosphates, causes death in 72 hours and toxicity persist for 7 days. It is safest to all insecticides kills storage pest, all vegetable pest, crop pest.
- **Diazinon** (Trade name- Basudin**)-** It is phosphoric acid esters used as fumigants having good penetrating quality.
- **Parathion** (Trade name- Folidol M, Metacid 50, Metaphos**)-** Extensively toxic to man, high toxic insecticidal properties, non volatile used against mites and aphids.
- **Schradan-** First organophosophate studied safer and most effective.
- **Monocrotophos-** restricted to vegetables.
- **Acetaphate-** Latest insecticide for aphids, leafminer, thrips and vegetable pest.
- **Phorate**- older pesticide used against corn rootworm.
- **Fenitrothion** (Trade name- Foliothion, Sumithion**)-** used for rice pest, bedbugs, fleas.
- **Phoxim-** It is exceptionally fast acting against lepidopterous larvae.



PARATHION



ORGANOPHOSPHORUS INSECTICIDE P- valency 5, R- short chain group, X- leaving group



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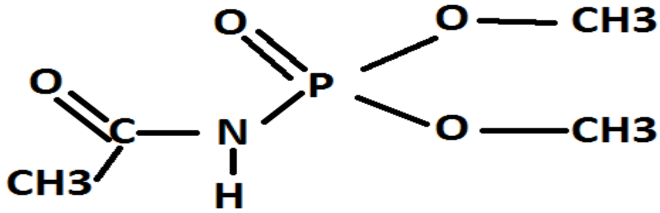
DICHLORVOS



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ACEPHATE

FIG 1.5: Chemical formula of organophophorous insecticides

- **Carbamates**- It is a derivative of carbamic acid having –OCON group and persist about 2-3 years.
  - **Isofenphos/ olfanol**- against rice stem borer, soil insects
  - **Methamidophos**- harmless to bees, eradicate resistant strains.
  - **Carbaryl-** oldest carbamates with low toxicity to human.
  - **Carbofuran-** highly toxic to human being, used against corn rootworms, nematodes, soil insect pest.
  - **Propoxur**-Against chinch bugs, adult mosquitoes extensively used in restaurant and in homes.
  - **Aldicarp** (Trade name- Temik)-against insect pest of potato.
  - **Pyrethroids-** They are synthetic analogues of plant product pyrethrin, most stable, Effects PNS and fastest developing group. It is grouped under categories
    Allethrin- I generation pyrethriod
    Resmethrin- II generation pyrethriod
    Permethrin- III generation pyrethriod
    Cypermethrin, deltamethrin against Lepidoptera and coleopteran.
- **Formamidines**- It is against those insect that develop resistance against organophosphate and carbamates. For example, chlordimeform (Trade name- Fundal, Galecron) most widely used and restricted to non food crops like cotton.
- **Thiocyanates-** Butaxyethoxyethyl thiocynates (Lethane 384) and isoborylthiocyanates (Thanite) causes knock down insecticides safer to use.

iv) Hydrocarbons such as petroleum, oil, kerosene used to wide variety on insects.

1.8 Concept of Ist, IInd, IIIrd generation of insecticides

All the insecticides are categorized in generation as Ist, IInd, IIIrd and even IV on the basis of their discoveries and introduction to the insecticidal world.

Ist **generation pesticides**

- 1st Generation pesticides are simple but they are usually very toxic chemicals which harm almost everything nearby them.
- They includes all the insecticides used in large-scale before 1950's both inorganic compounds like arsenical, fluorine compounds and botanical pesticides as nicotine, rotenone.
- **Inorganic compounds** include sulfur, arsenic, calcium arsenate, copper acetoarsenite, hydrogen cyanide, mercury, lead compounds which are persistent gropu, highly toxic, causes biomagnifications and are non specific in nature.
- **Botanical compounds** include nicotine sulfate, rotenone, pyrethrum, and chlordecone which have properties like non-persistent, highly toxic and causes nervous effects.
- 2500 BC ago the farmers started using the toxic chemical sulfur to kill pests from their crops.
- In 15th century AD wide variety of chemicals such as, arsenic, hydrogen cyanide, mercury and lead compound were used.
- In the starting of 17th century nicotine sulfate obtained from tobacco leaves was discovered observed to be effective pesticide, ants were controlled with mixtures of honey and arsenic.
- The jacamar vine plant and chrysanthemums come in use in 19th century to make the natural pesticides of rotenone and pyrethrin. Farmers were mainly using copper acetoarsenite (Paris green), calcium arsenate, nicotine sulphate and sulfur to control wide variety of insects.

IInd Generation pesticides

- They are the synthetic chemical compounds created for the intentional use as a pesticide.
- They are persistant, less toxic compared to inorganic compounds, short lived, causes biomagnifications and are water soluble.

- They are species specific and less harmful to human.
- In the year 1874, DDT was first synthesized.
- In 1939 scientist Paul Hermann Müller discovered the insecticidal properties of DDT in Switzerland..
- Aerosols developed in US in 1941.
- After World War second BHC, aldrin, dieldrin, endrin, DDT and 2,4-D were introduced and became widespread used as they are cheap.
- Carbamates were developed and put to use in 1958.
- 1962 **Rachel Carson** published his book Silent Spring which emphasize the impact of misuse and overuse of pesticides on environment (FIG 1.6).
- In 1946 parathion was first organophosphates to be used.
- Isolan was the first carbamate used in 1951 and dominate the pesticide market.
- 1970- EPA established
- 1972- DDT usage was banned in the Federal Environmental Pesticide Control Act in USA and in 1989 in India.
- 1976-Photostable and usable pyrethroid was developed in Japan
- In 1975 R.L.Metcalf and W.H.Luckmann published his book Introduction to Integrated Pest Management and in1976 IPM becomes recommended in the US by FDA
- 1984 Methyl isocyanate (MIC) gas was leaked in industrial accident in Bhopal, known as Bhopal Gas Tragedy, India.

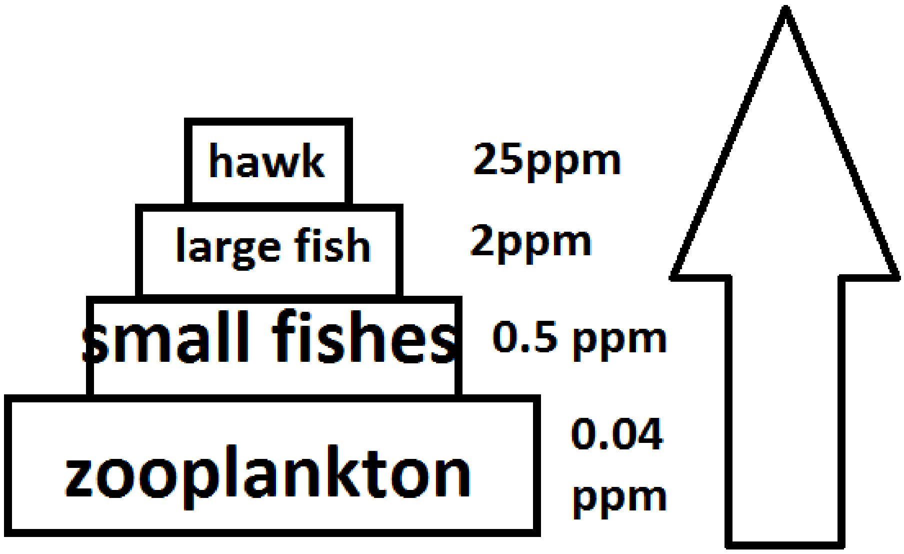

FIG 1.6: Food chain showing different trophic levels biomagnification of DDT

III^rd Generation Pesticides

- The pesticides or chemicals that are replacing DDT now a days have the advantage of degrading more quickly in the environment, but they still hit a broad spectrum of insects often beneficial ones and non target species.
- Most of the chemical companies looking forward for safer, more specific insecticides that simply have insect-killing value.
- Researchers motivate more stress on biological controls such as introducing parasites, predators, sterile males, specific diseases, natural enemies or natural hormones.
- A Harvard scientists Carroll M. Williams had discovered specific insecticides based on insects own hormones. And considered as WILLIAMS "third generation pesticides" which is much more superior to the lead arsenate and DDT.
- These chemicals are called as juvenile hormones, are secreted by two endocrine small glands in insect head. If the amount of the hormone is less in the eggs or late larvae, the eggs fail to hatch and the larvae die without metamorphising.
- In 1956, Williams isolated this hormone from silkworms and Elias J. Corey, Sheldon Emery Professor of Organic Chemistry, later

synthesized it. But like other artificial versions of juvenile hormone, this silkworm hormone affected many different types of insects along with the target moth.

- Third generation pesticide must be a species specific and do not harm natural enemies, non target organisms either it will be merely a more potent variety of DDT.
- The finding of Lynn M. Riddiford, Assistant Professor of Biology that juvenile hormone are absent in insect eggs for normal hatching to take place led to the possibility of releasing males with juvenile hormone on their genitalia. So that wild female that mates with one of these males would become sterile decreasing the target insect's population and the hormone would not affect other species.
- The other accidental discovery by Williams' group found that a European bug would grow fairly well in the Bio Labs until the last larval stage but died without metamorphising. This syndrome lead to another use of JH that, if some extra juvenile hormone hit the bugs it will not reproduce.
- Balsam fir used to make the paper towels produce a compound very similar to the bug's juvenile hormone and effect only a single family of bugs like silkmoth JH.

Pecocene I (7-methoxy,2,2-dimethyl chromene) and Precocene II (6,7-dimethoxy,2,2-dimethyl chromene) are now newly discovered and considered as **IV generation pesticides.**

Recent insecticides

Avermectins derived from fungus and belongs to a group of chemicals called macrolactones. They affect the nervous system as axonic poisons and bind to another protein in the nerve fiber called gamma amino butyric acid (GABA). Avermectins blocks the channel causing nerve hyper excitation resulting in tremors and uncoordinated movement.

Imidacloprid belongs to the chloronicotinyl chemical class of insecticides is another recent discovery which is also a synaptic nervous system poison. It mimics the action of a neurotransmitter called acetylcholine which normally turns on a nerve impulse at the synapse but its effects are terminated very quickly. Imidacloprid turns on the nerve impulse but cannot terminate it back like acetylcholine because of its chemical structure. Therefore, the nervous system is overexcited and the results are same as that of avermectins in causing tremors and uncoordinated movement.

The other new insecticide that affects the nervous system is fipronil. Fipronil is a phenylpyrazole chemical class insecticide showing similar action to that of cyclodiene insecticides (e.g. chlordane or aldrin). These chemicals are axonic poisons that affect the GABA-gated chloride channel.

1.9 Summary

A pesticide is any substance that is used to control or kill pests. Pests may be target insects, vertebrate like rat, mole, vegetation, weed, fungi, etc. Most measure used to control the pests is by poisoning them through pesticides but they can be poisonous to humans as well. Some are very poisonous, or toxic, and may contaminate the food, irritate the skin, eyes, nose, or mouth while using, should always keep out of reach to children. The most important thing to remember is that you should always use with great caution whenever you work with any pesticide.

Different use of pesticides causes toxicity which may be acute, dermal, inhaled, oral and chronic. Pesticide can be classified into inorganic and organic which may be further categorize into animal originated, plant originated, synthetic or hydrocarbons. There are three eras of chemical control as era of optimism, era of doubt and era of IPM.

1.10 Glossary

- **Active ingredient** (a.i.): The main chemical component in a product responsible for the pesticides effects.
- **Acute toxicity**: Immediate toxicity of a pesticide to an organism.
- **Bioconcentration:** It is the tendency for a compound to accumulate in an organism tissue.
- **Biomagnifications**: An increase in concentration of a compound in food chain.
- **Bound residues (pesticide):** Chemical pesticide usage in plants residing in tissues, particularly cell walls.
- **Contact insecticide**: Insecticide that kills an insect pest by coming in contact.
- **Pest control**: To kill the pest by any of the agent.

- **Pest:** An organism that competes with man for his food supply, damages his possession, and attacks his person.
- **Pesticide contamination**: Pollution of any chemical constituent to the environment with some pesticid**e.**
- **Pesticide:** A chemical, synthetic or natural, used to prevent, retard, or decline the growth of the target pest to desired level.
- **Systemic Insecticide**: Pesticide which is inoculated within a plant from the point of application to the point where the insect will contact or ingest it.
- **Volatilization:** It is the evaporation of a heated pesticide.

1.11 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Give the trade name of Aldicarp?
2. Give example of protoplasmic poison?
3. Name the plant having nicotine?
4. What are the categories of nerve poisons?
5. What is the example of chitin inhibitor?
6. Name the newly discovered pesticides?
7. Who gave the term Pest Management?
8. Who gave the concept of EIL and ETL?
9. Who reported chemical properties of DDT?
10. What was the first organ- phosphate insecticide developed?
11. Who published book Silent Spring?

Section -B (Short Answer Type):

1. Differentiate I, II and III generation pesticide?
2. Define term ETL and EIL?
3. What is the importance of inorganic pesticides?
4. Give in brief the role of synthetic pesticides?
5. Briefly explain the pesticide industry in India?
6. Write the pesticide classified on the basis of mode of entry?
7. What is acute and chronic toxicity?

Section -C (Long Answer Type)

1. What are pesticide and its different categories?

2. Define toxicology and its types?
3. What are the different eras in the history of chemical control?
4. Name different plants that are used to control pest?
5. Give the classification of pesticides based on different criteria?

Answer Key of Section-A

1. Temik
2. nitrophenols, nitro cresols.
3. *Nicotina tabaccum* and *Nicotina rustica*
4. Narcotics, axonic poison and synaptic poison
5. Dimilin
6. Avermectins, fipronil
7. P.W. Geier
8. V.M.Stern
9. Paul Muller
10. Parathion
11. Rachel Carson **in** 1962

1.12 References

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Unit - 2

Structure of insecticides

Structure of the Unit

2.1 Objectives

This unit describes the structure and mode of action of various insecticides such as organochlorides, organophosphates, carbamates, insects growth regulators, avermectines, rotenones etc. It gives detailed information on the Problems of pesticide hazards and environmental pollution.

2.2 Introduction

The chemicals which kill the insects by their chemical action are termed as insecticides. They include ovicides and larvicides used against insect eggs and larvae, respectively. Insecticides are used in agriculture, medicine, industry and by consumers. Insecticides are claimed to be a major factor behind the increase in agricultural 20th century's productivity. Nearly all insecticides have the potential to significantly alter ecosystems; many are toxic to humans; some concentrate along the food chain.

Insecticides can be classified in two major groups: systemic insecticides, which have residual or long term activity; and contact insecticides, which have no residual activity.

Furthermore, one can distinguish three types of insecticide. 1. Natural insecticides, such as nicotine, pyrethrum and neem extracts, made by plants as defences against insects. 2. Inorganic insecticides, which are metals. 3. Organic insecticides, which are organic chemical compounds, mostly working by contact.

The mode of action describes how the pesticide kills or inactivates a pest. It provides another way of classifying insecticides. Insecticides are classified on the basis of the mode of their entry into the insect body as stomach, contact and fumigant poisons. Mode of action is important in understanding whether an insecticide will be toxic to unrelated species, such as fish, birds and mammals.

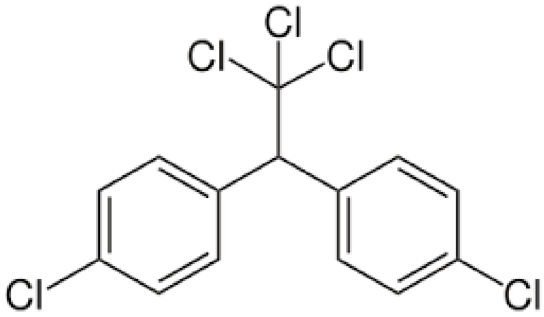
Insecticides are distinct from insect repellents, which do not kill.

2.3 Structure and mode of action of Organochlorides

Chlorinated hydrocarbons are the oldest insecticides having been the first widely used synthetic organic insecticides. All insecticides of this group contain at least chlorine, hydrogen and carbon. Some of the insecticides also contain oxygen and sulphur. There is a large number of chlorinated hydrocarbons including DDT, HCH (BHC), methoxychlor with their analogues and isomeric forms such as lindane (γ- BHC). Other insecticides of this group are chlorinated terpenes (toxaphene), cyclodienes (aldrin, dieldrin, chlordane, isodrin, heptachlor, endrin etc.) and other compounds like chlordecone (kepone) and endosulfan (thiodon).

Most of these chemicals have been banned from use because of their persistence in the environment and toxicity to nontarget organisms.

a) **DDT (Dichlorodiphenyl trichloroethane)**
   IUPAC name – 1,1,1- trichloro – 2,2 – di- (4 - chlorophenyl) ethane
   Structural formula

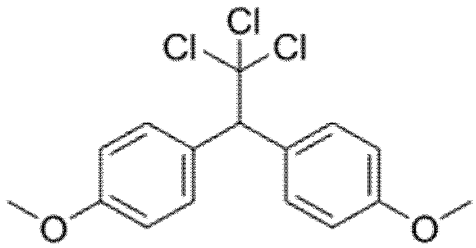


Chemical formula – $C_{14}H_9C1_{51}$

It is a very powerful insecticide which exercise a prolonged lethal residual effect till covered by the dust or dechlorinated. It is a creamy white, crystalline powder having a faint unpleasant odour. It is one of the first synthetic organic insecticides, which is representative of the organochlorine chemicals. Organochlorine molecules tend to be very stable because of the placement of the chlorine ions in the molecule.
It is almost insoluble in water but soluble in organic solvents like castor oils, cotton seed oils, xylene, benzene, kerosene, dioxane, ether, acetone, chloroform, liquid paraffin etc.
DDT act as either a contact or a stomach poison to insects, affecting the sensory organs and nervous system and causing violent agitation at first ,followed by paralysis and death. The effect is gradual but sure and persists for a long time. It is non phytotoxic except to cucurbits. It is very effective against most insects such as beetles, weevils, caterpillars, thrips, whiteflies and leaf hoppers. It is compatible with most insecticides and fungicides, except lime sulphur.
Considering the effective insecticidal dose, it is comparatively less toxic to mammals (a human fatal dose taken orally in 30 gms). Insolubility in water renders it harmless to use on human skin in dust or aqueous emulsion but when dissolved in oils, its large doses may cause a number of diseases like convolution, cerebral depression and necrosis of liver. Its inhalation is also harmful but due to its high toxicity for insects, large areas can be treated with small quantities of insecticides by ordinary hands or power sprayers.
It is never used in pure form but compounds are made with certain bases to form dust or spray. The dose of DDT ranges between 0.5 to 20% in mineral oils, 0.1 to 5% of emulsified dispersible or wettable powder in water and 2 to 10% in dust mixed with talc, clay, chalk, sulphur and other carriers.
Several DDT analogues also possess insecticidal activities. They are :

Methoxychlor (C6H15Cl13O2) –

It is a white crystalline pale flaky powder. It is less toxic to mammals and bring about rapid knock down of many insects (e.g.house flies). It does not accumulate in animal fatty tissues or excreted in milk.



It should not be mixed in alkaline material. It has also been found that its acute and chronic toxicity is relatively less than DDT. Its use is favoured for animal forage. It is used for the control of pests of vegetable crops and dairy cattle.

DDD (dichlorodiphenyl dichloroethane)

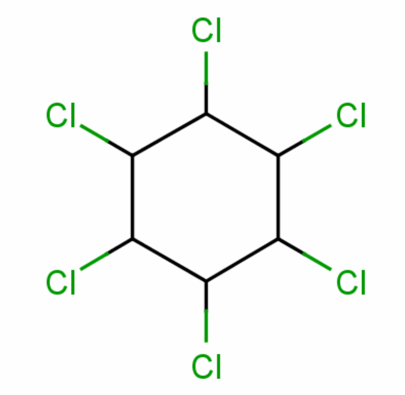
It is less toxic to mammals and is used for flies and vegetable pests. It is less effective against most insects than DDT.

Dilan – it is a commercial product containing a mixture of two nitro paraffins analogues of DDT. It is more effective than DDT against certain insects.

b) BHC or HCH (Benzene hexachloride)

IUPAC name – 1,2,3,4,5,6- hexachorocyclohexane

Structural formula



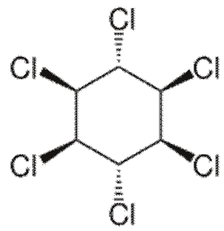
Chemical formula – $C_6H_6Cl_6$

It is a crystalline tasteless perfectly stable powder of sand colour, having a camphor like odour, practically insoluble in water but soluble in oils and paraffins. Commercial BHC contain 10- 13% gamma isomer, 55-70% alpha isomer, 5-14% beta isomer, and 6-8% epoilon isomer. The assay of effectiveness of BHC depend upon the content of gamma isomer and not on the total amount of insecticide in an insecticidal formulation.

It is available as a pure product or mixed with a carrier like lime, gypsum or chalk. It is perfectly compatible with sulphur and DDT but it decomposes, when mixed with alkalies like lime, Bordeaux mixture and nicotine etc. It is five times toxic than DDT hence acts more quickly but being volatile, the residual effect is less lasting.

It can serve both as stomach and contact poisons for most of the insects such as thrips, leafhoppers, aphids, woodlice and earwigs but less effective against flour moths. It can be used as a slow acting fumigant for stored products alone or in combination with carbon disulphide, carbon tetrachloride etc. It is less toxic to mammals when taken orally or absorbed to skin. A fatal oral dose for man is 30gms (its gamma isomer is more toxic and 15gms is fatal dose for man).

c) Lindane



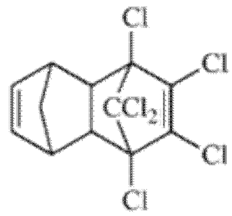
It is the coined name for the gamma isomer of BHC of a purity of not less than 99%. Using llindane in formulation eliminates the disagreeable odour and tastes on some crops which result when they are treated with BHC. It occurs as colourless crystals and is practically insoluble in water, slightly soluble in petroleum oils, soluble in acetone, aromatic and chlorinated solvents.

It exhibits strong stomach poison action, persistent contact toxicity and fumigant action, against a wide range of insects. It is non phytotoxic at insecticidal concentrations. The technical BHC causes “tainting” of many crops but there is less risk of this with lindane. It is stable to air, light, heat and carbon dioxide and is not attacked by strong acids but can be dehydrochlorinated by alkalies. It is effective against many soil insects e.g. beetle larvae and adults, fly larvae, ants and many biting and sucking insects e.g. aphids, psyllides, whiteflies, capsids, midges, thrips etc. This insecticide is now restricted in use.

d) Aldrin

IUPAC name – 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydri-1,4,5,8-dimethanonaphthalene

Structural formula



Chemical formula - $C_{12}H_8Cl_6$

It is a cyclodeine. It is a white crystalline solid, insoluble in water but is quite soluble in mineral oils and highly soluble in most organic solvents like acetone, benzene, xylene etc. It is stable to heat, alkaline and mild acids and can be mixed with alkaline soils, fertilizers and other insecticides like sulphur, Bordeaux mixture, calcium arsenate, nicotine, paris green, rotenone etc. It is a broad spectrum, persistent, nonphytotoxic insecticide.

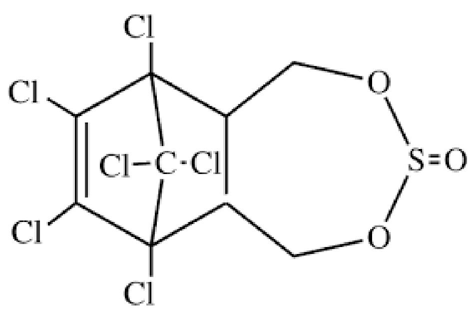
It acts as a stomach as well as a contact poison. Toxic effect on insects is cumulative and therefore it is not advised to use on edible crops. It is used against all soil insects like termites, beetles (both larvae and adults) fly larvae, cutworms, wireworms, crickets etc. Aldrin is dusted on soil at the rate of about 2.5 kg per acre. Aldrin can control a variety of soil insects at the depth of about 10-11 cm. It is used as 30% emulsifiable concentrate, 2.5-5% dust, 5 and 20% granules, 20-25% wettable powder or liquid seed dressing. The treated seeds should not be used for human or animal consumption.

Insecticidal preparations containing aldrin, should be handled with care. Respirators should be worn by those applying this material and excessive skin contact should be avoided.

e) Endosulfan (Thiodan/ Endosel)

IUPAC name – 6,7,8,9,10,10-Hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathirpine-3-oxide

Structural formula

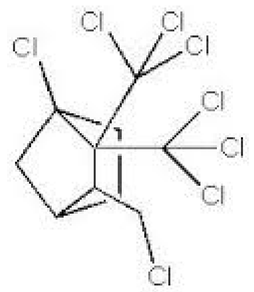


Chemical formula - $C_9H_6Cl_6O_3S$

It is a brownish crystalline solid. It does not accumulate in milk or fat but has a high mammalian toxicity. In plants and animals both, it is metabolized to a sulphate. It is extremely toxic to fish but is safe for bees. It is formulated as emulsifiable concentrate, wettable powder, dust and granules.

f) Toxaphene

Structural formula



Chemical formula - $C_{10}H_{10}Cl_8$

It is a chloroterpene and is used exclusively in agriculture. Until a few years ago, toxophene was the single most widely used insecticide in agriculture particularly against grasshoppers, cotton insects and livestock pests. It is unstable in the presence of prolonged exposure to sunlight. Toxaphene is formulated as a 25-40% wettable powder as an emulsive concentrate, as a kerosene solution and as a dust. Though it is not highly toxic to birds and mammals as they easily metabolised it but is highly toxic to fishes. Like other countries it is also banned for use in india.

2.4 Structure and mode of action Organophosphates

An organophosphate (sometimes abbreviated OP) or phosphate ester is the general name for esters of phosphoric acid. Organophosphate pesticides irreversibly inactivate acetylcholinesterase, which is essential to nerve function in insects, humans, and many other animals. The symptoms of poisoning due to organophosphorous compounds are hyperactivity, tremors, convulsions, paralysis and death in insects and muscarinic effects viz., nausea, salivation, lachrymation and myosis, nicotinic effects viz., muscular fasciculations and central effects such as giddiness, coma and convulsions in higher animals. Even at relatively low levels, organophosphates may be most hazardous to the brain development of fetuses and young children.

Organophosphate pesticides degrade rapidly by hydrolysis on exposure to sunlight, air, and soil, although small amounts can be detected in food and drinking water. Their ability to degrade made them an attractive alternative to the persistent organochloride pesticides, such as DDT, aldrin, and dieldrin. Although organophosphates degrade faster than the organochlorides, they have greater acute toxicity, posing risks to people who may be exposed to large amounts.

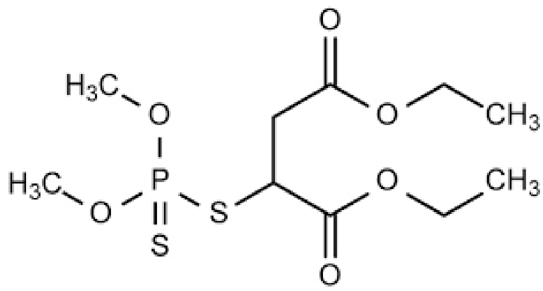
Commonly used organophosphates have included parathion, malathion, methyl parathion, chlorpyrifos, diazinon, dichlorvos, phosmet, fenitrothion, tetrachlorvi nphos, azamethiphos, and azinphos-methyl. The EPA banned most residential uses of organophosphates in 2001, but they are still sprayed agriculturally on fruits and vegetables.

a) Malathion

IUPAC name –

Diethyl 2-[(dimethoxyphosphorothioyl)sulfanyl]butanedioate

Structural formula



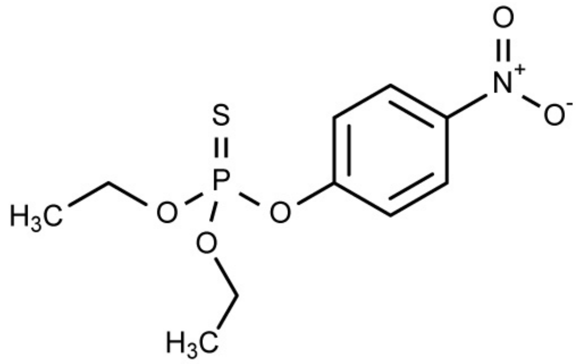
Chemical formula - $C_{10}H_{19}O_6PS_2$

It is yellowish brown liquid slightly soluble in water and miscible with most of the organic solvents. It has a strong penetrating, unpleasant smell and is broken up into non toxic ingradients when mixed with alkaline media. It can be used as stomach and contact poison, besides as a strong fumigant for mites and other insects which are not killed by other poisons for aphids, scale insects, mealy bugs, jassids and caterpillars in 5% dust or 25-50% emulsion for spraying. Two or three applications fortnightly will control white flies, mealy bugs and scale insects.

b) Parathion

IUPAC name – O,O-Diethyl O-(4-nitrophenyl) Phosphorothioate

Structural formula



Chemical formula – $C_{10}H_{14}NO_5PS$

Parathion, also called parathion-ethyl or diethyl parathion and locally known as "Folidol". It is a potent insecticide and acaricide. It is highly toxic to non-target organisms, including humans. Parathion is a white crystalline solid, however it is commonly distributed as a brown liquid that smells of rotting eggs or garlic. The insecticide is more or less stable, although it darkens when exposed to sunlight. It is insoluble in mineral oils and kerosene.

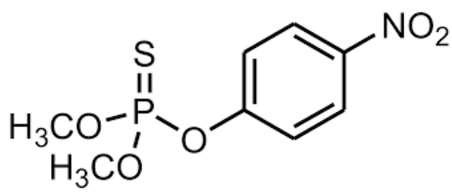
It is contact and stomach poison with slightly fumigant action. As a pesticide, parathion is generally applied by spraying. It is often applied to cotton, rice and fruit trees. The usual concentrations of ready-to-use solutions are 0.05 to 0.1%. The chemical is banned for use on many food crops. Parathion acts on the enzyme acetylcholinesterase, but indirectly. After being ingested by insects (and unintentionally, by humans), the parathion becomes oxidized by oxidases to give paraoxon, replacing the double bonded sulfur with oxygen. The phosphate ester is more reactive in organisms than the phosphorothiolate ester, as the phosphorus atoms become much more electropositive.

Degradation of parathion leads to more water-soluble products. Hydrolysis, which deactivates the molecule, occurs at the aryl esterbond resulting in diethyl thiophosphate and 4-nitrophenol. Degradation proceeds differently under anaerobic conditions: the nitro group on parathion is reduced to the amine.

c) Methyl parathion

IUPAC name – O,O-dimethyl-O-nitrophenyl-phosphorothionate

Structural formula



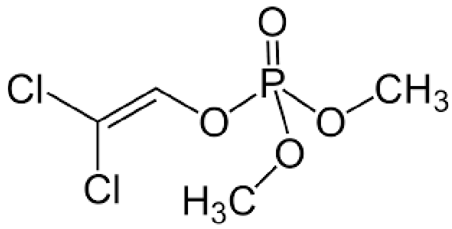
Chemical formula - $C_8H_{10}NO_5PS$

It is a white crystalline substance in pure state, sparingly soluble in water and well soluble in most organic solvents. It has a low thermal stability. It hydrolyzed rapidly in alkaline medium. Due to its low stability, toxicity is lost soon from the treated surface. In soil micro-organisms decompose it within a week. It is a contact and stomach poison with mild fumigant action. It is less toxic to mammals and highly poisonous to insects as compared to parathion. It is formulated in combination with DDT. It can be used against aphids, mites, leafhoppers, whiteflies, scale insects etc.

d) Dichlorvos or DDVP

IUPAC name – 2,2 –dichlorovinyl dimethyl phosphate or O, O – dimethyl – 2,2 – dichlorovinyl phosphate

Structural formula



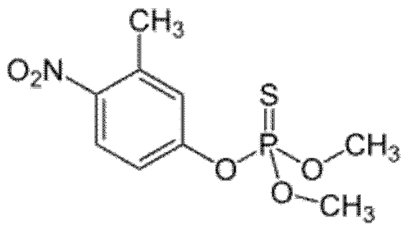
Chemical formula – $C_4H_7Cl_2O_4P$

It is colourless liquid and it is soluble in water and most organic solvents. It is hydrolysed slowly in neutral and acid media and rapidly in alkaline medium. It is effective against mushroom flies, aphids, spider mites, caterpillars, thrips, and whiteflies in greenhouse, outdoor fruit, and vegetable crops. It is also used in the milling and grain handling industries and to treat a variety of parasitic worm infections in dogs, livestock, and humans. It is fed to livestock to control bot fly larvae in the manure. It acts against insects as both a contact and a stomach poison. It is available as an aerosol and soluble concentrate. It is also used as a fumigant against mosquitoes and other dipterous insects. It is moderately toxic to fish and highly toxic to bees.

e) Fenitrothion

IUPAC name – O,O-Dimethyl O-(3-methyl-4-nitophenyl) phosphorothioate

Structural formula



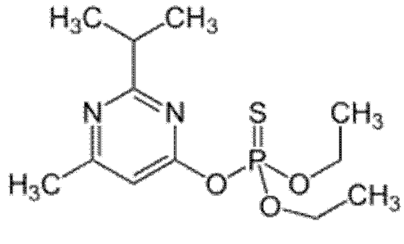
Chemical formula – $C_9H_{12}P_5NPS$

It is a brownish yellow liquid with faint smell and unstable in alkaline medium. It is insoluble in water but soluble in most organic solvents. Its thermal stability is also low and may explode at 100°C. It is a contact and stomach poison recommended against a wide range of insect pest of crops and certain mites specially for the control of rice pests. It is also useful for the control of mosquito larvae, bed bugs and poultry lice, fleas and ticks. Toxic to bees and phytotoxicity may be caused on Brassica crops, some susceptible apple varieties and on cotton at higher doses. Used in the form of 5% dust or 50% emulsifiable concentrate.

f) Diazinon

IUPAC name – *O*,*O*-Diethyl *O*-[4-methyl-6-(propan-2-yl)pyrimidin-2-yl] phosphorothioate

Structural formula



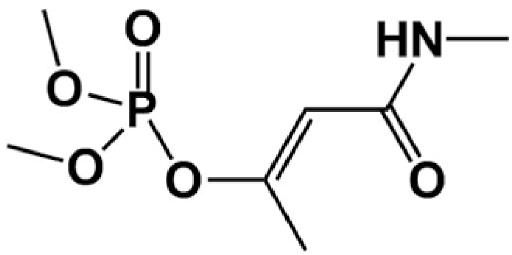
Chemical formula - $C_{12}H_{21}N_2O_3PS$

It is a non systemic insecticide with some acaricidal action. It may be phytotoxic at higher dosages. It is a colourless oil almost insoluble in water but is miscible with ethanol, acetone, xylene and is soluble in petroleum oils. It decomposes above 120°C and is susceptible to oxidation. Contact and stomach poison and has a fumigant effect and penetrating quality. A wide spectrum insecticide used against large number of insect pests attacking various crop. It is formerly used to control cockroaches, silverfish, ants, and fleas in residential, non-food buildings.

g) Monocrotophos

IUPAC name – Dimethyl (E)-1-methyl-2-(methylcarbamoyl)vinyl phosphate

Structural formula



Chemical formula – $C_7H_{14}NO_5P$

It is a crystalline solid with mild ester smell. It is miscible with water, soluble in acetone and ethyl alcohol but insoluble in kerosene and diesel. It is a fast acting stomach, contact and systemic insecticide. It can be used against a wide range of pests. It is absorbed by roots and then translocated to stem and leaves. Scorching of edges occur in some varieties of sorghum, apple and cherry. Monocrotophs is recommended for the control of aphids, white flies, leaf miners, thrips, shoot borers, boll worms, caterpillars, foliage feeder beetles and a number of other pests. It is formulated as emulsifiable concentrate.

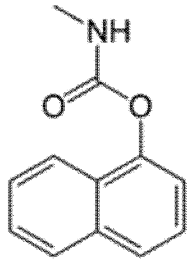
2.5 Structure and mode of action carbamates

A carbamate is an organic compound derived from carbamicacid (NH_2COOH). A carbamate group, carbamate ester (e.g., ethyl carbamate), and carbamic acids are functional groups that are inter-related structurally and often are interconverted chemically. Carbamate esters are also called urethanes. Included in this group are aldicarb (Temik), carbofuran (Furadan),carbaryl (Sevin), ethienocarb, fenob ucarb, oxamyl and methomyl. These insecticides kill insects by reversibly inactivating the enzyme acetylcholinesterase. The organophosphate pesticides also inhibit this enzyme, although irreversibly, and cause a more severe form of cholinergic poisoning.

a) Carbaryl

IUPAC name - 1-naphthyl methylcarbamate

Structural formula –



Chemical formula - $C_{12}H_{11}NO_2$

It is a white crystalline solid commonly sold under the brand name Sevin. It is a non specific insecticide effective against a wide spectrum of pests including those that are resistant to chlorinated hydrocarbon insecticides.

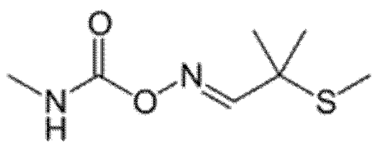
It is a contact and stomach poison having a longer residual action. The carbamates do not have the persistence of chlorinated pesticides. Although toxic to insects, carbaryl is detoxified and eliminated rapidly in vertebrates. It is neither concentrated in fat nor secreted in milk, so is favored for food crops. It is the active ingredient in Carylderm shampoo used to combat head lice until infestation is eliminated. 2.5% carbaryl dust is used in the control of human lice. 5% carbaryl dust is used for the control of ticks of cattles, sheeps, dogs and mites and lice of poultry. It is effective in controlling pests of cotton, coconut and vegetable.

Carbamate insecticides are slowly reversible inhibitors of the enzyme acetylcholinesterase. They resemble acetylcholine, but the carbamoylated enzyme undergoes the final hydrolysis step very slowly (minutes) compared with the acetylated enzyme generated by acetylcholine (microseconds). They interfere with the cholinergic nervous system and cause death because the effects of the neurotransmitter acetylcholine cannot be terminated by carbamoylated acetylcholinesterase.

b) Aldicarb

IUPAC name - 2-methyl-2-(methylthio) propanal O-(N-methylcarbamoyl) oxime

Structural formula



Chemical formula - $C_7H_{14}N_2O_2S$

in water and more soluble in organic solvents. Aldicarb is a carbamate insecticide which is the active substance in the pesticide Temik. It is effective against thrips, aphids, spider mites, lygus, fleahoppers, and leafminers, but is It is a crystalline white solid with slightly sulphurous odour. It is slightly soluble primarily used as a nematicide. In plants it is rapidly absorbed and oxidised to principal toxicant aldicarb silfoxide which is further oxidised to the aldicarb sulfone. It is a cholinesterase inhibitor which prevents the breakdown of acetylcholine in the synapse. In case of severe poisoning, the victim dies of respiratory failure.

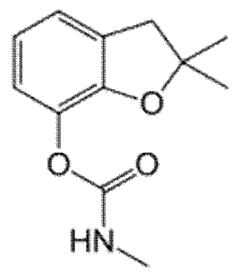
Aldicarb is one of the most widely used pesticides internationally, and is also one of the most environmentally toxic. Aldicarb poisoning from agricultural water runoff has led to the destruction of healthy ecosystems and the irreversible poisoning of fertile agricultural land. Poisoning from this pesticide is also believed to be linked to high cancer rates in communities located around the Aral Sea.

Aldicarb is effective where resistance to organophosphate insecticides has developed, and is extremely important in potato production, where it is used for the control of soil-borne nematodes and some foliar pests. Its high level of solubility restricts its use in certain areas where the water table is close to the surface. Exposure to high amounts of aldicarb can cause weakness, blurred vision, headache, nausea, tearing, sweating, and tremors in humans. High doses can be fatal to humans because it can paralyze the respiratory system.

c) Carbofuran

IUPAC name - 2,2-dimethyl-2,3-dihydro-1-benzofuran-7-yl methylcarbamate

Structural formula



Chemical formula - $C_{12}H_{15}NO_3$

It is a white crystalline solid with weak phionlic odour. It is non inflammable and unstable in alkaline media. It is marketed under the trade names Furadan. It is reversible cholinesterase inhibitor capable of causing systemic toxic effects when inhaled or ingested. It is used to control insects in a wide variety of field crops, including potatoes, corn and soybeans. Very effective against sucking pests, thrips, mites and soil inhabitating pests viz., paddy root weevil, corn root worms, flea beetle larvae, white grubs, maggots and nematodes. It is a systemic insecticide, which means that the plant absorbs it through the roots, and from here the plant distributes it throughout its organs where insecticidal concentrations are attained. Carbofuran also has contact activity against pests.

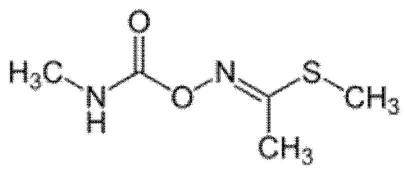
Carbofuran usage has increased in recent years because it is one of the few insecticides effective on soybean aphids.

d) Methomyl

IUPAC name -

(E,Z)-methyl-N-{[(methylamino)carbonyl]oxy}ethanimidothioate

Structural formula



Chemical formula - $C_5H_{10}N_2O_2S$

Methomyl is a carbamate insecticide introduced in 1966. It is highly toxic to humans, livestock, pets, and wildlife. Methomyl is a broad-spectrum insecticide that is used to kill insect pests. Methomyl is registered for commercial/professional use under certain conditions on sites including field, vegetable, and orchard crops; turf (sod farms only); livestock quarters; commercial premises; and refuse containers. Products containing 1% Methomyl are available to the general public for retail sale, but more potent formulations are classified as restricted-use pesticides: not registered for homeowner or non-professional application.

2.6 Structure and mode of action pyrethroids

A pyrethroid is an organic compound similar to the natural pyrethrins produced by the flowers of pyrethrums (*Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids now constitute the majority of commercial house hold insecticides. In the concentrations used in such products, they may also have insect repellent properties and are generally harmless to human beings in low doses but can harm sensitive individuals. They are usually broken apart by sunlight and the atmosphere in one or two days, and do not significantly affect groundwater quality.

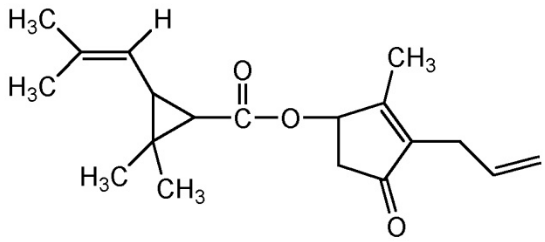
Pyrethroids are axonic excitoxins, the toxic effects of which are mediated through preventing the closure of the voltage-gated sodium channels in the axonal membranes. The sodium channel is a membrane protein with a hydrophilic interior. This interior is a tiny hole which is shaped precisely to strip away the partially charged water molecules from a sodium ion and create a favourable way for sodium ions to pass through the membrane, enter the axon, and propagate an action potential. When the toxin keeps the channels in their open state, the nerves cannot repolarize, leaving the axonal membrane permanently depolarized, thereby paralyzing the organism.

The earliest pyrethoids are related to pyrethrin I and II by changing the alcohol group of the ester of chrysanthemic acid. This relatively modest change can lead to substantially altered activities. For example the 5-benzyl-3-furanyl ester called resmethrin is only weakly toxic to mammals (LD50 (rat, oral) = 2,000 mg/kg) but is 20-50x more effective than natural pyrethrum and is also readily biodegraded. Other commercially important esters include tetramethrin, allethrin, phenothrin, barthrin, dimethrin, and bioresmethrin. Another family of pyrethroids have altered acid fragment together with altered alcohol components. These require more elaborate organic synthesis. Members of this extensive class include the dichlorovinyl and dibromovinyl derivatives. Still others are tefluthrin, fenpropathrin, and bioethanomethrin.

a) Allethrin

IUPAC name –

Structural formula



Chemical formula - $C_{19}H_{26}O_3$

The allethrins are a group of related synthetic compounds used in insecticides. They are synthetic pyrethroids, a synthetic form of a chemical found naturally in the chrysanthemum flower. Allethrin was the first pyrethroid.

The compounds have low toxicity for humans and birds, and are used in many household insecticides such as RAID as well as mosquito coils. It is highly toxic to fish and aquatic invertebrates. At normal application rates, allethrin is

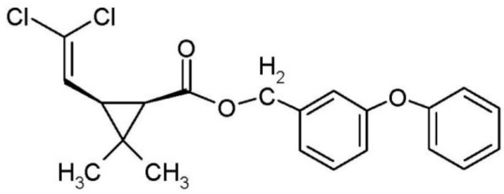
slightly toxic to bees. Insects subject to exposure become paralyzed (nervous system effect) before dying. Allethrins are toxic to cats because they either do not produce, or produce less of certain isoforms of glucuronosyltransferase, which serve in hepatic detoxifying metabolism pathways.
They are also used as an ultra-low volume spray for outdoor mosquito control.

b) Permethrin

IUPAC name -

(±)-3-phenoxybezyl-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate

Structural formula



Chemical formula - $C_{21}H_{20}Cl_2O_3$

Permethrin is a common synthetic chemical, widely used as an insecticide, acaricide, and insect repellent. It is functions as a neurotoxin, affecting neuron membranes by prolonging sodium channel activation. It is not known to rapidly harm most mammals or birds, but is dangerously toxic to fish and to cats: in cats it may induce hyperexcitability, tremors, seizures, and even death. In general, it has a low mammalian toxicity and is poorly absorbed by skin.

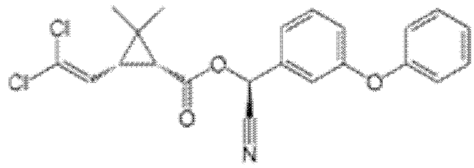
In medicine, permethrin is a first-line treatment for scabies; a 5% (w/w) cream is marketed by Johnson & Johnson under the nameLyclear. In Nordic countries and North America, it is marketed under trade name Nix, often available over the counter. It is on the World Health Organization's List of Essential Medicines, the most important medications needed in a basic health system.

It is a broad spectrum insecticide used against a variety of pests on nut, fruit, vegetable, cotton, ornamental, mushroom, potato and cereal crops. It is used in greenhouse, home gardens and for termite control. It also controls animal ectoparasites, biting flies and cockroaches. Permethrin is available in dusts, emulsifiable concentrates, smokes, ULV and wettable powder formulatins. It may persist in fatty tissues. Soil microorganisms play a large role in the degradation of permethrin in the soil.

c) Cypermethrin

IUPAC name - [Cyano-(3-phenoxyphenyl)methyl]3-(2,2-dichloroethenyl)-2,2-dimethylcydopropane-1-carboxylate

Structural formula



Chemical formula - $C_{22}H_{19}Cl_2NO_3$

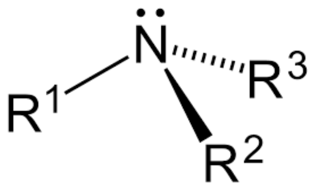
Cypermethrin is a synthetic pyrethroid used as an insecticide in large-scale commercial agricultural applications as well as in consumer products for domestic purposes. It behaves as a fast-acting neurotoxin in insects. It is easily degraded on soil and plants but can be effective for weeks when applied to indoor inert surfaces. Exposure to sunlight, water and oxygen will accelerate its decomposition. Cypermethrin is highly toxic to fish, bees and aquatic insects, according to the National Pesticides Telecommunications Network (NPTN). It is found in many household ant and cockroach killers, including Raid and ant chalk.

It is active against a wide range of insect pests, particularly leaf and fruit eating Lepidoptera, Coleoptera and Hemiptera, cattle ectoparasites, sheep scab, lice and ked.

2.7 Structure and mode of action tertiary amines and chlordimeform

Tertiary amines

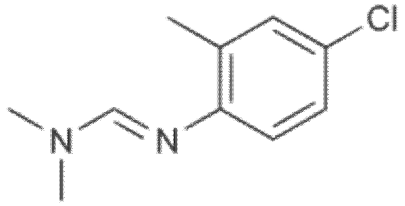
Structural formula



Amines are compounds and functional groups that contain a basic nitrogen atom with a lone pair. Amines are formally derivatives of ammonia, wherein one or more hydrogen atoms have been replaced by a substituent such as an alkyl or aryl group.

In tertiary amines, all three hydrogen atoms are replaced by organic substituents. Examples include trimethylamine, which has a distinctively fishy smell, ortriphenylamine. It acts as acetylcholinesterase inhibitor.

Chlordimeform
IUPAC name - N’-(4-chloro-2-methylphenyl)-N,N-dimethylmethanimidamide
Structural formula



Chemical formula - $C_{10}H_{13}ClN_2$

Chlordimeform is an acaricide (pesticide) active mainly against motile forms of mites and ticks and against eggs and early instars of some *Lepidoptera* insects. After the International Agency for Research on Cancer reported sufficient evidence that its major metabolite, 4-chloro-*o*-toluidine, was a carcinogen, its use has ceased and its registration has been withdrawn in most countries.

2.8 Structure and mode of action Chitin synthesis inhibitors

Chitin synthesis inhibitors work by preventing the formation of chitin, a carbohydrate needed to form the insect's exoskeleton. With these inhibitors, an insect grows normally until it moults. The inhibitors prevent the new exoskeleton from forming properly, causing the insect to die. Death may be quick, or take up to several days depending on the insect. Chitin synthesis inhibitors can also kill eggs by disrupting normal embryonic development. Chitin synthesis inhibitors affect insects for longer periods of time than hormonal insect growth regulators. These are also quicker acting but can affect predaceous insects, arthropods and even fish. Compounds include benzoylurea pesticides.

Benzoylurea

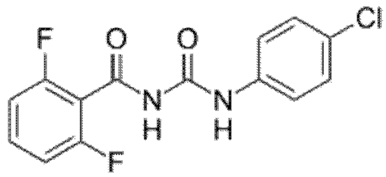
Benzoylureas are chemical derivatives of *N*-benzoyl-*N′*-phenylurea (benzoylurea). They are best known for their use as insecticides. They act as insect growth regulators by inhibiting synthesis of chitin in the insect's body. One of the more commonly used benzoylurea pesticides is diflubenzuron. Others include chlorfluazuron, flufenoxuron, hexaflumuron, andtriflumuron. Lufenuron is the active compound in flea control medication for pet dogs and cats.

When applied in a dispersed way, for example through fumigation or spraying, these chemicals have an effect against a wide range of insect species, some of which may be beneficial to human activities, including crop-pollinators such as bees.

Diflubenzuron

IUPAC name – N-[(4-chlorophenyl)carbamoyl]-2,6-difluorobenzamide

Structural formula



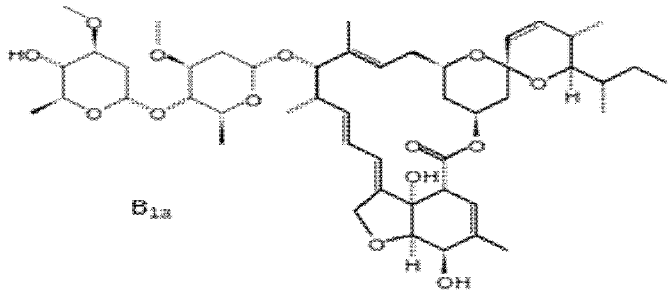
Chemical formula – $C_{14}H_9ClF_2N_2O_2$

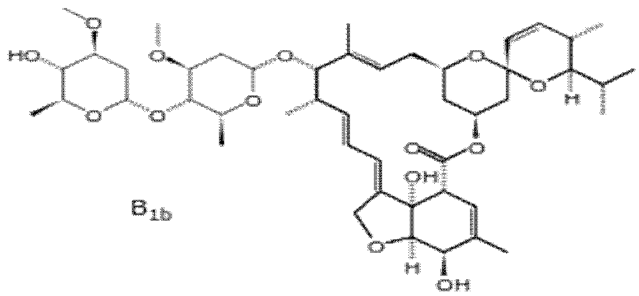
Diflubenzuron is a benzoylurea-type insecticide of the benzamide class. It is used in forest management and on field crop to selectively control insect pests, particularly forest tent caterpillar moths, boll weevils, gypsy moths, and other types of moths. Themechanism of action of diflubenzuron involves inhibiting the production of chitin which is used by an insect to build its exoskeleton.

2.9 Structure and mode of action Avermectins and Nitroguandines

Avermectins

Structural formula





Chemical formula – $C_{48}H_{72}O_{14}$

The avermectins are a series of drugs used to treat parasitic worms. They are a 16-membered macrocyclic lactone derivatives with potent anthelmintic and insecticidal properties. These naturally occurring compounds are generated as fermentation products by *Streptomyces avermitilis*, a soil actinomycete. Eight different avermectins were isolated in 4 pairs of homologue compounds, with a major (a-component) and minor (b-component) component usually in ratios of 80:20 to 90:10. Other anthelmintics derived from the avermectins include ivermectin, selamectin, doramectin and abamectin.

Half of the 2015 Nobel Prize in Physiology or Medicine was awarded to William C. Campbell and Satoshi Ōmura for discovering avermectin, "the derivatives of which have radically lowered the incidence of River Blindness and Lymphatic Filariasis, as well as showing efficacy against an expanding number of other parasitic diseases".

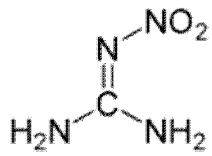
A commonly used therapy in recent times has been based on oral, parenteral, topical, or spot topical (as in veterinary flea repellant "drops") administration of avermectins. They show activity against a broad range of nematodes and arthropod parasites of domestic animals at dose rates of 300 microgram/kg or less (200 micrograms / kg ivermectin appearing to be the common interspecies standard, from humans to horses to housepets, unless otherwise indicated). Unlike the macrolide or polyene antibiotics, they lack significant antibacterial or antifungal activities.

The avermectins block the transmittance of electrical activity in invertebrate nerve and muscle cells mostly by enhancing the effects of glutamate at the invertebrate-specificglutamate-gated chloride channel, with minor effects on gamma-aminobutyric acid (GABA) receptors. This causes an influx of chloride ions into the cells, leading to hyperpolarisation and subsequent paralysis of invertebrate neuromuscular systems; comparable doses are not toxic for mammals because they do not possess glutamate-gated chloride channels.

Nitroguandines

IUPAC name - 1-nitroguanidine

Structural formula



Chemical formula - $CH_4N_4O_2$

It is a colorless, crystalline solid that melts at 232 °C and decomposes at 250 °C. It is not flammable and is a low-sensitivity explosive; however, its detonation velocity is high. It is used as a propellant (air bags), fertilizer, and for other purposes. Nitroguanidine derivatives are used as insecticides, having a comparable effect to nicotine. Derivatives include clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

2.10 Structure and mode of action neonicotinoids and Oxadiazines

Neonicotinoids

Neonicotinoids (sometimes shortened to neonics ("NEE-oh-Nicks")) are a class of neuro-active insecticides chemically similar to nicotine. In the 1980s Shell and in the 1990s Bayer started work on their development. The neonicotinoid family includes acetamiprid, clothianidin, imidacloprid, nitenpyram, nithiazine, thiacloprid and thiamethoxam. Imidacloprid is the most widely used insecticide in the world. Compared to organophosphate and carbamate insecticides neonicotinoids cause less toxicity in birds and mammals than insects. Some breakdown products are toxic.

In the late 1990s neonicotinoids came under increasing scrutiny over their environmental impacts. Neonicotinoid use was linked in a range of studies to adverse ecological effects, including honey-bee colony collapse disorder (CCD) and loss of birds due to a reduction in insect populations. In 2013, the European Union and a few non EU countries restricted the use of certain neonicotinoids.

Imidacloprid is effective against sucking insects, some chewing insects, soil insects and fleas on domestic animals. It is systemic with particular efficacy against sucking insects and has a long residual activity. Imidacloprid can be added to the water used to irrigate plants. Controlled release formulations of imidacloprid take 2–10 days to release 50% of imidacloprid in water. It is applied against soil pests, seed, timber and animal pests as well as foliar treatments.

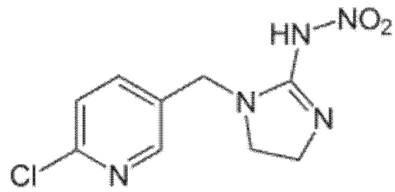
As of 2013 neonicotinoids have been used In the U.S. on about 95 percent of corn and canola crops, the majority of cotton, sorghum, and sugar beets and about half of all soybeans. They have been used on the vast majority of fruit and vegetables, including apples, cherries, peaches, oranges, berries, leafy greens, tomatoes, and potatoes, to cereal grains, rice, nuts, and wine grapes. Imidacloprid is possibly the most widely used insecticide, both within the neonicotinoids and in the worldwide market.

Neonicotinoids, like nicotine, bind to nicotinic acetylcholine receptors of a cell and trigger a response by that cell. In mammals, nicotinic acetylcholine receptors are located in cells of both the central nervous system and peripheral nervous systems. In insects these receptors are limited to the central nervous system. Nicotinic acetylcholine receptors are activated by the neurotransmitter acetylcholine. While low to moderate activation of these receptors causes nervous stimulation, high levels overstimulate and block the receptors, causing paralysis and death. Acetylcholinesterase breaks down acetylcholine to terminate signals from these receptors. However, acetylcholinesterase cannot break down neonicotinoids and their binding is irreversible.

a) Imidacloprid

IUPAC name - N-{1-[(6-chloro-3-pyridyl)methyl]-4,5-dihydroimidazol-2-yl} nitramide

Structural formula



Chemical formula - $C_9H_{10}ClN_5O_2$

Imidacloprid is a systemic insecticide which acts as an insect neurotoxin and belongs to a class of chemicals called theneonicotinoids which act on the central nervous system of insects, with much lower toxicity to mammals. The chemical works by interfering with the transmission of stimuli in the insect nervous system. Specifically, it causes a blockage of the nicotinergic neuronal pathway. By blocking nicotinic acetylcholine receptors, imidacloprid prevents acetylcholine from transmitting impulses between nerves, resulting in the insect's paralysis and eventual death. It is effective on contact and via stomach action.[1] Because imidacloprid binds much more strongly to insect neuron receptors than to mammal neuron receptors, this insecticide is more toxic to insects than to mammals.[2]

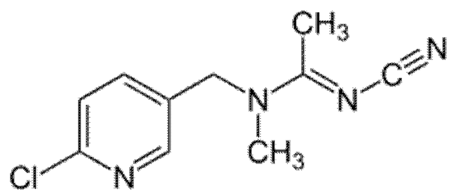
Imidacloprid is currently the most widely used insecticide in the world. Although it is now off patent, the primary manufacturer of this chemical is Bayer CropScience (part of Bayer AG). It is sold under many names for many uses; it can be applied by soil injection, tree injection, application to the skin of the plant, broadcast foliar, ground application as a granular or liquid formulation, or as a pesticide-coated seed treatment. Imidacloprid is widely used for pest control in agriculture. Other uses include application to foundations to prevent termite damage, pest control for gardens and turf, treatment of domestic pets to control fleas, protection of trees from boring insects, and in preservative treatment of some types of lumber products (e.g., Ecolife brand).

It is effective against aphids, cane beetles, thrips, stink bugs, locusts, emerald ash borer termites, carpenter ants, cockroaches, fleas Japanese beetle.

b) Acetamiprid

IUPAC name - N-[(6-chloro-3-pyridyl)]-N'-cyano-N-methyl-acetamidine

Structural formula



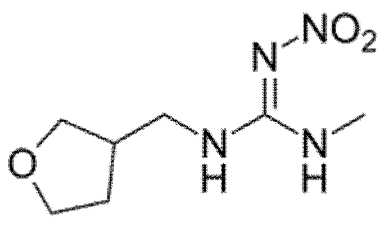
Chemical formula - $C_{10}H_{11}ClN_4$

It is an odourless white powder insecticide produced under the trade names Assail, and Chipco by Aventis Crop Sciences. It is systemic and intended to control sucking insects on crops such as leafy vegetables, citrus fruits, pome fruits, grapes, cotton, cole crops, and ornamental plants. It is also a key pesticide in commercial cherry farming due to its effectiveness against the larvae of the cherry fruit fly.

c) Dinotefuran

IUPAC name - 2-methyl-1-nitro-3-[(tetrahydro-3-furanyl)methyl] guanidine

Structural formula



Chemical formula - $C_7H_{14}N_4O_3$

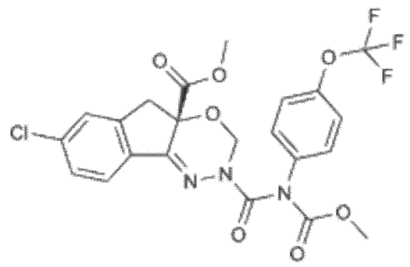
It is used for control of insect pests such as aphids, white flies, thrips, leafhoppers, leafminers, sawflies, molecricket, whitegrubs, lacebugs, bill bugs, beetles, mealy bugs, and cockroaches on leafy vegetables, in residential and commercial buildings, and for professional turf management. Its mechanism of action involves disruption of the insect's nervous system by inhibiting nicotinic acetylcholine receptors. In order to avoid harming beneficial insects such as bees, it should not be applied during bloom.

Dinotefuran is also used in veterinary medicine as a flea and tick preventative for dogs and as a flea preventative for cats. It is used in combination with pyriproxifen or permethrin.

Oxadiazines

IUPAC name - Methyl-7-chloro-2,5-dihydro-2-[[(methoxycarbonyl)[4-(trifluoromethoxy)phenyl]amino]carbonyl]indeno[1,2-e][1,3,4]oxadiazine-4a(3H)-carboxylate

Structural formula



Chemical formula - $C_{22}H_{17}ClF_3N_3O_7$

Indoxacarb is an oxadiazine pesticide developed by DuPont that acts against lepidopteran larvae. It is marketed under the names Indoxacarb Technical Insecticide, Steward Insecticide and Avaunt Insecticide. It is also used as the active ingredient in Syngenta line of commercial pesticides: Advion and Arilon. Its main mode of action is via blocking of nerve sodium channels. It is fairly lipophilic with a K_{ow} of 4.65. Indoxacarb is the active ingredient in a number of household insecticides, including cockroach and ant baits, and can remain active after digestion.

2.11 Structure and mode of action Phenyl Pyrozoles

Phenylpyrazoles are a relatively modern chemical class of pesticides introduced in the early 1990's both for agricultural and veterinary use. However, they can be considered as classic synthetic pesticides both by their mode of action and by their general features.

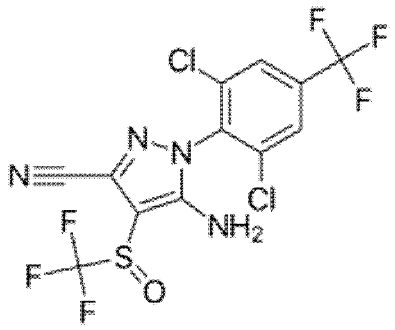
They have a broad spectrum of insecticidal and acaricidal activity and are effective against a number of veterinary parasites such as fleas, flies, ticks, lice and mites. They are not systemic and have a tarsal activity, i.e. they act by contact.

Phenylpyrazoles are inhibitors of GABA (gamma-aminobutyric acid), a key neurotransmitter in the central nervous system. This mechanism exists not only in insects but also in mammals and other vertebrates. However phenylpyrazoles seem to be much less effective on GABA receptors in vertebrates than in invertebrates.

a) Fipronil

IUPAC name - (RS)-5-amino-1-[2,6-dichloro-4-(trifluoromethyl)phenyl]-4-(trifluoromethylsulfinyl)pyrazole-3-carbonitrile

Structural formula



Chemical formula - $C_{12}H_4Cl_2F_6N_4OS$

Fipronil is a broad-spectrum insecticide that disrupts the insect central nervous system by blocking GABA-gated chloride channels and glutamate-gated chloride (GluCl) channels, resulting in central nervous system toxicity. This causes hyper excitation of contaminated insects' nerves and muscles. Specificity of fipronil on insects may come from a better efficacy on GABA receptor, but also because GluCl channels do not exist in mammals.

It is used against major lepidopteran (moth, butterfly, etc.) and orthopteran (grasshopper, locust, etc.) pests on a wide range of field and horticultural crops and against coleopteran (beetle) larvae in soils. Fipronil is the main active ingredient of Frontline TopSpot, Fiproguard, Flevox and PetArmor (used along with S-methoprene in the 'Plus' versions of these products); these treatments are used in fighting tick and flea infestations in dogs and cats.

2.12 Structure and mode of action insect growth regulators

An insect growth regulator (IGR) is a substance (chemical) that inhibits the life cycle of an insect. IGRs are typically used to control populations of harmful pests, such as cockroaches or fleas.

As an insect grows, it undergoes a process called molting, where it grows a new exoskeleton under its old one and then sheds to allow the new one to swell to a new size and harden. IGRs prevent an insect from reaching maturity by interfering with the molting process. This in turn curbs infestations because immature insects cannot reproduce. Because IGRs work by interfering with an insect's molting process, they take longer to kill than traditional insecticides. Death typically occurs within 3 to 10 days, depending on the product, the insect's life stage when the product is applied and how quickly the insect develops. Some IGRs cause insects to stop feeding long before they die.

Hormonal IGRs

Hormonal IGRs typically work by mimicking or inhibiting the juvenile hormone (JH), one of the two major hormones involved in insect molting. IGRs can also inhibit the other hormone, ecdysone, large peaks of which trigger the insect to molt. If JH is present at the time of molting, the insect molts into a larger larval form; if absent, it molts into a pupa or adult. IGRs that mimic JH can produce premature molting of young immature stages, disrupting larval development. They can also act on eggs, causing sterility, disrupting behavior or disrupting diapause, the process that causes an insect to become dormant before winter. IGRs that inhibit JH production can cause insects to prematurely molt into a nonfunctional adult. IGRs that inhibit ecdysone can cause pupal mortality by interrupting the transformation of larval tissues into adult tissues during the pupal stage.

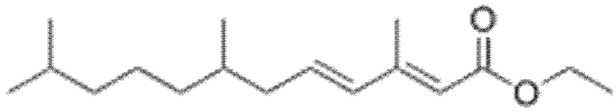
Chitin synthesis inhibitors

Chitin synthesis inhibitors work by preventing the formation of chitin, a carbohydrate needed to form the insect's exoskeleton. With these inhibitors, an insect grows normally until it molts. The inhibitors prevent the new exoskeleton from forming properly, causing the insect to die. Death may be quick, or take up to several days depending on the insect. Chitin synthesis inhibitors can also kill eggs by disrupting normal embryonic development. Chitin synthesis inhibitors affect insects for longer periods of time than hormonal IGRs. These are also quicker acting but can affect predaceous insects, arthropods and even fish. Compounds include benzoylurea pesticides.

a) Hydroprene

IUPAC name - Ethyl (2E,4E)-3,7,11-trimethyl-2,4-dodecadienoate

Structural formula



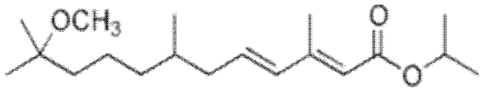
Chemical formula - $C_{17}H_{30}O_2$

Hydroprene is an insect growth regulator used as an insecticide. It is used against cockroaches, beetles, and moths. Products using hydroprene include Gencor, Gentrol, and Raid Max Sterilizer Discs.

b) Methoprene

IUPAC name - 1-methylethyl(E,E)-11-methoxy-3,7,11-trimethyl-2,4-dodecadienoate

Structural formula



Chemical formula - $C_{19}H_{34}O_3$

Methoprene is a juvenile hormone (JH) analog which acts as a growth regulator when used as an insecticide. It is an amber-colored liquid with a faint fruity odor which is essentially nontoxic to humans when ingested or inhaled. It is used in drinking water cisterns to control mosquitoes which spread dengue fever and malaria.

Methoprene does not kill insects. Instead, it acts as an insect growth regulator, mimicking natural juvenile hormone. Juvenile hormone must be absent for a pupa to molt to an adult, so methoprene-treated larvae will be unable to successfully change from pupae to adults. This breaks the biological life cycle of the insect, preventing recurring infestation. Methoprene is used in the production of a number of foods, including meat, milk, mushrooms, peanuts, rice, and cereals. It also has several uses on domestic animals (pets) for controlling fleas. Methoprene is considered a biological pesticide because rather than controlling target pests through direct toxicity, methoprene interferes with an insect’s lifecycle and prevents it from reaching maturity or reproducing.

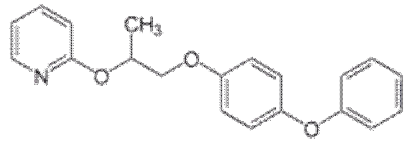
Methoprene is commonly used as a mosquito larvicide used to help stop the spread of the West Nile virus.

Methoprene is also used as a food additive in cattle feed to prevent fly breeding in the manure.

c) Pyriproxyfen

IUPAC name - 4-phenoxyphenyl (RS)-2-(2-pyridyloxy)propyl ether 2-[1-(4-phenoxyphenoxy)propan-2-yloxyl]pyridine

Structural formula



Chemical formula - $C_{20}H_{19}NO_3$

Pyriproxyfen is a pyridine-based pesticide which is found to be effective against a variety of arthropoda. It was introduced to the US in 1996, to protect cotton crops against whitefly. It has also been found useful for protecting other crops. It is also used as a prevention for fleas on household pets.

Pyriproxyfen is a juvenile hormone analog, preventing larvae from developing into adulthood and thus rendering them unable to reproduce.

2.14 Structure and mode of action microbials

Pathogens include bacteria, fungi, viruses, protozoans, rickettsia, nematodes etc. that cause disease or physiological disturbances to insect pests. Pathogenic microorganisms attack insects and have life cycle more or less characteristic or similar microorganisms developing in other groups of animals. Insects are probably subject to as wide as variety of disease as are the vertebrates. Except for the fungi, disease organisms gain entry in the host via mouth or the digestive tract, that is the insect host must eat plant or other food contaminated with pathogen. In case of fungi, entrance is gained through the insect integument and free water or very high humidity is generally required. Thus, fungi tend to be restricted to moist environment.

Virtually no insect disease organisms occur in mammals and none have been recorded from man. Thus they are safe to use in biological control even in large scale microbial spraying operations.

Bacteria

Because it can be produced fairly easily on a large scale and has a wide spectrum of activity, Bacillus thuringiensis was of the first microorganisms to be incorporated into a commercial microbial insecticide. The most sensitive insects appear to be lepidopterous caterpillars, particularly those in which alkaline conditions prevail in the midgut. This is related to the fact that the spores (it is a crystal bearing spore former and can be conveniently stored and applied in the resistant state without loss of potency) can only enter the insect on ingestion and that the proteinaceous crystals of toxin is only liberated at around pH 9-10.

Those pathogenic bacteria which do not form spores have proved to be of little practical value in the field and indeed only two other groups of spore formers have been employed with any success i.e., Bacillus popilliae and Bacillus cereus. The former species produces a condition known as milky disease in the Japanese beetle, Popillia japonica and has been used extensively in North America for control of this pest and Chaffer beetles, it also requires closely defined mid gut conditions with an optimum around pH 7. This Bacillus is active against the codling moth and certain Hymenopterous pests.

Viruses

The classic example of the employment of viruses in pest control is the highly successful use of a polyhedrosis viruses against the pine sawfly, Neodiprion sertifer in Canada. A related pest similarly controlled by a polyhedrosis virus.

Another example is the control of alfalfa caterpillar, Colias eurytheme by introduction of polyhedrosis virus. The cabbage looper, Trichoplusia ni and other group of viruses, the granulosis type has been used against pests in field, in this case the Lepidopterans, Pieris brassicae and Pieris rapae.

Fungi and Nematodes

Pathogenic fungi have several properties which should make them ideal organisms for use in biological control. They produce highly resistant stages and are capable of prolific spore production once they became established. However, their great dependence on microclimatic conditions, especially humidity has seriously curtailed their use and only a few have been employed successfully of these Entomophthora exitialis has produced promising results against the spotted alfalfa aphid, Therioaphis maculate.

The most common fungi pathogenic to insects belong to three subdivisions of Eumycotina, viz. Deuteromycotina, Mastigomycotina and Ascomycotina; the majority being in Deuteromycotina. The important genera are :

Coelomomcyces, Entomophthora, Massospora (Mastigomycotina), Cordyceps, Podonectria, Torrubiella (Ascomycotina) and Aschersonia, Aspergillus, Beauveria, Fusarium, Hirsutella, Metarhizium, Nomuraea, Paecilomyces etc., (Deuteromycotina) causing diseases among lepidopteran, homopteran and coleopteran insect pests.

Among the nematodes species belonging to Steinernematidae, Mermithidae and Heterorhabitidae are symbiotically associated with bacteria attacking insect pests belonging to Lepidoptera and Coleroptera.

Protozoa

More than 1000 species of protozoa pathogenic to insects have been described. Most of these are chronic debilitating agents affecting host vigour, longevity and fecundity of the host. Nosema fumiferarae is being exploited for the management of spruce budworm, Choristoneura fumiferana, the most destructive forest pest of North America.

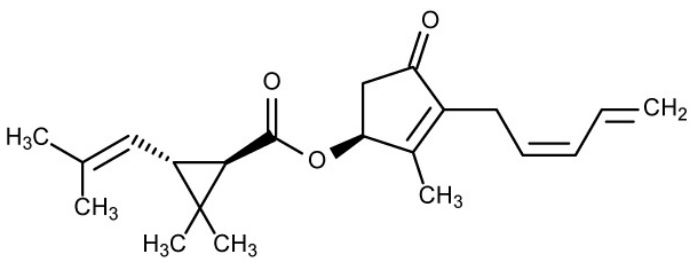
Many protozoa appear to cause chronic rather than acute symptoms in their victims and the microsporidian, Thelohania hyphantriae takes upto four weeks to exert its full effect which has been shown to cause mortality in the fall webworm, Hyphantria cunea.

2.15 Structure and mode of action botanicals or plant origin insecticides

These are insecticides derives from plants and majority of them are contact poisons. They have several uses in insect control. The most important insecticides of plant origin are nicotine, pyrethrum, rotenone, sabadilla, ryania and neem, all of which serve as insect toxicants.

a) Pyrethrins

Structural formula



Chemical formula - $C_{21}H_{28}O_3$

The pyrethrins are a class of organic compounds normally derived from *Chrysanthemum cinerariifolium* that have potent insecticidal activity by targeting the nervous systems of insects. Pyrethrin is synthetically made by industrial methods, but it also naturally occurs in the Chrysanthemum flowers, and thus is often considered an organic insecticide, or at least when is not combined with piperonyl butoxide or other synthetic adjuvants. Their insecticidal and insect repellent properties have been known and utilized for thousands of years.

It is prepared by extracting the toxins with kerosene, alcohol or ethylene dichloride from flowers of the Chrysanthemum. This concentrated form may be diluted with petroleum oil and used as sprays. Concentrated extracts as acetone, alcohol or a hydrocarbon solvent are available for spraying plants. These are diluted with water to form aqueous emulsion. Pyrethrum is harmless to warm blooded animals and man but is highly toxic to most insects.

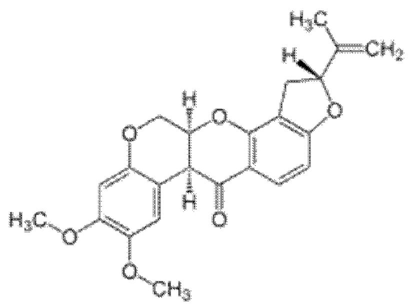
Pyrethrins delay the closure of voltage-gated sodium ion channels in the nerve cells of insects, resulting in repeated and extended nerve firings. This hyperexcitation causes the death of the insect due to loss of motor coordination and paralysis. The most important characteristics of these compounds is their irritating effect or “knock down” which causes the insect to stop feeding as soon as it encounters a treated surface.

Specific pest species that have successfully controlled by pyrethrum include: potato, beet, grape, and six-spotted leafhopper, cabbage looper, celery leaf tier, Say’s stink bug, twelve-spotted cucumber beetle, lygus bugs on peaches, grape and flower thrips, and cranberry fruit worm.

b) Rotenone

IUPAC name - (2R,6aS,12aS)-1,2,6,6a,12,12a-hexahydro-2-isopropenyl-8,9-dimethoxychromeno[3,4-b]furo(2,3-h)chromen-6-one

Structural formula



Chemical formula - $C_{23}H_{22}O_6$

Rotenone is an odorless, colorless, crystalline ketonic chemical compound used as a broad-spectrum insecticide, piscicide, and pesticide. It occurs naturally in the seeds and stems of several plants, such as the jicama vine plant, and the roots of several members of Fabaceae (Derris, Lonchocarpus etc.). It was the first described member of the family of chemical compounds known as rotenoids.

Rotenone may be extracted with a solvent like chloroform or carbon tetrachloride and a concentrated extract is then prepared. This may be diluted in sprays or mixed with a dust carrier and used as an impregnated dusts. It is nontoxic to warm blooded animals and man. It is also non phytotoxic. But it is poisonous to cold blooded animals. Rotenone sprays and dusts loose their toxicity rapidly on exposure to light and air.

Rotenone works by interfering with the electron transport chain in mitochondria. To be specific, it inhibits the transfer of electrons from iron-sulfur centers in complex I to ubiquinone. This interferes with NADH during the creation of usable cellular energy (ATP). Complex I is unable to pass off its electron to CoQ, creating a back-up of electrons within the mitochondrial matrix. Cellular oxygen is reduced to the radical, creating a reactive oxygen species, which can damage DNA and other components of the mitochondria. They are used in combating cattle grubs, lice, aphids and beetles.

c) Neem products

A lot of work has been done in the past few decades and several seminars and symposia were held to evaluate the insecticidal properties of various parts of the neem tree viz., leaves, flowers, fruit kernels in the powder or oil form to control insect pests infesting various crops and crop products. It has been stated that the neem is an important source of insecticide and all its parts viz., leaves , bark, flower, kernel and kernel oil are variously used as insect repellents. Since ancient times, its leaves are kept amongst woollen and silken clothes and books to protect them against insects. Farmers throughout the country are aware of the need to protect the grains from spoilage during storage and use of neem leaves in grain heaps.

The oil is also used as a disinfectant and emulsifying agent in insecticides. The maximum insecticidal activity has been found in neem kernel. Several workers have tried the neem leaves and kernel powder as grain protectant. Mixing of seeds with neem powder at 1.0 and 2.0% effectively protected from pest infestation. Neem oil at 0.5 and 1.0% provided the beat surface protection when applied to pulses against the pulse beetles Callosobruchus chinensis and C. Maculates. Repellent effect of extracts of neem leaves, flowers and kernels against rust red beetle Tribolium castaneum and khapra beetle Trogoderma granarium has been evaluated and found that neem kernel extract was more repellent than the leaf or the flower. Adults of T. Castaneum failed to reproduce when fed with flour treated with neem kernel extract. Neem oil was found effective in preventing adult emergence and prolonging the development from egg to adult stage of Rhizopertha dominica.

Chopped leaves of neem were found effective in controlling the Sitotroga cerealella in stored rice. In addition to stored grain pests, numerous other pests of agricultural importance have been controlled by neem products in the form of powder, seed cake or aqueous and solvent extracts.

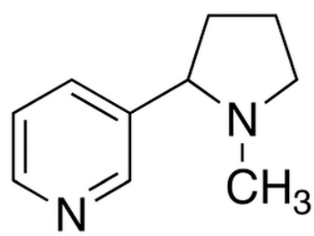
Several commercial formulations have been evaluated against pest of tobacco, groundnut, black papper, pulses, cotton, oil seeds, vegetable and other agricultural crops. Neem plant parts also act as growth regulator, repellent and antifeedant, thus help to control crop pest population without altering the quality and nutritive value. One of the most potent derivatives of neem is Azadiractin. It is a highly oxidized tetranortriterpenoid which boasts a plethora of oxygen bearing functional groups, including an enol ether, acetal, hemiacetal, tetra-substituted epoxide and an variety of carboxylic esters.

Powdered flowers and fruit kernel powder treated rice, caused mortality of Sitotroga adults, 59-64% after 7 days, 2-8% powder was used. As pointed out above neem oil 1-2% was found most effective in reducing adult population of Sitophilus, Rhizopertha and Ephestia. The neem kernel powder when mixed with cowpea Vigna sinensis at 3%, caused 85-95% mortality of Callosobruchus.

d) Nicotine

IUPAC name - (s)-3-[1-Methylpyrrolidin-2-yl]pyridine

Structural formula



Chemical formula - $C_{10}H_{14}O_2$

Nicotine is a potent parasympathomimetic alkaloid found in the nightshade family of plants (Solanaceae) and is a stimulant drug. Nicotine is a nicotinic acetylcholine receptor(nAChR) agonist, except at nAChRα9 and nAChRα10 where it acts as an antagonist. It is made in the roots of and accumulates in the leaves of the nightshade family of plants. Nicotine is found in the leaves of *Nicotiana rustica* in amounts of 2–14%, the tobacco plant *Nicotiana tabacum*, *Duboisia hopwoodii* and *Asclepias syriaca*.

It constitutes approximately 0.6–3.0% of the dry weight of tobacco and is present in the range of 2–7 µg/kg of various edible plants. It functions as an anti herbivore chemical; consequently, nicotine was widely used as an insecticide in the past and neonicotinoids such as imidacloprid are currently widely used.

Among the twelve alkaloids, nicotine, nornicotine and anabasine are important. Nicotine is not found free in the plant but in the form of maleates and citrates. Nicotine is essentially a non persistent contact insecticides. It affects the neuromuscular junction in vertebrates and central nervous system in insects. Its mode of action consists in mimicking acetylcholine when it binds with its receptor in the post synaptic membrane of the muscular union. The acetylcholinic receptor is a site of action of the postsynaptic membrane which reacts with acetylcholine and alters the membrane permeability. Nitocitne activity causes the production of new impulses which cause convulsions and death.

Commercial formulation containing 40% nicotine was effective against several soft bodied insects. Now, however in India it has been banned this and the manufacture is permitted for export purposes only. Synthetic derivatives of the nicotine structure have been developed recently and are called as neonicotinoids. These include imidacloprid, thiacloprid, nitempiran, acetamiprid and thiamethoxan, among others.

e) Pongamia sp.

Pongamia oil is derived from the seeds of the *Millettia pinnata* tree, which is native to tropical and temperate Asia. *Millettia pinnata*, also known as *Pongamia pinnata* or *Pongamia glabra*, is common throughout Asia and thus has many different names in different languages, many of which have come to be used in English to describe the seed oil derived from *M. pinnata*; *Pongamia* is often used as the generic name for the tree and is derived from the genus the tree was originally placed in.

Other English names for this oil include Honge oil (from Kannada), Kanuga oil (from Telugu), Karanja oil (from Hindi), and Pungai oil (from Tamil).

Karanja Oil is used in agriculture and pharmacy just like neem oil. It has similar insecticidal properties as neem oil and acts against a number of pests and insects. It is pale yellow in colour and viscous. It is known for its medicinal and antiseptic properties for centuries in its naive India. it is often used in pet care for the treatment of fleas, mange and scabies. As it has insecticidal properties it is great for agriculture use serving as a natural pest repellent. It is also used for skin care purposes and can be used to treat eczema, psoriasis, skin ulcers, dandruff. Karanjin is the main active ingredient of Karanja Oil. It acts as an acaricide and insecticide. Karanjin also have nitrification inhibitory properties.

2.16 Structure and mode of action of new promising compounds

Spinosad

Spinosad is a fermentation product derived from actinomycete, Saccharopolyspora spinosa. It has a remarkable selectivity between insects and mammals. It is highly effective against Helicoverpa and Spodoptera, but induces the populations of sucking insects including mites. Since its mode of action is different from those of pyrethroids, it is effective against those populations, which exhibit resistance against pyrethroids. Spinosad is an acetyocholine receptor agonist. The exact mechanism of spinosad is somewhat different than that of the neonicotinoid class, but the end result is the same.

Formamidines

Formamidines have a unique mode of action.. these compounds are locomotor stimulants, anorexiens and eclosion inhibitors in insects. Formamidines mimic octopamine and stimulate the octopamine receptors. Chlordemiform was withdrawn as it was suspected to be carcinogenic. Another compound of this group, amitraz, is effective against sucking pests, mites and cattle ticks as well.

Nereistoxins

Nereistoxins is a poison from marine annelids, Lumbrineris brevicirra and L. heteropoda. Synthetic compounds viz., cartap, bensultap, thiocyclam etc. were developed.

Amino triazinones

Pymetrozine represents not only a new class of chemistry but also a unique mode of action. Although it has no knock down effect and is not directly toxic to insects it acts on salivary pumps causing immediate and irreversible cessation of feeding. The exposed insects appear normal for several days before they die from starvation. Being contact and systemic in action pymetrozine is effective sucking pests.

Quinazolines

Quinazolines inhibit the mitochondrial electron transport chain.

Oxidative phosphorylation disruptors

Oxidative phosphorylation is the process through which ATP is synthesized in plants and animals. Organotin miticides inhibit oxidative phosphorylation directly, while pyrroles work by uncoupling oxidative phosphorylaion from electron transport. Diafenthiuron, a thiourea derivative is a potent acaricide/insecticide. In the presence of sunligjt diafenthiuron is converted to its carbodiimide derivative, which is a potent inhibitor of mitochondrial ATPase. The end result for these groups of compounds is that the cell is unable to produce ATP for energy.

2.17 Problems of pesticide hazards and environmental pollution

The environmental impact of pesticides consists of the effects of pesticides on non-target species. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, because they are sprayed or spread across entire agricultural fields. Runoff can carry pesticides into aquatic environments while wind can carry them to other fields, grazing areas, human settlements and undeveloped areas, potentially affecting other species. Other problems emerge from poor production, transport and storage practices. Over time, repeated application increases pest resistance, while its effects on other species can facilitate the pest's resurgence.

Each pesticide or pesticide class comes with a specific set of environmental concerns. Such undesirable effects have led many pesticides to be banned, while regulations have limited and/or reduced the use of others. Over time, pesticides have generally become less persistent and more species-specific, reducing their environmental footprint. In addition the amounts of pesticides applied per hectare have declined, in some cases by 99%. However, the global spread of pesticide use, including the use of older/obsolete pesticides that have been banned in some jurisdictions, has increased overall.

Pesticides are used extensively in agriculture and farming practices to eradicate insects, rodents, weeds and other forms of life considered to be pests. They are widely used on lawns, fields, golf courses, inside buildings, and even directly on our pets in some cases, to control pests. They are also used for controlling the spread of disease, for example, to eradicate malaria carrying mosquitos in the tropics. They come in all forms from powders, liquid sprays, gels, granules, pellets or lotions to name a few, and can be applied using various methods.

Pesticide/class	**Effect**
Organochlorine DDT/DDE	Egg shell thinning in raptorial birds Endocrine disruptor Thyroid disruption properties in rodents, birds, amphibians and fish Acute mortality attributed to inhibition of acetylcholine esterase activity
DDT	Carcinogen Endocrine disruptor
DDT/ Diclofol, Dieldrin and Toxaphene	Juvenile population decline and adult mortality in wildlife reptiles Susceptibility to fungal infection
Organophosphate	Thyroid disruption properties in rodents, birds, amphibians and fish Acute mortality attributed to inhibition of acetylcholine esterase activity Immunotoxicity, primarily caused by the inhibition of serine hydrolases or esterases Oxidative damage Modulation of signal transduction

	pathways Impaired metabolic functions such as thermoregulation, water and/or food intake and behavior, impaired development, reduced reproduction and hatching success in vertebrates.
Carbamate	Thyroid disruption properties in rodents, birds, amphibians and fish Impaired metabolic functions such as thermoregulation, water and/or food intake and behavior, impaired development, reduced Interact with vertebrate immune systems Acute mortality attributed to inhibition of acetylcholine esterase activity
Pyrethroid	Thyroid disruption properties in rodents, birds, amphibians and fish
Nicotinoid	respiratory, cardiovascular, neurological, and immunological toxicity in rats and humans Disrupt biogenic amine signaling and cause subsequent olfactory dysfunction, as well as affecting foraging behavior, learning and memory.

Effect on soil

When pesticides enter the soil, they kill the tiny micro organisms present in the soil that are important for keeping the soil healthy. Microscopic bacteria and fungi are essential for decomposing organic matter to make nutrients available to plants for growth. The decomposed organic matter, or humus, is not only rich in nutrients, but it also acts as a sponge and aids in water retention in the soil. As soil condition deteriorates, farmers compensate by adding chemical fertilizers to enhance crop growth. The poor soil condition results in nutritionally compromised crops of inferior quality.

Air

Pesticides can contribute to air pollution. Pesticide drift occurs when pesticides suspended in the air as particles are carried by wind to other areas, potentially contaminating them. Pesticides that are applied to crops can volatilize and may be blown by winds into nearby areas, potentially posing a threat to wildlife. Weather conditions at the time of application as well as temperature and relative humidity change the spread of the pesticide in the air. As wind velocity increases so does the spray drift and exposure. Low relative humidity and high temperature result in more spray evaporating. The amount of inhalable pesticides in the outdoor environment is therefore often dependent on the season. Also, droplets of sprayed pesticides or particles from pesticides applied as dusts may travel on the wind to other areas, or pesticides may adhere to particles that blow in the wind, such as dust particles. Ground spraying produces less pesticide drift than aerial spraying does. Farmers can employ a buffer zone around their crop, consisting of empty land or non-crop plants such as evergreen trees to serve as windbreaks and absorb the pesticides, preventing drift into other areas. Such windbreaks are legally required in the Netherlands.

Pesticides that are sprayed on to fields and used to fumigate soil can give off chemicals called volatile organic compounds, which can react with other chemicals and form a pollutant called tropospheric ozone. Pesticide use accounts for about 6 percent of total tropospheric ozone levels.

Effect on plants

Nitrogen fixation, which is required for the growth of higher plants, is hindered by pesticides in soil. The insecticides DDT, methyl parathion, and especially pentachlorophenol have been shown to interfere with legume-rhizobium chemical signaling. Reduction of this symbiotic chemical signaling results in reduced nitrogen fixation and thus reduced crop yields. Root nodule formation in these plants saves the world economy $10 billion in synthetic nitrogen fertilizer every year.

Pesticides can kill bees and are strongly implicated in pollinator decline, the loss of species that pollinate plants, including through the mechanism of Colony Collapse Disorder, in which worker bees from a beehive or western honey bee colony abruptly disappear. Application of pesticides to crops that are in bloom can kill honeybees, which act as pollinators. The USDA andUSFWS estimate that US farmers lose at least $200 million a year from reduced crop pollination because pesticides applied to fields eliminate about a fifth of honeybee colonies in the US and harm an additional 15%.

On the other side, pesticides have some direct harmful effect on plant including poor root hair development, shoot yellowing and reduced plant growth.

Effects on animals

Many kinds of animals are harmed by pesticides, leading many countries to regulate pesticide usage through Biodiversity Action Plans.

Animals including humans may be poisoned by pesticide residues that remain on food, for example when wild animals enter sprayed fields or nearby areas shortly after spraying.

Pesticides can eliminate some animals' essential food sources, causing the animals to relocate, change their diet or starve. Residues can travel up the food chain; for example, birds can be harmed when they eat insects and worms that have consumed pesticides. Earthworms digest organic matter and increase nutrient content in the top layer of soil. They protect human health by ingesting decomposing litter and serving as bioindicators of soil activity. Pesticides have had harmful effects on growth and reproduction on earthworms. Some pesticides can bioaccumulate, or build up to toxic levels in the bodies of organisms that consume them over time, a phenomenon that impacts species high on the food chain especially hard.

Birds

Bald eagles are common examples of nontarget organisms that are impacted by pesticide use. Rachel Carson's book *Silent Spring* dealt with damage to bird species due to pesticide bioaccumulation. There is evidence that birds are continuing to be harmed by pesticide use. In the farmland of the United Kingdom, populations of ten different bird species declined by 10 million breeding individuals between 1979 and 1999, allegedly from loss of plant and invertebrate species on which the birds feed. Throughout Europe, 116 species of birds were threatened as of 1999. Reductions in bird populations have been found to be associated with times and areas in which pesticides are used. DDE-induced egg shell thinning has especially affected European and North American bird populations. In another example, some types offungicides used in peanut farming are only slightly toxic to birds and mammals, but may kill earthworms, which can in turn reduce populations of the birds and mammals that feed on them.

Some pesticides come in granular form. Wildlife may eat the granules, mistaking them for grains of food. A few granules of a pesticide may be enough to kill a small bird.

The herbicide paraquat, when sprayed onto bird eggs, causes growth abnormalities in embryos and reduces the number of chicks that hatch successfully, but most herbicides do not directly cause much harm to birds. Herbicides may endanger bird populations by reducing their habitat.

Aquatic life

Fish and other aquatic biota may be harmed by pesticide-contaminated water. Pesticide surface runoff into rivers and streams can be highly lethal to aquatic life, sometimes killing all the fish in a particular stream.

Application of herbicides to bodies of water can cause fish kills when the dead plants decay and consume the water's oxygen, suffocating the fish. Herbicides such as copper sulfite that are applied to water to kill plants are toxic to fish and other water animals at concentrationssimilar to those used to kill the plants. Repeated exposure to sublethal doses of some pesticides can cause physiological and behavioral changes that reduce fish populations, such as abandonment of nests and broods, decreased immunity to disease and decreased predator avoidance.

Application of herbicides to bodies of water can kill plants on which fish depend for their habitat.

Pesticides can accumulate in bodies of water to levels that kill off zooplankton, the main source of food for young fish.[55] Pesticides can also kill off insects on which some fish feed, causing the fish to travel farther in search of food and exposing them to greater risk from predators.

The faster a given pesticide breaks down in the environment, the less threat it poses to aquatic life. Insecticides are typically more toxic to aquatic life than herbicides and fungicides.

Amphibians

In the past several decades, amphibian populations have declined across the world, for unexplained reasons which are thought to be varied but of which pesticides may be a part.

Pesticide mixtures appear to have a cumulative toxic effect on frogs. Tadpoles from ponds containing multiple pesticides take longer tometamorphose and are smaller when they do, decreasing their ability to catch prey and avoid predators. Exposing tadpoles to theorganochloride endosulfan at levels likely to be found in habitats near fields sprayed with the chemical kills the tadpoles and causes behavioral and growth abnormalities.

The herbicide atrazine can turn male frogs into hermaphrodites, decreasing their ability to reproduce. Both reproductive and nonreproductive effects in aquatic reptiles and amphibians have been reported. Crocodiles, many turtle species and some lizards lack sex-distinct chromosomes until after fertilization during organogenesis, depending on temperature. Embryonic exposure in turtles to various PCBs causes a sex reversal. Across the United States and Canada disorders such as decreased hatching success, feminization, skin lesions, and other developmental abnormalities have been reported.

Humans

Pesticides can enter the body through inhalation of aerosols, dust and vapor that contain pesticides; through oral exposure by consuming food/water; and through skin exposure by direct contact. Pesticides secrete into soils and groundwater which can end up in drinking water, and pesticide spray can drift and pollute the air.

The effects of pesticides on human health depend on the toxicity of the chemical and the length and magnitude of exposure. Farm workers and their families experience the greatest exposure to agricultural pesticides through direct contact. Every human contains pesticides in their fat cells.

Children are more susceptible and sensitive to pesticides, because they are still developing and have a weakerimmune system than adults. Children may be more exposed due to their closer proximity to the ground and tendency to put unfamiliar objects in their mouth. Hand to mouth contact depends on the child's age, much like lead exposure. Children under the age of six months are more apt to experience exposure from breast milk and inhalation of small particles. Pesticides tracked into the home from family members increase the risk of exposure. Toxic residue in food may contribute to a child’s exposure. The chemicals can bioaccumulate in the body over time.

Exposure effects can range from mild skin irritation to birth defects, tumors, genetic changes, blood and nerve disorders, endocrine disruption, coma or death. Developmental effects have been associated with pesticides. Recent increases in childhood cancers in throughout North America, such as leukemia, may be a result of somatic cell mutations. Insecticides targeted to disrupt insects can have harmful effects on mammalian nervous systems. Both chronic and acute alterations have been observed in exposees. DDT and its breakdown product DDE disturb estrogenic activity and possibly lead to breast cancer. Fetal DDT exposure reduces male penis size in animals and can produce undescendedtesticles. Pesticide can affect fetuses in early stages of development, in utero and even if a parent was exposed before conception. Reproductive disruption has the potential to occur by chemical reactivity and through structural changes.

Persistent organic pollutants

Persistent organic pollutants (POPs) are compounds that resist degradation and thus remain in the environment for years. Some pesticides, including aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex and toxaphene, are considered POPs. Some POPs have the ability to volatilize and travel great distances through the atmosphere to become deposited in remote regions. Such chemicals may have the ability to bioaccumulate and biomagnify and can bioconcentrate (i.e. become more concentrated) up to 70,000 times their original concentrations. POPs can affect non-target organisms in the environment and increase risk to humans by disruption in theendocrine, reproductive, and immune systems.

2.18 Summary

- The chemicals which kill the insects by their chemical action are termed as insecticides. They include ovicides and larvicides used against insect eggs and larvae, respectively. Insecticides are used in agriculture, medicine, industry and by consumers.
- Insecticides can be classified in two major groups: systemic insecticides, which have residual or long term activity; and contact insecticides, which have no residual activity.
- Chlorinated hydrocarbons are the oldest insecticides having been the first widely used synthetic organic insecticides. All insecticides of this group contain at least chlorine, hydrogen and carbon.

- Organophosphate pesticides irreversibly inactivate acetylcholinesterase, which is essential to nerve function in insects, humans, and many other animals.
- A carbamate is an organic compound derived from carbamic acid (NH_2COOH). A carbamate group, carbamate ester (e.g., ethyl carbamate), and carbamic acids are functional groups that are inter-related structurally and often are interconverted chemically. Carbamate esters are also called urethanes.
- A pyrethroid is an organic compound similar to the natural pyrethrins produced by the flowers of pyrethrums (*Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids now constitute the majority of commercial house hold insecticides. In the concentrations used in such products, they may also have insect repellent properties and are generally harmless to human beings in low doses but can harm sensitive individuals.
- The avermectins are a series of drugs used to treat parasitic worms. They are a 16-membered macrocyclic lactone derivatives with potent anthelmintic and insecticidal properties. These naturally occurring compounds are generated as fermentation products by *Streptomyces avermitilis*, a soil actinomycete.

2.19 Model Examination Questions

Section -A (Very Short Answer Type)

1. What is DDT?
2. Write the IUPAC name of BHC, parathion and carbryl.
3. Which insecticides are used as insect growth regulators?
4. Give any three name of plant origin insecticides.
5. Which plant produced the pyrethroid insecticide?

Section -B (Short Answer Type)

1. Describe the structure and mode of action of DDT.
2. Write short notes on:
    a) Phenyl Pyrozoles
    b) Oxadiazines

3. Write an assay on structure and mode of action of microbials.
4. Give a detailed account on chitin synthesis inhibitors and nitroguandines.
5. Write short notes on:
    a) Chlordimeform
    b) Allethrin

Section -C (Long Answer Type)

1. Describe the IUPAC name, structural formula and mode of action of Organochlorides.
2. Write short notes on:
    a) Insect growth regulators
    b) Neonicotionids
    c) Avermectins
3. Write an assay on Problems of pesticide hazards and environmental pollution.
4. Describe the IUPAC name, structural formula and mode of action of Carbamets.
5. Write an assay on plant origin insecticides.
6. Give a detailed account on organophosphates.
7. Describe the IUPAC name, structural formula and mode of action of Pyrethroids.

2.20 References

- A text book of Agricultural Entomology by Kumar & Nigam
- Introduction to General and Applied Entomology by V. B. Awasthi
- Wikipedia
- http://www.ozonebiotech.com/karanjaoil.html

Unit - 3

Principles of evaluation of toxicity of insecticides

Structure of the Unit

3.1 Objectives

After going through this unit you will be able to understand

- The general and basic concept of Toxicology.
- Evaluation of Insecticide Toxicity.
- Lethality Tests.
- Joint Action of Insecticides
- Factors Affecting Toxicity of Insecticides.
- Insecticide Compatibility and Selectivity.
- Phytotoxicity.

3.2 Introduction

Swiss Physician Paracelsus (1493-1541) credited with being the " father of Modern Toxicology" said 'All substances are poisons: there is none which is not a poison .The right dose differentiates a poison from a remedy'.

The study of adverse effects of chemical agents on living organism s is toxicology. Adverse effects refers to any change from an organism's normal state which is dependent upon the concentration of active compound at the target site for a sufficient time. Poison=toxicant are inorganic and organic lifeless substances that causes deleterious effects in a living organism. Toxin is a poisonous substance produced by a living organism such as a plant, animal or micro-organism.

3.3 Principal of Toxicology (The Basic Concepts)

The word toxicology is derived from greek word 'Toxin, Toxicum or Toxicon = poison and logus = knowledge meaning the science of poisons'. Presently the toxicology is not restricted to the knowledge of only poisons, but the study of nature and mechanism of toxic results of poison on living individuals as well as other biological systems. In 1969, the first ever research institute of toxicological research in our country was established at Lucknow as ITRC (Industrial toxicology research centre).

For the basic approach towards toxicology, the type of problem, nature of toxicant, effect of toxicant on living organism and the time of disposal are taken, as the study stand points. The toxicologists must know the physical, chemical and biological components of the environment, concentration of toxicants in the environment, factors influencing the toxicity, dose- response relationship and methods of testing the toxicity.

Basic Concepts :

3.3.1 Environment

The environment includes abiotic (physical and chemical) as well as biotic components (biosphere). Thus ecosystem is a product of interaction between abiotic and biotic components. Adaptation in living organisms, biodiversity and different make up in structural and functional responses makes the assessment of a chemical highly complicated.

3.3.2 Toxicant

Toxicant is an agent which produces an adverse response in a biological system by damaging its structure (anatomy) and function (physiology). The foreign substance in the form of toxicant is introduced in the ecosystem, accidentally or through experimentation. The quality of environment is deteriorated and impaired, which makes is unfavorable for living beings. The toxicants may also concentrate in the ecosystem through agricultural and urban run off, bottom sediments disposal, atmospheric fall outs, effluents from industries, waste disposals, municipal wastes etc. the toxicants may be natural, artificial or synthetic.

3.3.3 Toxicity

Toxicity is the capacity of a substance to cause low or high injury to a living individual. A highly toxic substance cause a great damage, even in a micro quantity while a low toxic substance produces its toxicity when used in large amount. Hense the toxicity of an administered substance can not be estimated through its dose, but it must be measured through absorbed dose inhalation, ingestion, injection, distribution duration (e.g. single dose, double dose, repeated dose etc.) and the time needed to result in injury. The injuries may be as corrosives, irritants, narcotics, systematic. On the basis of intensity of injury, the toxicity may be acute, sub acute or chronic toxicity.

3.3.4 Effects and responses

Biological change due to toxicant in an individual is the 'effect' while the proportion of a population that demonstrates a defined effect is denoted as "response" (i.e. incidence rate of an effect). The acute effects are resulted due to short term single exposer to a pesticide. They generally cause lethality. While chronic or subchronic effects are sublethal showing physiological, biochemical or histological changes in exposed organisms. In many cases the effects are 'reversible' when the exposed individuals are able to escape from the toxic environment and get that damages tissues regenerated.

3.3.5 Dose – Response – Relationship

Various factors e.g. rate of absorption in the tissue, distribution, detoxification, excretion of a chemical, interaction of toxicant with other chemical, hypersensitivity and tolerance, genetic factors and the health status of an organism are important in dose – response relation of a chemical with that exposed organism.

3.3.6 Statistical Concepts

The data collected from the toxicity investigation are statistically analysed by some appropriate methods e.g. concentration, response relationships, mortality as an index for LD_{50} or LC_{50} estimation.

3.3.7 Margin of Saftey

The ratio of lethal or toxic dose to therapeutic dose is expressed as 'margin of safety'. The larger ratio, the greater is the relative safety.

3.3.8 Toxicity of Chemical mixtures

Here the LD_{50} environment of two compounds may antagonize or synergise the effect of each other.

3.4 Evaluation of Insecticide Toxicity : Methods of Toxicity Testing

Methods of Toxicity Testing

The investigators have developed various methods for toxicity testing of pesticides or other chemicals from time to time, which have been designed according as -

(i) Eco taxonomic methods (e.g. Single indicator species, multi species or community and eco system)

(ii) Acute toxicity methods (lethal effects)

(iii) Chronic and sub chronic tests (lethal or sub lethal effects including reproductive cycle, early stages of life cycle, bioaccumulation, biochemical and physiological tests, behavioural response, histopathological tests.)

(iv) Specialized methods or tests.

Different types of methods for animal toxicological or toxicity testing are thus :

3.4.1 Acute toxicity

(a) LD50 estimation (7 to 14 days observation)
   - (i) Two species (one is non- rodent)
   - (ii) Two routes of administration of poison

(b) Irritation studies
   - (i) Desmal
   - (ii) Eye sensitiveness (irritation)

3.4.2 Sub acute toxicity

(a) Duration about 90 days
(b) Two species
(c) Three dose levels
(d) Route of administration according to the route of exposure.

3.4.3 Chronic toxicity

(a) Duration – two years
(b) Species (two ; one species non rodent)
(c) Three dose levels
(d) Route of administration (according to route of exposure)

3.4.4 Specified (special) tests

(a) Metabolism
(b) Neurotoxicity
(c) Reproduction and teratogenicity(at least one species)
(d) Carcinogenicity
(e) Mutagenicity

Toxicity tests are conducted in two ways :

- The effects of toxicity can be estimated in a laboratory with limited number of variables.

- The effects of toxicity can be estimated in a natural ecosystem (in field).

3.4.5 Test Design

In the laboratory toxicity tests are initiated from short term tests to complex long term tests. The tests must be based on the results obtained from previous investigation and the general test design must remain similar (however the details may differ).

We must go through the following steps :

- pH, temperature, dissolved oxygen, photoperiod concentration or % of chemical etc. must be carefully controlled.
- Test organisms must be exposed in test chambers to various doses (concentration) of test material dissolved in a medium (e.g. aqueous solution for aquatic organism and acetone or other solvents for terrestrial organism)
- Mortality, growth, reproduction etc. are evaluated by comparision of chemically treated organisms with untreated organism(control experiment).
- The species of target organism must be correctly selected. For example in aquatic toxicological test methods static test, recirculation test, renewal test and flow through test are used.

Some commonly applicable test methods are discussed as an outline below :

3.4.6 Indicator tests (single-species)

When a single species is used as a target organism, indicator test method is used applicable. Here the response of an ecosystem having interacting species is predicted from single species toxicity tests. The single species tests are done for years where no adverse ecosystem or multispecies effects were observed. community test according to weis (1985) have not been found successful because the species which is most sensitive can automatically protect the entire community. This is because the investigator would not use extra dose of the chemical to access the impact above the particular level.

3.4.7 Community Structure (multi species tests)

Ecosystem or community tests can also be exercised in the laboratory. Here the small enclosures (glass or plastic contents) with samples from ecosystem e.g. sediment, fish, small invertebrates are used. The effect of pesticide on many species is simultaneously estimated. It all the condition remain uniform, then the tests can standerdise the replicates. Taub (1985) performed 24 replicates test by using 10 species of algae, 5 species of animal and numerous number of bacterial species.

3.4.8 Acute Toxicity Tests

The tests were conducted for about 40 years with industrial effluents and lateron with drilling mud, mine tailings etc. Acute toxicity is severe effects of short terms exposure of organisms to toxicity chemicals. Through these tests the dose or concentration of a test material is estimate that produced a particular response on a group or species or strain of an organism in a short term exposure under controlled conditions. The results are obtained by calculating the number of dead or moribund organisms.

3.5 Lethality tests (LC_{50} or LD_{50} tests)

3.5.1 LC50

The concentration of material in a medium to which test organism are exposed, is found lethal (causing mortality) to 50% of the test organisms. The LC50 is expressed as a time dependent value. e.g. 24 hrs., 48 hours or more. LC50 is the statistical estimate of the dose concentration necessary to kill 50% of large population of test species under standard conditions. The chemical at graded doses is administered to a group of selected organisms and by observing mortality group of selected organisms and by observing mortality in a set time period, the acute toxicity is estimated –

Three different approaches for LC50 estimation are evolved :

(i) Parametric method
(ii) Moving average method
(iii) Non parametric method

3.5.2 LD50

The dose of material which is estimated as lethal to 50% population of selected organism is LD50 value.

The LC50 and LD50 values are calculated by any of the following two methods in general :

(A) Graphical interpolation method :

In this method data is plotted on semi logarithmic co-ordinate paper where concentration of chemical is taken as logarithmic and mortality percentage of test animal as arithmetic scale. Then mortality is plotted against logarithmic concentration of chemical. A straight line is drawn between two points representing the LC50 value.

(B) Statistical method :

From the data obtained from acute toxicity test, the time dependent LC50 or LD50 values and their 95% confidence limits are calculated by any of the statistical methods (Litch field and Wilcoxon, 1949; Golden, 1959; Finney, 1971). The widely used method is Finney's(1971) probit analysis method. The logarithmic values are seen for each concentration or dose and probit values are seen for percent mortality.

Now a graph is plotted between logarithmic concentration dose and the probit mortality. The result curve is termed as probit mortality curve. From the curve, the value of expected probits are seen in the probit table and corrected probits are calculated by finney's(1971) formula and finally the LC50 or LD50 values are estimated.

If the mortality is also observed in 'control' groups of test organism, then the data are corrected by Abbott's (1925) formula :

$$\% \text{ Corrected mortality} = \frac{\% \text{ Test mortality} - \% \text{ Control mortality}}{100 - \% \text{ Controlled Mortality}} * 100$$

The data of acute toxicity tests enable to determine no observed effect dose or concentration which is minimum dose / concentration of test chemical causing +no toxic effect on test animals. It provides the data on lowest observed effect. The acute toxicity data are beneficial in fixing the sub lethal dose / sub lethal concentration for chronic toxicity tests.

3.5.3 LT50

This is the time required to kill 50% of the population of test individual at a certain dose or concentration.

3.6 Joint Action of Insecticides

In pesticide treatment, the mixture of chemicals are known to have advantages over the chemicals applied singly or individually. In the pest control techniques, the use of mixture of chemical has been found superior to single pesticide. The mixtures show following advantages –

- Increased effectiveness against target organisms.
- Safety towards non- target organisms.
- Utilization of lesser quantities of chemicals without any loss in effectiveness.

- Less residues are deposited in the environment
- Cost benefit of the material because of utilization in lesser quantity.

3.6.1 Potentiation :

Potentiation is a phenomenon in which the toxicity of a chemical substance on an organisms is markedly increased by another chemical substance which when used alone has no toxic effect on that organism. Iso propanol is a chemical substance, which has no toxic effect on liver but when used with carbon tetra chloride (CCI_4) increases its hepato – toxicity considerably. Similarly scopolamine and morphine are sedative drugs. The combined (joint) administration of these two drugs results in far more sedation than the sum of two drugs, when given at different times separately. Thus the administration of two drugs jointly to exert a greater response is termed "potentiation" , where one toxicant potentiates the toxicity of the other toxicant.

Drug used	Degree of response
X	A
Y	B
X+Y	C

According to definition of potentiation

$C > A+B$

A number of chemically related compounds e.g. chloroform, carbon tetra chloride, tetra chloro ethane and phosphorus show similar potentiation action. The potentiation test can be performed through a very simple exercise. A fraction of lethal doses of two toxicants having similar mode of action are exposed to test. Animals and a parameter is selected on the basis of their mode of action individually. Then similarly the same fraction of both toxicants is applied together and the toxic effect produced by two toxicants is quantified.

Example of Potentiation :

- DDT + Benzene -----> More toxicity than individual.
- C2H5OH + Barbiturate -----> More toxicity.
- Morphine + Heroin -----> Higher toxicity.

3.6.2 Synergism

Both chemical compounds which produce higher toxic effects in combination in comparison to that when used individually are termed synergists if the chemical agents at on the same organ or tissue and to toxic effect is algebric sum of their individual action than it is called an additive effect (e.g. 1+1= 2). But if the response is greater than the algebric sum of the individual effect the term used is positive summation or synergism (1+1= > 2). For example, the two cholinesterase inhibiting pesticides, EPN (o-ethyl, o-para nitrophenyl phosphorthiate) and malathion, when given jointly to test animal are found to show more toxicity than the sum of their individual toxicities.

3.6.3 Antagonism

In contrast to potentiation or synergism one of the two agents may antagonize the toxicity of other administered chemical. There may also found non compatibility between chemicals when they are mixed with each other. When the toxic effect of one drug or chemical is suppressed by the use of other chemical in combination, the ‘ antagonism’ is said to occur, where the toxicity of two chemicals is estimated to be less than individual effect (e..g. 1+1= < 2).

3.7 Factors Affecting Toxicity of Insecticides

Toxicity tests are performed for evaluation of adverse effects of a chemical on living organism under standerdised reproductive conditions. In the environment also the concentration, transport, transformation and disposition of a chemical are primarily controlled by the following factors :

- The physical properties of the compound
- The chemical properties
- The physical, chemical and biological properties of the ecosystem and
- The source and rate of input of the chemical into the environment.

The physical and chemical properties of a chemical compound include molecular structure, solubility in water, rate constant for hydrolysis, biodegradation, evaporation, sorption uptake by organism, partition coefficients (e.g. air : water; sediment : water; octanol : water).

The properties of aquatic environment are, surface area to volume relationships; temperature salinity. pH, depth, flow, amount of suspended material, size of sediment particle and the carbon content in the sediment.

All the above parameter not only predict the environmental concentration of toxicants but also the mobility of a chemical ; the kinds of chemical and biological reaction that take place during transport as well as after deposition ; the resulting chemical form of the toxicant and the persistence of the chemical.

In the environment a chemical exists in various forms :

In aqueous medium a chemical exists in three different forms which affect its availability to organisms.

i) Dissolved form
ii) Adsorbed to biotic or abiotic component and suspended in water column or at the bottom.
iii) Accumulated in the organism.

Water soluble chemical may persist and retain their physico – chemical characteristics when transported and distributed in the environment.

The chemical which are not significantly degraded can be accumulated in the environment as toxic levels. The chemicals which are not degraded show their persistence as a 'half life'. The biotic and abiotic transformation converts the chemicals into other forms. Biotransformations are enzymatically mediated and affect the environmental concentration of toxicants, which are soluble forms of generally lesser toxicity.

The toxicity is also influenced by –

- Exposure
- Organism
- Environmental factors
- Chemical

Exposure :

For adverse response in organism the compound must react with a particular receptor site at a high concentration at a required duration. The concentration and adverse effect vary with the species, chemical, and severity of the effect. The contact reaction of organism and chemical is called 'exposure'.

The significant factors related to exposure are

- The type
- Duration and

- Frequency of the exposure and
- Concentration of the toxicant

The toxic effects are observed by acute (short- term) or chronic (long term) exposure to chemicals. The exposure of intermediate duration are called subchronic exposure.

1. **Acute exposure :** In short term exposure the target organism are exposed to chemicals in a short time. The chemicals are rapidly absorbed and generally show delayed effects.
2. **Chronic exposure :** In long term exposure organism are exposed to low concentration of toxicant over a long period of time.
3. **Subchronic exposure :** The duration of exposure is one month to several months. These exposures include sensitive early stages of development.

Factors Related To The Organism : Species and strain (if available), size, sex, age, diet, changes in the internal environment due to physiological factors, stress, hormones etc.

External Environmental Factors : Dissolved oxygen, temperature, pH salinity, hardness of water and dissolved solids in water affect The toxicity to the organism. The physical environment e.g. light temperature and relative humidity also affect the toxicity.

Factor Related To The Toxicant : The toxicity of a chemical is influenced by its composition. The identity and purity of the pesticides are important in toxicity testing. The solubility of toxicant in water, oils, organic solvents etc. and their vapour pressure and pH are also directly related to the chemicals. These factors affect the bio availability, persistence, transformation and ultimate fact of the toxicant in the environment.

Selective Toxicity : The chemicals have also been found species specific in their selective activity. They may be more toxic for one species and less harmful for another. Two significant mechanisms are involved for selective action of chemicals:

- Presence or absence of specific target (receptive sites) in the exposed cell system. The target may be altered by the chemical.
- The factors that are responsible for the distribution and alteration of the concentration of the toxicant (chemical) at specific cell or tissue sites.

3.8 Phytotoxicity

It refers to plant injury of all pesticide types as a group, herbicides are considered to have the greatest potential for causing phytotoxicity, since they are designed to control unwanted vegetation. Inert ingredients in pesticide formulations may also be capable of causing phytotoxicity.

Many species of plants in natural and undeveloped areas are desirable because they protect the watershed by reducing erosion and runoff . They also provide food and cover for wildlife and part of an ecosystem's balance. A disruption of this balance may increase the likelihood of undesirable vegetation becoming more prevalent .There are situations where desirable plants are injured because of one or more of the following reasons:-

1. Excessive application rate.
2. Inadequate mixing and agitation.
3. Environmental conditions such as extremely hot temperatures and high humidity at the time of application.

Positive confirmation of toxicity caused by pesticides can be difficult. Keeping accurate application records can assist in trying to determine if a pesticide is responsible for the suspected injury.

Even with accurate records pesticide injury can easily be confused with environmental disorders.

Diagnosis of Phytotoxicity: Phytotoxicity can show up as spotting on leaves and fruits, unusual growth patterns, blighting leaves or flowers , stunted growth, reduced root growth as well as complete plant death. Symptoms often develop within few days of an application, although in some cases phytotoxicity may take much longer to develop. The causes of phytotoxicity can be summarized as follows:

1. Direct toxicity
2. Overdose
3. Improper mixing of Pesticides.
4. Incompatibile spray schedules.
5. Excessive Concentrations.
6. Climatic Factors.

3.9 Summary

After going through this unit you have understood that toxicology is the study of nature and mechanism of toxic results of poison on living individuals as well as other biological systems. The basic concepts of it includes the environment ,toxicant, its toxicity ,effects and responses and dose -response relationship.

Methods of acute,sub-acute,chronic and specific toxicity evaluation by LD_{50},LC_{50} and LT_{50} were studied .Potentiation, Synergism and Antagonism and their role in application of pesticides was understood. The various factors affecting toxicity of insecticides were enumerated and Lastly we explained how Phytotoxicity or plant injury due to pesticides takes place.

3.10 Glossary

- **Toxicant**: Toxicant is an agent which produces an adverse response in a biological system by damaging its structure (anatomy) and function (physiology).
- **Potentiation:** Potentiation is a phenomenon in which the toxicity of a chemical substance on an organisms is markedly increased by another chemical substance which when used alone has no toxic effect on that organism.
- **Synergism** :Both chemical compounds which produce higher toxic effects in combination in comparison to that when used individually are termed synergists if the chemical agents at on the same organ or tissue and to toxic effect is algebric sum of their individual action than it is called an additive effect.
- **Antagonism** :In contrast to potentiation or synergism one of the two agents may antagonize the toxicity of other administered chemical.
- **Phytotoxicity:**It refers to plant injury of all pesticide types as a group, herbicides are considered to have the greatest potential for causing phytotoxicity, since they are designed to control unwanted vegetation.

3.10 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. Define Toxicology.
2. Who is called the father of Modern Toxicology?
3. What is Phytotoxicology?
4. What is LT_{50} ?
5. What is the duration of Chronic Toxicity?

6. Name the factors affecting Toxicity.
7. What is Synergism?
8. Define Antagonism?

Section -B (Short Answer Type)

1. Explain the basic Concepts of Toxicology.
2. Enumerate the various methods of Toxicity Testing..
3. Write about the factors affecting Toxicity of Insecticides..
4. Explain the Joint Action of Insecticides
5. Write a short note on Phytotoxicity.

Section -C (Long Answer Type)

1. Explain what is Toxicology with its principles of evaluation .
2. Write in detail about the factors affecting Toxicology and the joint action of Insecticides

Unit - 4

Metabolism of insecticide and insecticide Resistance

Structure of the unit

4.0 Objective

The objective of present unit is to understand the mechanism of Metabolism of Insecticides and Insecticide Resistance. It is important to study the detoxification enzymes present in the body of the insect involved in the metabolism of Insecticides. Need, Scientific bases of selectivity are to be studied so are the three principles for selective toxicity. It will acquaint the learner with the different mechanisms of selectivity in toxicity and the advantages of selectivity of insecticide actions. In the next part the learner will understand the concept of insecticide resistance, the various traits of insecticide resistance and the mechanism of development of resistance. Lastly genetics of insecticide resistance and its management have been discussed.

4.1 Introduction

Elucidation of the metabolism and fate of organic insecticides in plants and animals is prerequisite to the development of these chemicals for use in insect control. From a public health viewpoint , information on the chemical behavior and reactions of insecticides in living systems is essential for the assessment of hazards arising from the use of these compounds .Identification and establishment of the toxological properties of the metabolic products formed in plants and animals after exposure to insecticides is indeed mandatory before residual hazards may be assessed .From a more fundamental aspect, metabolism studies are necessary for our understanding of the mode of action of insecticidal chemicals i.e. the elucidation of the intoxication and detoxication processes that occur in biological systems .Explanations for such important phenomena as insecticide specificity and the development of insecticide resistance are often found in the intoxication and detoxication reaction that occur in the animal ..

The metabolism of the organic insecticides may be divided into two large but distinct categories (1) Activation and (2) Detoxication. Activation is defined as the metabolic reaction or reactions that convert an intrinsically inactive compound to an active compound or an active compound to another active compound .In some cases a number of toxic compounds may be produced .Detoxication is defined as the reaction or reactions that lead to non- toxic substances.

There are a number of ways insect can become resistant to insecticidal crop protection and public health products. Resistant insect may detoxify or destroy the toxic faster than susceptible insects, or quickly rid their bodies of the toxic molecules. Metabolic resistance is the most common mechanism and often presents the greater challenge. Insects use their internal enzyme systems to break down the insecticides. Resistance strains may possess higher levels or more efficient forms of these enzymes . In addition to being more efficient , these enzymes systems also may have a broad spectrum of activity (i.e. they can degrade many different insecticides.)

4.2 Insecticide Metabolism

4.2 .1 Detoxification Enzymes And Their Role In Metabolism

It has been estimated for many decades, say about 60 years, the insect pests are showing resistance towards many pesticides. The generations of pests are able to inherit the resistance, further creating a hurdle in insect pest control through chemical pesticides. It has been observed through number of investigations, that these insect pests have many enzymes which can detoxify the chemical pesticides and help in development of resistance in their body toward such chemicals. Some detoxification enzymes which have been recognized for detoxifying the pesticides are glutathione S- transferases, carboxy esterases, phosphorotriester hydrolases, DDT dehydrochlorinase etc.

The ‘resistance’ is known as a highly complex term in which many mechanism work simultaneously in a single insect ‘strain’ behaving as pests. Some other biochemical mechanism for resistance development in insect pests are penetration mechanisms, behavioral pattern and altered target sites eg. Cholinesterase and binding proteins.

In resistant tobacco budworm larvae (heliothis viresens) a high concentration of glutathione S – transferase is reported. The high levels of the enzyme are also found in many strains of resistant houseflies. The enzyme is able to detoxify some organophosphates.

DDT resistant insect pest strains are found to have sufficient amount of DDT – dehydrochlorinase.

The ester-containing insecticides are detoxified by carboxyesterase enzymes resulting in resistance among many strains of insect pests.Some strains of sheep bow fly, Lucilia, some house flies, a strain of mosquitoes *Culex tarsalis,* rust red flour beetle, *Tribolium castneum, Blatella germanica*(a strain of cockroach), have been reported to show a high resistance towards malathion.

Phosphotriester hydrolases are the detoxification enzymes which have also been reported to develop resistance towards many organophosphorus pesticides among various strains of insect pests e.g. *Myzus persicae* (a strain of house fly), rice leaf hopper, sheep blow fly etc.

4.2.2 Detoxification Enzyme’s Inducers

In the living individuals a variety of inorganic and organic compounds can induce various enzymes. An overall increase in xenobiotic metabolizing enzymes is reported as major induction, which is generally non specific. Some insecticides e.g. cyclodienes, phosphoric acid esters, polycyclic hydrocarbons, phenobarbitol, juvenile hormones (analogs), DDT etc. have found to induce cytochrome P-450 among insect pests. The chlorinated hydrocarbon insecticides have been found more effective inducers than organophosphates, carbamates and other insecticides.

4.3 Selectivity of Insecticidal Actions

The chemical toxicants are able to produce injury to one group of living organism without harming another group even though the two groups are living in the same territory. Here the living individuals which have been injured or are toxicated are called uneconomic forms and the individuals which are protected are called economic forms (desirable). In agriculture there are insects, crop, fungi and other competitive plants that injure the original desirable crop. Here the selection of appropriate pesticides is needed which can save the life of desirable species and have toxic effect on undesirable one.

4.3.1 Need of the selectivity of insecticide

It has became multi disciplinary in life science to select the insecticide. Obviously it is an achievement of the prime importance to select the toxic agents which can be applied in agriculture to remove many uneconomic species without causing deleterious effect to the economic species.

In the animal husbandry man's domestic as well as economic animals are affected with ecto as well as endo parasites. The application of potent selective toxicant to remove parasites gives an explaination of selective toxicity needed for these organisms.

4.3.2 Scientific bases of selectivity of an insecticide

A favorable selective effect is exerted by an agent through three principles –

The toxicant can be found equitoxic to all the species but on the other hand accumulated by uneconomic species. It may react with cyto chemical or biochemical feature which plays an important role in uneconomic in comparison to economic species.

4.3.3Three principles for selective toxicity

- Selectivity through accumulation
- Selectivity through comparative biochemistry

- Selectivity through comparative cytology.

1. Selectivity through accumulation :

Comparatively large surface area (per unit weight) of an insect resting on a mammal brings about greater retention of sprayed toxicant by uneconomic species. Similarly selective accumulation can be measured in a positive way. For example- orally administered phenothiazine is highly toxic to the intestinal worms in a sheep than to the sheep it self.

2.Selectivity through comparative biochemistry :

All the living beings e.g. plants, animals and microbes have a common universal biochemistry. In animal life one species functions differently from another strong species differences depend upon homologous proteins.

The N- terminal amino acids in the fibrinogen of seven mammals were studied by Blombacs & Yamoshina, 1958 :

Sheep and Goat	-> Glyeine, alanine, tyrosine
Dog and Horse	-> Threonine and tyrosine
Pig	-> Alanine(2) and tyrosine
Ox	-> Glutamic acid and tyrosine
Man	-> Alanine and tyrosine

1. **Selectivity through comparative cytology :**

The plants and animals have remarkable cytological differences. Even there are differences among the cells of plants species and animal species among them. And there are noticeable differences among different tissues of same animal or plant species. Hence the difference in the structure of the cells make them selective for toxic agents also.

4.3.4 Mechanism of Selectivity In Toxicity

I. Due to differences in translocation of chemical

Morphological, anatomical and cytological differences in the cell structures of different organisms and even organs of same individuals account for differential absorption, distribution and accumulation of toxicants (selective toxicity). For instance , the insect have large surface area as compared to mammals per unit body weight. It causes greater absorption and accumulation of toxicant in insects. DDT can be easily absorbed through chitinous skeleton of insect but poorly absorbed through the mammalian skin (Hayes, 1955). Hence it (DDT) causes deleterious effects on insects but very less in mammals.

II. Selective toxicity due to differences in biotransformation

Biotransformation is the conversion of one form of toxicant into another in the body of organisms. The chemical may be bio activated in 'one group' of organisms while in 'other' they can be deactivated or converted into inactive forms. Thus the toxicant is found more injurious to former group and lesser injurious to the later. The biotransformation of a toxicant thus can alter the translocation and hence the toxicity also. Heath (1961) reported the signification of the rates of bio catalytic activation and inactivation of organophosphate insecticides as determinates of their selective toxicity to insect pests.

These pesticides cause toxicity inhibition of acetyl chlorine esterase activity. The species in which the rate of oxidation of hydrolysis is slow, the active form of compounds accumulates, causing toxicity of the chemical. In others if the rate of hydrolysis is rapid, the activated chemicals rapidly convert into inactive or less active form, hence the toxicity is diminished. This is the reason why the mammals get less harm in comparison to insects.

III. Selective toxicity due to presence or absence of receptors

However all the cells of economical or uneconomical species are equally exposed to same concentration or toxicants, even then the toxicant induce there effects on account of their interaction with various receptors in organism. The chemical is toxic to one species having appropriate receptors for a particular chemical while it may be non toxic for those organisms which are devoid of such receptors.

4.3.5 Advantages of Selectivity Of Insecticide Actions

- Selective toxicity solves much of the problems of diseases in plants, domestic animals and human beings. e.g. spraying of some organophosphorus insecticides on the exposed breeding sites of tse tse fly. The tripanosomiase is controlled, because the biological cycle of the parasites is broken due to veiling of the vector.
- Selectively toxic agents are found economic in the control off weeds.
- They can control insect pests to a great extent.
- They show advantage in seed protection.
- In veterinary science, the selectivity of insecticide action is also advantages.
- The diseases in economical animals can be caused.

- The infectious diseases in man can be controlled to a great extent through selective use of toxicants.

Conclusion : The selectively toxic agents have been found not only toxic to many of pests but they are also used for animal husbandry, agricultural practices and forests.

4.4 Insecticide Resistance

'The ability to tolerate the doses of pesticides in certain strains of insects is called resistance'. The dose has been found lethal to majority of organism of the same species. The ability of tolerance to pesticides, is inherited in generations showing the capacity to tolerate the toxicant. The resistance depends on genetic variability of the population exposed to the toxicant. A.L. Melander in 1914 first of all evaluated the phenomenon of resistance in scale insects towards lime sulfur . Then in 1916 the red scale (pest) was found resistance to cyanide in California by Quale. Many more cases of developing resistance were regularly reported towards arsenicals, cyanide, selenium etc. The houseflies were identified to show resistance towards DDT in 1947. Up to 1938, 7 species of mites and insects were found to show resistance while up to 1984, 447 species were discovered as resistant towards all classes of insecticides e.g. cyclodienes, DDT, carbamates, organophosphates and pyrethroids.

The resistance has been more widely studied in order 'Diptera' which includes 156 resistant species , while in Lepidoptera, only 67 species have been discovered to develop resistance , 'Coleoptera' has 66 specie 'Acarine' 58 species, Homoptera 46 species and Heteroptera 20 species. The resistance towards cyclodienes has been found maximum i.e.62% while DDT resistance species are 47% .

Now days, the resistant species can resist the toxicants in two, three, four or all the five classes of pesticides. 17 species have been found to show resistance towards five classes of the toxicants.

The phenomenon of the resistance is observed under field conditions where a toxicant, at a fixed application rate progressively becomes inable to control the target pest. However during laboratory conditions the resistance can be estimated by treating the generations of target pest with little higher dose every time than the previous dose to kill a large percentage of pests (say about 90%) . The next breeding is obtained by 10% remaining survivors. Some insects with resistance genes survive and pass their resistance capacity (Trait) to their offspring through natural selection by the insecticide. The resistant pests continue to multiply while susceptible insects are killed and eliminated from the population. Hence the resistant insects gradually supersede over the susceptible strain and pesticide is found no longer effective to them.

There are some draw backs of resistance in resistant insects.

. They show poor viability.

. Some strains of resistant bud worm larvae grow very slowly.

.Their weight is somewhat lesser than the susceptible ones.

.Resistant females release less pheromones.

.They lay fewer number of eggs.

.They have higher natural mortality than susceptible strains.

Thus susceptible strains have an advantage over resistant strains provided that no insecticide selection pressure is imposed on them. The resistant strains sometimes revert back to susceptible strains when the pressure of insecticides is discontinued.

The disadvantage of resistance is that the scientists have to switch over to a different pesticide which is more costly and more frequent application of them on the pest is needed.

4.4.1 Insecticide- Resistant Traits

In a selected population some individuals can tolerate certain amount of dose of the toxicant while other individuals can not do so. It follows the rule of Darwininian selection due to natural mutations or gene amplification.

4.4.2 Natural mutations

The insecticide resistant genes have altered function which are expected to be reported at a low frequency. They can also show incomplete dominance. The incomplete dominance has economic importance because the genetic selection favour the rare dominant or incomplete dominant genes than the rare recessive genes. In dominant genes the insecticides resistance has been found difficult to manage. The heterozygotes are killed by somewhat higher insecticide doses and more higher doses in recessive strains. Hence resistant individuals have been reported to be recessive genetically.

4.4.3 Gene amplification

When activated multiple copies of a gene are obtained resulting in increased synthesis of messenger RNA, and hence increased transfer RNA, finally the increased synthesis or amount of respective protein.

Once a gene amplified becomes homozygous the duplications are observed at a higher frequency in every successive generation.

The mechanism of pesticide resistance:

The mechanism of development of resistance can be studied as behavioral, penetration, knock down, metabolic, altered site of action and increased excretion.

1. **Behavioral resistance (pseudo resistance):**
   The resistance insects can detect a danger and immediately avoid the toxin. The insect start quitting the feeding or go away from that area of application of pesticide. Such resistance is difficult to be estimated in the laboratory conditions because there, they do not get the places to hide themselves and have to remain in touch to the applied pesticide. Here they will be recognized as sensitive strains.
2. **Penetration resistance :**
   The insects develop barriers in their cuticle through which absorption of insecticides is found very slow. The amount of pesticide sprayed or applied can be measured by topical application. The left over chemical on cuticle is estimated but the actual amount of penetrated pesticide remains unobserved. The chemically inert compounds e.g. dieldrin retardation of knock- down is reported.
3. **Knock down resistance (kdr) :**
   In the insect with Kdr the symptoms of poisoning takes longer duration in comparison to sensitive insects. Kdr mechanism was seen by Busvine (1951) for resistance of DDT in *Musca domestica*. He saw that susceptible strain had fast knock down, while Kdr genes in Italian (having Kdr like genes) Musca resisted the knock- down. In Sardinian genes recovered soon. One or more recessive genes on chromosome 3 govern the Kdr.
4. **Metabolic resistance :**
   Here the resistance strains of pests can detoxify the toxicants at a higher rate than susceptible ones. The resistant pests utilize their enzymes to degrade the insecticides while the sensitive strains can degrade them at a

very low rate. The enzymes in resistance strains may show broad spectrum activity, degrading many pesticides at one time.

5. **Altered site of action :**

   The active sites of the body of a pest where the toxicant initiate their toxic action are genetically modified and enormous amount of the toxicant is required to show the knock down symptoms in comparison to previous treatments.

6. **Increases in the rate of excretion :**

   Guthrie et al fed biosynthetic c^{14}. nicotine to tobacco hornworm. They reported that 90% of the oral dose was excreted in just four hours and the insects got rid of the dose completely in one day.

   When they injected the nicotine, the 83% of the dose was defecated within 15 minutes of the injection. Hence the tobacco horn worm has become resistant towards nicotine due to its rapid rate of excretion and defecation.

4.4.4 Genetics of Insecticide Resistance

As already discussed the resistance generally depends in single genetic factor, the R – factors. But there are also some examples where gene amplifications have been also found to induce resistance.

The resistance can genetically be studied as ‘cross’ and ‘multiple’ resistance:

Cross – Resistance:

The gene responsible for resistance is designated as R- gene. The experiments are carried over to identify this gene to show resistance towards on selected insecticide. But during the investigations, it has been estimated that not only the selected insecticide but a number of other toxicants are found harmless to the test insect. This is called the ‘ Cross – resistance’.

In a group of insect DDT include resistance is found in closely selected toxicant e.g. methoxychlor, but not resistant to dieldrin, lindane and non-chlorinated compounds. It has also been reported that one toxicant is correlated with susceptibility to other (negative correlated cross resistance). For example spider mites have increased susceptibility to synthetic pyrethroids but highly resistance to an organophosphorus compound ; azinphos – methyl.

Multiple – Resistance:

When a number of R – mechanisms are noticeable the multiple resistance is said to occur. In houseflies spider mites, cattle ticks, spodoptera species etc. the multiple resistance results due to continuous use of certain pesticides even after their replacement by others.

Besides the major genes responsible for resistance, modifier genes enhance the resistance. The linked genes (genes very close to R- genes) are never selected for investigation because they do not have any effect on resistance.

Induction :

The enzymes which are derived from the food intake treatment with chemical or those which normally occur in the body are activated by the including substances. However the induction is non heritable. Due to induction, the reaction of the individuals to the presence of the insecticides and toxicants induces less sensitivity and hence the increase in the tolerance. Eventually the development of resistance is the result.

4.4.5 Management of Insecticide Resistance

All the effective insecticide resistance management (IRM) strategies seek to minimize the selection of insecticide for resistance.

In Egypt unlimited use of same insecticide on cotton and other crops against *Spodoptera litura* has given way to develop resistance. The authorities restricted the use of photostable pyrethroids against. *S. litura* on cotton and allowed a single treatment of pyrethroids per year throughout the country. The resistance was gradually decreased and finally no case of resistance was reported through this strategy.

In 1983 at Emerald the larvae of *Helicoverpa armigera* were found to show resistance towards pyrethroids. The use of pyrethroids was immediately banned there and good results were obtained. The laboratory assays showed that 10 % of *H. armigera* collected from restricted areas heterozygos for pyrethroids resistance while homozygos individuals were very few. The further investigation in these areas showed that there was resurgence of resistance where endosulfan was frequently sprayed.

An another report of resistance towards pyrethroids in houseflies in United kingdom was made to show the widespread sequential application of DDT and trichlorfen both the mechanism show cross resistance to pyrethroids

4.5 Summary

The development of resistance in insects has been prominent in the last few decades. The factors responsible for it may be detoxification enzymes, other biochemical mechanism like penetration mechanisms, behavioral patterns and altered target sites. The ability of insecticide to produce its toxicity in one group of organism s without harming another group living in same territory is termed as selectivity. The selectivity has three principles and it operates through

various mechanisms . The resistance developed by an insect affects its physiology too and the genetics of insect plays a role in resistance. Management of insecticide resistance involves various means.

4.6 Glossary

- **Resistance:** 'The ability to tolerate the doses of pesticides in certain strains of insects is called resistance'.
- **Behavioral Resistance:** The resistance insects can detect a danger and immediately avoid the toxin. The insect start quitting the feeding or go away from that area of application of pesticide.
- **Penetration resistance** : The insects develop barriers in their cuticle through which absorption of insecticides is found very slow.
- **Knock down resistance (kdr**) :In the insect with Kdr the symptoms of poisoning takes longer duration in comparison to sensitive insects.
- **Metabolic resistance :**Here the resistance strains of pests can detoxify the toxicants at a higher rate than susceptible ones.
- **Cross–Resistance:**The gene responsible for resistance is designated as R- gene. The experiments are carried over to identify this gene to show resistance towards on selected insecticide.
- **Multiple–Resistance**:When a number of R – mechanisms are noticeable the multiple resistance is said to occur. In houseflies spider mites, cattle ticks, spodoptera species etc.

4.7 Self- learning Exercise

Section A- Very Short type questions

1. Define the term ' Insecticidal Resistance'.
2. Name two detoxifying Enzymes.
3. Write the name of some insects which developed high resistance towards malathion.
4. What are the three principles of Selective Toxicity?
5. What is gene Amplification?
6. Define 'Altered site of Action'.

Section-B Short Answers types questions

1. Write a note on Detoxification Enzyme's Inducers.
2. Explain Selectivity of Insecticidal Actions in brief.
3. What are Insecticide Resistant traits?
4. Describe the mechanisms of development of Insecticidal Resistance.

Section-C Long Answer Type Questions

1. Write a detailed note on mechanism of selectivity in toxicity and its advantages.
2. Explain the insecticide resistance genetics and also write about resistance management strategies.

Unit - 5

Insecticide residue and poisoning: Microbial and environmental degradation of pesticides

Structure of the unit

5.0 Objective

The objective of the present unit is to enable the learner to understand what is insecticide residue and how it can accumulate in the environment and result in biomagnifications. This unit also describes the microbial and environmental degradation of pesticides. Lastly the legal acts related to registration, quality control of insecticide have been discussed along with safe use , diagnosis and treatment of insecticide poisoning

5.1 Introduction

Insecticide Residue includes any derivative of a pesticide, such as conversion products , metabolites and impurities considered to be of toxological significance. Apart from those stemming from direct application to above and underground parts of the crop, residues also include those from unknown or unavoidable sources such as contaminated water and air pollution .When a crop is treated with an insecticide a very small amount of the insecticide or what it changes in the plant(its metabolite or degradation product) can persist in the crop or its surrounding environment .This is known as the residue which may be present in fruits and vegetables, processed food and drink made from the crop and fresh or prepared animal products . Occasionally residues may also result from environmental or other 'indirect' sources .Residues of old pesticides like DDT, endosulfan, chloropyrifos etc. are an example of such environmental contaminants.

5.2 Breakdown of the chemicals in the environment

The pesticides have been found as the biggest source of chemical pollutants which regularly accumulated in the environment creating basic cause of its pollution. Based on their molecular structures there are some pesticides which can be biodegraded very easily but some other groups of pesticides are of such complex structures that their degradation is very slow.

Besides having no adverse effect on the non - target organisms, a pesticides should be biodegradable for minimizing any possible harmful ecological side effects.

Different types of pesticides exist in the environment for different durations. Some are short lived and degraded very fast while others are available persistently in the environment. If persistent toxicants enter the biosphere they can be detected any where and can be transported from one organism to the other through food chain. Some chlorinated hydrocarbon insecticides have been estimated in arctic region which is about 1000 miles away from the point where the insecticide were originally applied. Biomagnification occurs when the pollutant (toxicant) is persistent and lipophilic. The lipophilic nature tends to give entrance of pesticide into lipids of both prokaryotes and eukaryotes from surrounding water. In the food web the chemical is neither degrade nor excreted and thus concentrates in higher and higher tropic levels. Hence the top consumers of food chain carry the pollutants that exceeds the environmental concentration by a factor of 10^4-10^6. Thus biomagnification is a serious threat causing death or malfunctioning in the top most trophic levels.

The pesticide for the use in agriculture or other place must be ideal in having biodegrable structure, which can be easily degraded through 'microbes'.

Three major natural mechanisms are required for the breakdown of toxicants in the environment:

- Auto oxidation
- Degradation by sunlight
- Microbial degradation

It has been evaluated that most of the xenobiotics (which are the chemicals foreigners to the ecosystem), deposit in the soil and then run with water. As sunlight can not properly work in water, the microbial degradation is the only mean for complete mineralization of xenobiotics in soil and water.

Many metabolic processes in microbes make them unique tools for biodegradation or detoxification. These metabolic processes are :

(i) Fermentation
(ii) Anaerobic metabolism
(iii) Chemo lithotrophic metabolism
(iv)Metabolism through exo enzymes
(v) Adaptability to unfavourable environment through mutation and induction.

5.3 Microbial Degradation of Toxic Chemicals

The microbes can detoxify or biodegrade the toxicants by enzymatic or non enzymatic processes. The compound can be bio transformed through oxidation, reduction, hydrolysis, and condensation. The synthetic pesticides contain halogen, amino, nitro hydroxyl and other functional groups.

The aliphatic hydrocarbons are oxidized to fatty acids, these fatty acids are degraded via β- oxidation sequence, resulting in formation of C_2 fragments which are then metabolized through TCA cycles.

The aromatic ring structures are metabolized by dihydroxylation and ring cleavage mechanisms. Before these transformations the substituent on the ring may be completely or partially removed. The substituent e.g. halogen, nitro and sulphonate initiate oxygenation and cause recalcitrance. Sometime a simple change in the substituent of a pesticide can make the difference between 'recalcitrance' (a complete resistance to biodegradation) and biodegradation. The herbicide 2, 4 – D is degraded within few days, while 2, 4, 5 – T persists for many months. The reason behind it is 2, 4, 5 – T possesses an additional chlorine substitution in the meta position.

Propham (a toxicant) can be cleaved by microbial amidases very rapidly. While an other pesticide propachlor (having a tertiary amine groups) can not be cleaved by these enzymes and persist for a longer duration. Methoxychlor is less peisistent than DDT because the p- methoxy groups can undergo dealkylation in them. While in DDT, p- chloro substitution give the DDT a greater biological as well as chemical stability. In some other cases one part of the toxicant molecules is susceptible to degradation while the other group is recalcitrant. Some acylamide herbicides can be cleaved by microbial amidases and the aliphatic moiety of the molecules is mineralized (changes into co_2 and h_2o). while the aromatic moiety is stabilized by chlorine substitution and resists mineralization.

In the transformation of acylanilide herbicide propanil, microbial acyl amydases, oxidases and peroxidases are used.

A good range of micro organisms have been discovered to be used in environmental biodegradation of various pesticides.

Pesticides	Microbes used for biodegradation	Pathway or enzymes used
DDT,Lindane, Heptachlor, Chlordane (chlorinated hydrocarbons)	*Aerobacter aerogenes*, E. *coli*, *Klebsiella pneumonia*, *Proteus vulgaris*, *Chlostridium*, *Pseudomonas fluorescens*, P. *putida*, *Nocardia*, *Streptomyces*, *Aspergillus flavus*, *Saccharomyces*.	Reductive dechlorination (anaerobic), Dehydrochlorination (aerobic)
Diazinon, Parathion, Chloropyrifan, Paraoxon, Malathion, Fenetrothion (organophospahtes), Carbaryl, Carbofuran	*Arthrobacter*, *Streptyomyces*, *flavobacterium*, *Pseudomonas*, *Nocardia*, *Corgnebacterium*, *Trichoderma viride*, *Pseudomonas striaia*, *Achromobacter* strain WM-III	Hydrolysis of alkyl and aryl bonds, reductive transformation, Phosphotriesterase; Reductive demethylation, hydrolases.

TABLE : Examples of environmental use of micro organisms in biodegradation detoxification of pesticides used in agricultural practices.

5.4 Environmental Implication of Insecticide Residues

The chemical in the bodies of organism have various routes of their excretion. Some of these chemicals including toxicants are metabolized by many organisms to eliminate them from the body. Generally the metabolic processes occur in the liver while the exertion takes place through kidneys. The processes of metabolism of toxic chemical into non – toxic ones to eliminate them from the body are included in 'excretion' and 'biotransformation'. The pollutants can easily enter the food chain. The rate of elimination of a chemical from the organism can affect the accumulation potential of a xenobiotic. Hence the exertion, transformation and accumulation of toxicants are interrelated processes.

The environmental concentration of any toxicant is not only controlled by its physical and chemical properties or the source and rate of input of the toxicant in the environment, But also by the physical, chemical and biological properties of the ecosystem.

Bio Accumulation :

The entrance of the toxicants in the food chain and the process of their concentration from the environment to first trophic level and then further trophic levels is referred to as 'Bioaccumulation'. It is the tendency of toxicants to concentrate in the higher trophic levels from the lower ones. Even micro quantities of chemicals in the environment get their entrance into the organisms and accumulate in high doses in higher trophic levels of food chain, eventually affecting the environment.

During 1960s DDT,DDD methyl mercury etc. residues were reported in fish and wild life, and gained public attention towards bio accumulation of environmental pollutants.

Thus 'Bioaccumulation' has been discussed as a common term for accumulation of toxicants in living organism. These toxicants can accumulate in the tissues, fat bodies or any other organ of the organism. These toxicant can enter the organism through epidermal contact with substance; food intake, through respiration or by any other means.

The level to which a toxicant can bio accumulate, depends on many factors e.g.

- Rate of uptake of the substance
- The mode of uptake (through food, through gills, through other respiratory means or through skin)
- The rate of excretion or elimination of the toxicants from the animal's body
- Transformation of the pollutants by metabolic processes
- Lipid content of the organism
- The hydrophobicity of the pollutant
- Environmental factors, and
- Other biological and physical factors.

The substance which is more hydrophobic can bio accumulate in the organism (e.g. fish) to a great extent. Bio accumulation does not necessarily result in bio magnification.

The bio accumulation is a normal and essential process for growth and nutrition of the organism. However vitamin - 'A', vitamin - 'D', vitamin - 'K', trace elements. Fats, amino acids etc. are daily bio accumulated in all animals including humans, but in a toxicological review, the ' bio accumulation' is the accumulation of the substance in the body at the level which can cause the harm. When a chemical enters into animal cells from the environment the bio accumulation is said to begin with.

BIOMAGNIFICATION :

Biomagnification is the process of accumulation of toxicants in the food chain tropics levels by the transfer of residues in smaller organisms and from them into higher tropic level organisms. Through the biomagnification the organisms of higher tropic level receive higher concentration of a chemical than is present in their food (lower tropics level). The chemical becomes more and more concentrated as it is shifted to higher tropics level from lower level of food chain.

The pollutants which have the following characteristic can only be biomagnified:

- The pollutant must be persistent (long lived)
- It must show high mobility

- It must be lipid soluble
- It must have high biological activity.

If a toxicant is found less persistant than it may be degraded before becoming dangerous. If it is less mobile or immobile, it can not be taken up by high tropic level organism. If the toxicant is soluble in water then it may be excreted with other nitrogenous excretory substance. Hence the pollutants are generally estimated in adipose or fatty tissues of the organisms because they are found in these tissues as of their solubility in lipids. In mammals, the toxicants can also be tested in milk because it also has some facts which can receive the toxicants through their mobility. All the above characteristics necessary for bio magnification are seen in chlorinated hydrocarbons (e.g. DDT), cyclodiens (endrin, aldrin, heptachlor, chlordane).

Bio magnification has been illustrated by the study of availability of DDT residues. The investigation have show that DDT is found @ 10 ppm in soil, while in earthworms, its concentration reaches @ 141 ppm and the robins which are the consumers of earthworms have its residues upto 444 ppm. The high enough concentration of toxicant at high tropic level are the main causes of death or ill effects on reproduction, resistance towards diseases.

The DDT and PCBs (Poly chlorinated biphenyls) show very less bio degradability. These chemicals are in indiscriminated use in agriculture and other pest control techniques. Measurable amounts of BHC, DDT, PCBs residues are recorded in soil, air, water etc. If for example DDT enters a pond or lake, it is absorbed by plants and other produces as such. These residues enter the successive consumers, zooplanktons (feeding on produces), then enter the minnows eating the zooplankton, then to the fish and then to the top consumers the birds who eat the fish. It has been found more threatening that DDT concentration continuously increases in successive tropic levels of food chain. This is the reason that our food in the form of vegetables, grains, fruits etc. contain a sufficient amount of pesticide residues.

Besides the pesticides some metals like lead, mercury, copper etc. have shown the bio magnification in food chain. The radioactive substances e.g. Strontium-90, Iodine-131,Calcium-137 etc. accumulated in the body tissues and result in bio magnification.

5.5 Insecticide Act & Environmental Legislation

The disciplines of toxicology have been influenced by legislation for regulation of chemicals in the environment. Environment has been toxified due to agricultural and industrial effluents and global ecosystem has been identified as threatened at an international level.

The World Commission on Environment and Development had discussed major threats to earth's environment.

Environmental Legislation :

The scientists have developed standardised procedures for evaluation of the effect of chemical on life of individuals the legislation also provides focal point for the standardization of evaluation processes of hazards.

A national environmental policy act (NEPA) of 1969, associated with environment quality and public awareness towards problems was launched. Then in 1970 environmental quality improvement act (EQIA) was implemented. Then an independent federal agency the Environmental Protection Agency (EPA) was created. Under the EPA the previously existing FIFRA – 1947 (Federal Insecticide, Fungicide and Rodenticide ACT); FWPCA – 1948 (Federal Water Pollution Control ACT); MPRAS – 1972 (Marine Protection, Research and Sanctuaries ACT) and TSCA – 1976 (Toxic Substance Control ACT) were brought within the jurisdiction of Environmental Protection Agency (EPA).

In India, Department of Environment, Forests and Wild Life was set up in 1980 to serve as the focal point in the Government administrative structure of environmental programs. The integrated department of environmental, forests, and wild life in the ministry of environment and forests was launched in 1985. The regulation of the hazardous chemicals is taken over by central and state pollution control bounds.

International regulation of chemical manufacture :

Japan, UK, Canada, USA and others 23 members nations of organization for economic co- operation and development (OECD) have recognized the essentiality for an international effort to protect humans and its environment from exposure to hazardous toxicants. OECD agreement have resulted in publication of data called MPD – 1981 (Minimum –Pre marked Data) for use in the assessment of chemical.

Enforcement of quarantines :

The legislative measures in different countries now can be grouped into 5 classes :

i. Legislation to prevent the introduction of foreign pests (international quarantines).
ii. Legislation to prevent the spread of already established pests (Domestic quarantines).
iii. Legislation to enforce the suppression of pests in limited areas (State level quarantines).
iv. Legislation regarding the insect and insect and residue contamination in food stuffs.
v. Legislation to prevent the adulteration and misbranding of pesticides (Insecticide act – 1968).

The insecticide ACT – 1968 (no.46 of 1968) has been implemented by government of India for the regulation of import, manufacture, sale, transport, distribution and use of pesticides to prevent risks to human being and animals. Govt. of India has constitute the central insecticide board for giving advise to central and state governments on technical matters through administration of this Act. The Insecticide Rule (1971) framed under Insecticide Act -1968 came into force from 1971. According to this act the firms engaged in the insecticide manufacture should get registered themselves, highlighting the name, address of manufacturer and brands and trade name of the insecticide and also the active ingredients of products and net contents in the unit pack. They must also print detailed directions of use as well as antidotes during poisoning. The standardized products must carry ISI (Indian Standards Institute) mark.

5.6 Insecticide Residue

All the toxicants (pesticides) are hazardous and risky molecules for life of individuals. Their indiscriminate use deposits the residues in the environment, soil, plants, surfaces, water leading to animal and human health hazards the pesticides (Toxicants) are the chemicals which includes insecticides acaricides, herbicides, fungicides, bacteriocides, molluscicides, nematicides and rodenticides. A nobel laureate Paul muller (1940's) has been designated as a land mark in the discovery of insecticide properties in DDT. Many other scientists have also discovered insecticidal properties in thousands of chemicals. However the misuse of insecticides beyond the suggested levels has created unwanted problems to harm the animals, humans, and ultimately the environment. The effect of pesticides is found acute and chronic. The proper application of these pesticides can minimize the risk to the applicator, but indiscriminate use of these toxicants increases the risks manifold. The dosages received through exposure e.g. walking over a treated area, food consumption through treated vegetables can create sufficient health problems.

Dispensing of pesticides deposit, their residues in a variable amount depending on the toxicity and rate of metabolism of the metabolites is very important. The 'residues' include derivatives of pesticides e.g. conversion products metabolites reaction products and impurities .

Rachel Carlson published a book in 1962 by the name "Silent Spring" in which he first of all discussed about the deposits of pesticides as residues. Now a days, through many researches it has been proved that cancer, hormonal and reproductive imbalance decreased immune function, sensitivity, neurotoxicity, digestive disruption etc. are mainly associated with the deposits (residues) of pesticides.

In Karnataka during 1980s, a 'Handigolu syndrome' among farmers (who consumed fish from paddy fields) was reported. It was proved later that the syndrome was due to deposition of residues of high doses of organochlorine insecticides in paddy fields which were deposited in the fish bodies and the farmers consuming those fishes were affected with Handigolu syndrome.

In the environment including soil, water air etc., many techniques of pesticide residue measurement are applied.

Thus pesticide 'residues' are specified substance in food, agricultural produce, trophic levels of food chain and even human beings which are considered to be of toxicological significance. They can be estimated even after many days of the application in field, houses, gardens, buildings, offices etc.

Pesticide Residue analysis :

For the analysis of pesticide residues any sample can be analyzed going through the following steps-

- Transport and storage of the sample (Sampling)
- Preparation of laboratory sample (Working solution)
- Extraction of pesticide residue
- Clean up process.
- Identification of the residue.
- Quantification (to estimate the percentage of pesticide in the sample)
- Analysis and result.

5.7 Safe Use of Insecticide

In recent years great attention is paid towards the hazards associated with the manufacture, distribution, utilization and disposal of chemicals. A 'risk' is a measure of probability that a certain adverse effect may happen while a 'Hazard' is the prediction of the magnitude and duration of concentration of a toxicant in various segment of the environment resulting because of a chemical in the food water or/and air which become harmful to a representative species, populations and the ecosystem.

Poisoning :

'Poisoning' or toxicity is the potential of a chemical to create deleterious effects in biological systems. It is the function of the exposure concentration or dose and the nature of biological system that is exposed to a chemical.

Safety :

The term is defined as the value judgment of the acceptability of a risk towards a chemical.

The toxicants (insecticides, fungicides, acaricides, rodenticides, nematicides) are toxic not only to insects and other pests but also to domestic animals and human beings. They may cause toxicity through skin contact, breathing (inhalation) or ingestion of toxic food. The risks and hazards are caused only when the toxicants are not properly handled and precautions are avoided during then application.

On the basis of the toxicity on mammalian fauna the pesticides are classified as :

(i) Non hazardous (e.g. sulphur, pyrethrum based pesticides etc.)
(ii) Moderately hazardous (e.g. BHC, DDT, carbaryl, malathion, endosulfan, fenitrothion etc.)
(iii) Hazardous or dangerous (e.g. endrin, parathion, DDVP, Carbofuran, thimet etc.)

The hazards are generally noticeable due to accidental poisoning, suicidal intention, killing intention, careless application, residue deposits (Post application hazard)etc.

The users or applicators of insecticides (generally including researchers, farmers and laymen) should strictly follow the instructions during handling of toxicants :

- Label on the pesticide container must be carefully read to follow the direction of use.
- The toxicants must be stored in their original packing containers in a safe locked room where no food material must be kept.
- The pesticide must not be measured by the utensils of daily use in the house. They must be measured through separate utensils.
- The containers which have become empty after the use of insecticides must be buried and should not be used for any other purpose (even not for cleaning purpose etc.)
- Always, the contact with the skin must be avoided
- For dusts and mists use of mask must be compulsory.
- Even after so many safety measures, the hands, face and other body parts must be thoroughly washed with soap and water.
- Complete bath is necessary after application of hazardous pesticides.
- During handling of the toxicants smoking drinking or eating food must be avoided.
- Always wear boots, gloves, goggles, masks and other protective clothing during the use of pesticides.
- Knife or cutting utensil must be separate for opening the container or bags of pesticides.
- A long handled mixer must be used during preparation of spray solutions. The hands must also be covered (wear gloves)
- If the person handling the insecticide feels nausea, vomiting and headache the pesticide application must be immediately stopped.
- The recommended rates of application of pesticides must not be exceeded.
- The safety period after spray must be strictly seen to avoid the residue deposits.
- The pesticides contains must not be washed in the field soil and must not be thrown in the stream, pond or near the place of live stocks.
- Spraying must be done in the early morning or afternoon periods. The hot conditions must be avoided.

- Beneficial insects like honey bees must be protected by the use of selective insecticides
- Poultry, dairy or meat animals must be kept away from pesticide treated area for a safe period.
- Insecticide treated fields or places must be labeled highlighting the date of spray.
- If signs of poisoning are observed the person must immediately go for a treatment.
- Children and old persons must not be allowed to enter the field during spray.

5.8 Diagnosis of Insecticide Poisoning

Headache, nausea, vomiting, tireness, palpitation, irregularity in heart beat, respiratory problems etc. when any or almost all the symptoms are observed immediately consult a doctor. The doctor must clearly know the cause of insecticide poisoning. Tell the doctor, whether insecticide was inhaled or swallowed or touched through the skin.

5.9 Treatment of Poisoning

First Aid Box – Every person handling the pesticide must have the first aid box having the following items :

- 5 ml disposable syringe.
- Ammonium carbonate.
- Ground mustard seed.
- Common salt
- Potassium permanganate
- Tannic acid
- Vinegar
- Milk of magnesium
- Charcoal
- Amyl nitrile pearls
- Atropin sulfate
- Caffeine
- Apomorphin capsules

- Stomach cleaning tubes.

TREATMENT OF POISONING BY MISTAKE

- Poison must be immediately washed out from the body.
- Antidote must be immediately used.
- Excretory waste should be collected for pathological test.
- Patient must be immediately admitted for proper treatment in the hospital.

TREATMENT OF PERSON WHO HAS SWALLOWED THE POISON

- If a person has swallowed the poison, a glass of warm water with a table spoon of salt must be given to induce vomiting till the vomiting fluid looks clear.
- The vomiting is induced by one gm. of zinc sulfate in a glass of water or apomorphine hydrochloride injection of 1/10 grain.
- The patient must lie down and must not be disturbed
- The unconscious person must not be given any oral treatment
- Vomiting should not be induced through salt or other chemical if we observe 'fits' or unconsciousness in a patient or if he/ she has swallowed petroleum product or concentrated acid or caustic soda. The stomach cleaning must be done through the expert treatment of a doctor.
- There are some universal antidotes (e.g. an antidote made of charcoal 2 parts: tannic acid 1 part: milk of magnesia 1 part) which must be immediately given to patient after vomiting or cleaning of stomach. The above mixture is an antidote of acid, glycoside, and heavy metal poisoning. But in corrosive substance poisoning the above antidote must be followed by giving gastric lavage also.

  Some other antidotes which are generally used in insecticide poisoning are atropine sulphate, diacetyl mono hexene and pyridine aldoxymet etc.

TREATMENT OF PERSON WHO HAS INHALED THE POISON

- Take the patient to fresh air
- All the windows and doors must be opened if the patient is inside a room.
- All tight cloth must be loosened.

- Patient must be prevented from chilling effect.
- He must be covered with a blanket.
- If irregular breathing is observed artificial respiration must be applied till the patient is taken to the hospital.

5.10 Summary

The pesticide are the biggest source of chemical pollutants which gets accumulated in the environment whose degradation may be slow and hence tend to accumulate in the ecosystem. The nature of insecticide makes its bioaccumulating or biodegradable. There are natural mechanisms for breakdown of insecticide and microbes play a important role in it. Insecticide residue pose a major threat to environment and can result in biomagnifications. The insecticide acts and environmental regulation provide for judicious use of these chemicals. The safe use of insecticide with minimum harm is recommended for best results .The safety during application and post accident can save from poisoning.

5.11 Glossary

- **'Poisoning'** or toxicity is the potential of a chemical to create deleterious effects in biological systems.
- **Safety :**The term is defined as the value judgment of the acceptability of a risk towards a chemical.
- **Biomagnification** :It is the process of accumulation of toxicants in the food chain tropics levels by the transfer of residues in smaller organisms and from them into higher tropic level organisms.
- **Bio Accumulation** :The entrance of the toxicants in the food chain and the process of their concentration from the environment to first trophic level and then further trophic levels is referred to as 'Bioaccumulation'.

5.12 Self- learning Exercise

Very short Answer Type Questions

1. Define Biomagnification.
2. Name the three major natural mechanisms required for the breakdown of toxicant in the environment.

3. Name the metabolic processes in microbes which make them unique tool for biodegradation.
4. What is Bioaccumulation ?

Short Answer Type Questions

5. Explain microbial degradation of toxic Chemicals.
6. Give suitable examples of biomagnification.
7. Write a note on treatment of insect poisoning.
8. What do you understand by ‘risk’ and ‘Hazard’.

Long Answer Type Questions

3. What is insecticide Act 1968?Explain in detail.
4. Give a detailed account of safety measures adapted during handling of a toxicant.

Unit - 6

Agricultural Pests – I

Structure of the Unit

6.1 Objectives

After completing the unit, you will be able to understand about-

- Pest

- Different harmful effects of pest on agricultural crops
- Effective methods of pest control
- Monophagous Pest
- Oligophagous Pest
- Polyphagous Pest
- Biology, Life Cycle, Nature of Damage and different types of control measures of Polyphagus Pests - *Schistocerca gregaria, Locusta migratoria, Hieroglyphus* spp., Termites (*Odontotermes obesus, Microtermes obesus) Amascata* spp.
- Brief idea about maize and millets and its different pests.
- Biology, Life Cycle, Nature of Damage and different types of control measures of Pests of maize and millets- *Chilo zonellus*, *Sesamia inferens*.

6.2 Introduction

A pest is any living organism which is invasive or prolific, detrimental, troublesome, noxious, destructive, a nuisance to either plants or animals, human or human concerns, livestock, human structures, wild ecosystems etc. Pest refers to any animal or plant causing harm or damage to people or their animals, crops, or possessions, even if it only causes annoyance. Pests belong to a broad spectrum of organisms including insects, mites, ticks and other arthropods, mice, rats, and other rodents, slugs, snails, nematodes, cestodes and other parasites, weeds, fungi, bacteria, viruses and other pathogens. In its broadest sense, a pest is a competitor of humanity.

Often animals are designated as pests when they cause damage to agriculture by feeding on crops or parasitizing livestock, such as codling moth on apples, or boll weevil on cotton. An animal could also be a pest when it causes damage to a wild ecosystem or carries germs within human habitats. Examples of these include those organisms which vector human disease, such as rats and fleas which carry the plague disease, mosquitoes which vector malaria, and ticks which carry Lyme disease.

Agriculture is the keystone of the Indian economy and the largest contributor to the country’s GDP. Over 58% of the rural households rely on agriculture as their primary means of livelihood. Ensuring food security for more than 1.3 billion population is an arduous task considering the diminishing cultivable land resource because of urbanization. Agricultural pest contribute to a great degree in agricultural loss. It has caused losses virtually on countless number of crops.

India is facing crop losses and problem of food security as agricultural pests, such as insects, viruses, bacteria, fungi, and weeds are spreading. Pests belong to a broad spectrum of organism which causes annoyance, harm or damage to people, animals, crops or possessions. They harm the ecology by preying directly on native fauna, decreasing their number and the balance on ecology. Pests harm agriculture by feeding on crops or parasitizing livestock. Plants need to be protected from variety of different pests that presents threat to the crops.

The causes of pest outbreaks and crop losses are due to different factors creating changes in the agricultural ecosystem. Outbreaks can impair fertilization rates or seed recovery. The use of pesticide destroys beneficial natural enemies, damage crops and alters physiology of crops making them susceptible to pest attack. Some pests appear due to certain weather patterns, too much or too little rain can trigger pest outbreak. Sudden pest outbreak could ruin a whole season’s worth of planting and cultivation, leading to financial loss. The most direct economic impact of agricultural pest is the reduced efficiency of agricultural production may it be crops or animals, which reduces farmer’s income.

Many of the known pest control methods and technologies provide economic benefits when used in a satisfactory manner. Crop protection products such as insecticides, fungicides and herbicides are chemical method of pest control management. By their nature, crop protection can be toxic against the pests they are aimed at but sometimes have a negative impact on agriculture.

In India there is a need of raising awareness for management of the vast range of pest that threaten agricultural crops by use of low external inputs and traditional techniques by using non-chemical alternatives is widely advocated. The efforts are broadly classified as integrated pest management, low external input sustainable agriculture and organic agriculture. Integrated Pest Management is the most commonly recommended and widely adopted. These technological options could help create sustainable ways and decrease the needs for expensive and undesirable effects of chemical pesticides and promote greater production.

6.3 Biology, Nature, Extent of Damage And Control Of Phytophagus Pests

For feeding, reproduction and survival purpose organisms uses various types of resources. These resources are combinly termed as ecological range of organism. Similarly insect use the plant resources for fulfilling their different requirements such as shelter, food, protection from different predators. However use of host plant range is relatively different in the phytophagous insect species. Entomologist classified the plant feeding insect into two categories such as generalist and specialist according to the mode of host plant used by them.

Generalist insects can be defined as those insects which use wide range of plant species as their host, whereas the specialist insect uses a specified range of host plants in its life span. Phytophagous insects can be differentiated into three categories such as monophagous, oligophagous and polyphagous.

Monophagous Pests– The insect species which usually feed on plants which comes under single genus or only a single species of plants. *Tryporyza incertulus* (The Yellow Stem borer (Lepidoptera: Pyralidae)) is a monophagous pest and attacks only on paddy plants.

Oligophagous Pests– The insects species which confine their feeding activity to wide range of plants of different genera but belonging to one taxonomic group i.e., one family. A well known example is the cabbage butterfly.

Polyphagous Pests- The insects feed on wide range of plants under different families. Most of the phytophagous insects are specialized for choosing their host plant. *Schistocerca gregaria*, *Locusta migratoria* are polyphagous insect pests.

LOCUSTS

Locusts are the swarming phase of certain species of short-horned grasshoppers in the family Acrididae of order Orthoptera. Locusts are the short-horned grasshoppers with highly migratory habit, marked polymorphism and voracious feeding behaviour. In the solitary phase, these grasshoppers are harmless, their numbers are low and they cause little economic threat to agriculture. They are capable of forming swarms of adult's congregation and hopper bands of nymphal congregation. They cause great devastation to natural and cultivated vegetation. However, under suitable conditions of drought followed by rapid vegetation growth, serotonin in their brains triggers a dramatic set of changes.

They start to breed abundantly, becoming gregarious and nomadic when their populations become dense enough. They form bands of wingless nymphs which later become swarms of winged adults. Both the bands and the swarms move around and rapidly strip fields and cause damage to crops. The adults are powerful fliers, can travel great distances, consuming most of the green vegetation wherever the swarm settles.

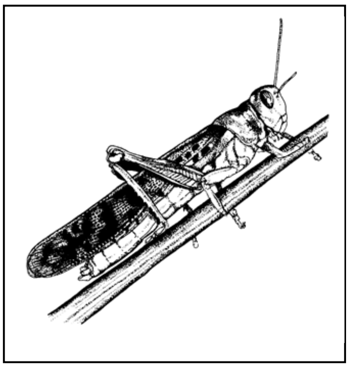
There are 10 important species of locusts in the world which are as follows:-

S. No.	**Common Name**	**Scientific Name**
1.	The Desert Locust	*Schistocerca gregaria*
2.	The Bombay Locust	*Nomada crissuccincta*
3.	The Migratory Locust	*Locusta migratoria manilensis* *Locusta migratoria migratoriaoides*
4.	The Italian Locust	*Callipta musitalicus*
5.	The Moroccan Locust	*Dociostaurus morocannus*
6.	The Red Locust	*Nomada crisseptemfaciata*
7.	The Brown Locust	*Locusta napardalina*
8.	The South American Locust	*Schistocerca paranensis*
9.	The Australian Locust	*Chortoicetes termenifera*
10.	The Tree Locust	*Anacridium* spp.

From the above species only four species viz. Desert locust (*Schistocerca gregaria*), Migratory locust (*Locusta migratoria*), Bombay Locust (*Nomada crissuccincta)* and Tree locust (*Anacridium* sp.) are found in India. The desert locust is most important pest species in India as well as in intercontinental context. We will study about two species -The Desert Locust (*Schistocerca gregaria*) and The Migratory Locust (*Locusta migratoria*) in this unit.

6.4 Schistocerca Gregaria (Desert Locust)

Systematic Position



Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Orthoptera
Family:	Acrididae
Genus:	*Schistocerca*
Species:	*gregaria*

Distribution:

The invasion area of *Schistocerca gregaria* covers about 30 million sq km which includes whole or parts of nearly 64 countries. This includes countries like North West and East African countries, Arabian Peninsula, the Southern USSR, Iran, Afghanistan, the Indian sub-continent. The widespread outbreaks (Plagues) of desert locusts have threatened agricultural production in Africa, the Middle East and the Asian countries. The livelihood of at least one-tenth of the world's human population can be affected by this voracious insect. The desert locust is potentially the most dangerous of the locust pests because of the ability of swarms to fly rapidly across great distances. It has two to five generations per year. During recession periods when locust occurs in low densities, it inhabits a broad belt of arid and semi-arid land which stretches from the Atlantic Ocean to North West India. Thus, it covers over 16 millions sq kms in 30 countries.

Main host plants- Polyphagous with some preference for Gramineae (Barley, Maize, Sorghum, Wheat). Although it can be present on nearly all crops, and noncrop plants like Pearl Millet, Rice, Pasture Grasses, Sugarcane, Cotton, Fruit Trees, Date Palms, Banana Plants, Vegetables, Citrus, Corn, Cotton, Oats, Peanuts, Rye, Sugarcane, Tobacco, Vegetables, Rangeland Grasses, *Acacia*, Pines and Weeds.

6.5 Insect Biology

Life Cycle

The life cycle of the desert locust consists of three stages, the egg, the nymph known as the hopper and the winged adult. Copulation takes place when a mature male hops onto the back of a mature female and grips her body with his legs. Sperm is transferred from the tip of his abdomen to the tip of hers, where it is stored. The process takes several hours and one insemination is sufficient for a number of batches of eggs. Locusts usually breed in sandy areas in deserts, where soil is loose enough to hold egg pods and abundant *Cyperus* weed to serve as food for the nymphs. The female seeks suitable soft soil to lay her eggs. It needs to be in the right temperature and degree of dampness and be in close proximity to other egg-laying females. She probes the soil with her abdomen and digs a hole into which an egg pod containing up to a hundred eggs is deposited. The egg pod is 3 to 4 cm long and the lower end is about 10 cm below the surface of the ground. The eggs are surrounded by foam and this hardens into a membrane and plugs the hole above the egg pod. The eggs absorb moisture from the surrounding soil. The incubation period before the eggs hatch may be two weeks or much longer, depending on the temperature. There are several generations per year.

EGGS

Eggs are laid in pods in moist sandy soil at a depth of about 10 cms at an interval of 7 – 10 days by thrusting the ovipositor. The ovipositor is used to make a hole in the sand, about 10 cm deep. Gregarious female usually lay 2-3 egg pods having 60-80 eggs in average. Eggs are laid in a frothy mass which hardens to form a tubular egg pod. Solitarious female mostly lay 3-4 times having 150-200 eggs in average. Fecundity is 4-5 egg pods per female or 500-1000 eggs per female. Each egg is 1.2-1.5 mm long and 0.7-0.8 mm wide and whitish in colour. Eggs are rice shaped. The rate of development of eggs depends on soil moisture and temperature. No development takes place below 15°C. Eggs are incubated by the sun rays heating the sandy soil. The incubation period is 10-12 days when the optimum temperature is between 32-35°C.Depending on the temperature, the development of the eggs will take average two weeks or longer.

Nymphs / Hoppers

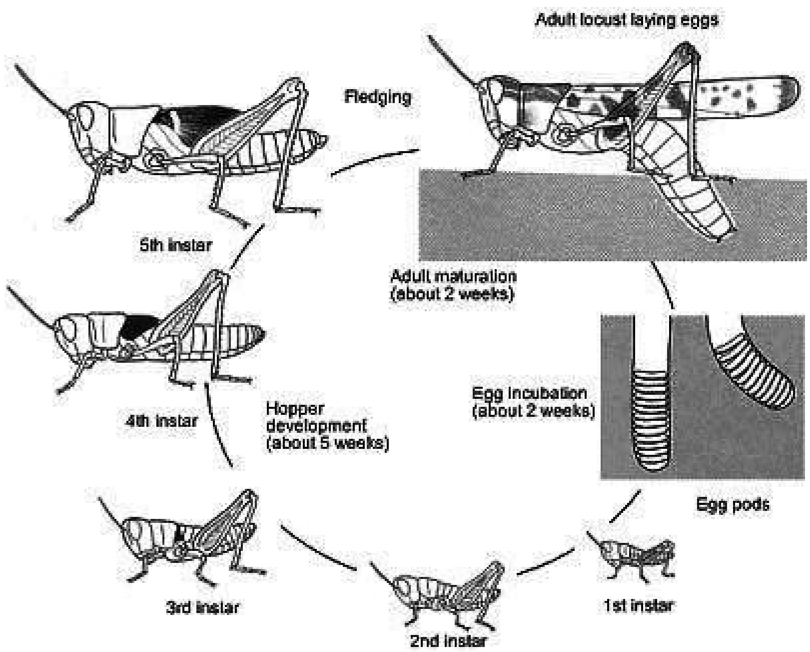
After incubation is complete, the eggs hatch and nymphs (young ones) emerge. The first worm like nymph finds its way through the egg pod to the soil surface. There it molts and becomes a "hopper". There are 5 instars in gregarious and 5-6 instars in solitarious population. In each instar there is a growth and change in characteristic coloration.

Ist Instar	Newly hatched are white but turns black in 1-2 hours.
IInd Instar	Head is larger and pale colour pattern is conspicuous.
IIIrd Instar	Two pairs of wing buds projects on each side of thorax
IVth Instar	Colour is conspicuously black and yellow.
Vth Instar	Colour is bright yellow with black pattern.

The rate of development in hopper depends on temperature. It takes 22 days when the mean air temperature is hot say about 37°C and may be delayed up to 70 days when the mean temperature is below 22°C.

Adult

The fifth Instar nymph moults into adult stage. This change is called **fledging** and the young adult is called fledgling or immature adult means they are sexually immature. The period of sexual maturity varies. In suitable condition the adult may mature in 3 weeks and under cool and dry condition it may take 8 months. During this stage, the adults fly for search of favourable breeding condition and may cover thousands of kilometers. Young immature adults are pink in color but old ones become dark red or brown in cold condition. On maturation the adults become bright yellow. Males matures faster than females. Oviposition commences within two days of copulation.



The desert locust lives a solitary life until it rains. Rain causes vegetation growth and allows the female to lay eggs in the sandy soil. The new vegetation provides food for the newly hatched locusts and provides them with shelter as they develop into winged adults. During quiet periods, called recessions, desert locusts are confined to a 16-million-square-kilometer belt that extends from Mauritania through the Sahara Desert in northern Africa, across the Arabian Peninsula, and into northwest India. Under optimal ecological and climatic conditions, several successive generations can occur, causing swarms to form and invade countries on all sides of the recession area, as far north as Spain and Russia, as far south as Nigeria and Kenya, and as far east as India and southwest Asia. Locust swarms fly with the wind at roughly the speed of the wind. They can cover from 100 to 200 kilometers in a day, and will fly up to about 2,000 meters above sea level. Therefore, swarms cannot cross tall mountain ranges such as the Atlas Mountains, the Hindu Kush or the Himalayas. They will not venture into the rain forests of Africa nor into Central Europe.

Nature of Damage:

The desert locust can cause injury to nearly all crops, and non-crop plants like pearl millet, maize, sorghum, barley, rice, pasture grasses, sugarcane, cotton, fruit trees, date palms, banana plants, vegetables, citrus, corn, cotton, oats, peanuts, rye, sugarcane, tobacco, vegetables, grasses, acacia, pines and weeds.

The plants are damaged by the locust gnawing on the leaves, and young vegetable plants can be eaten to the ground. It is estimated that desert locusts consume the equivalent of their body weight (2 gm approximately) each day in green vegetation. They are polyphagous and feed on leaves, shoots, flowers, fruit, seeds, stems and bark. Significant damage to plants occurs when these insects become very abundant. Abundance commonly increases with increase in favoured foods, typically weedy grasses. This can result from weather that favours grasses such as mild winters, increased rainfall, suppression of grazing by livestock, or soil tillage.

Schistocerca gregaria maintain optimal temperature by climbing up and down vegetation, and by moving to more exposed like sunny or less exposed like shady locations. When they are abundant they may climb up screen enclosures around pools, and up the sides of houses. They destroy their surroundings because their mandibles are sharp even they can make holes in the fiberglass screening.

The greatest level of damage is caused by last instar nymphs and young adults. This corresponds to the overall greater level of activity of these stages. Nymphs and adults feed on the leaves and soft shoots. They eat from the margin inwards which results in irregularly shaped feeding marks. Swarms will usually completely defoliate crops. Locust droppings are toxic, and spoil any stored food that is left uneaten. Swarms usually defoliate the crops completely. Damage can be destructive over a wide area.

Control

- The desert locust is a very difficult pest to control, and control measures are further compounded by the large and often remote areas of 16-30 million km^2 where locusts can be found. Undeveloped basic infrastructure in some affected countries, limited resources for locust monitoring and control, and political turmoil within and between affected countries further reduce the capacity of a country to undertake the necessary monitoring and control activities.
- Farmers often try mechanical means of killing locusts, such as digging trenches and burying hopper bands, but this is very labour intensive and is difficult to undertake when large infestations are scattered over a wide area. Farmers also try to scare locust swarms away from their fields by making noise, burning tires or other methods. This tends to shift the problem to neighbouring farms, and locust swarms can easily reinfest previous fields.

- At present, the primary method of controlling desert locust infestations is with insecticides applied in small concentrated doses by vehicle-mounted and aerial sprayers at ultra-low volume rates of application. The insecticide is acquired by the insect directly or via secondary pickup. Control is undertaken by government agencies in locust-affected countries or by specialized organisations.
- Natural enemies such as predatory and parasitic wasps and flies, predatory beetle larvae, birds, and reptiles may have limited effects on desert locusts because they can be easily overwhelmed by the sheer magnitude of most swarms and hopper bands. On the other hand, they may be effective in keeping solitary populations in check.
- A range of commercial controlling agents for locusts are available in market. The most appropriate control agent is dependent on a number of factors, including where it is to be used such as within a crop, pasture, stock or sensitive site scenarios, withholding periods and environmental considerations.
- *Fenitrothion* is registered for use against locusts on pasture and a wide range of cereal and other crops. It is available as EC (ground control) and as a ultra-low volume (ULV) formulation for aerial control.
- *Fipronil*, also a ULV formulation for aerial control, is suitable for pasture and sorghum situations.
- *Chlorpyrifos* is suitable for ground control only in crop or pasture situations.
- *Metarhizium*, is a biological control agent which can be used in environmentally-sensitive areas and in areas of organic farming or chemical sensitivity. The agent is derived from a naturally-occurring fungus (*Metarhizium anisopliae*) that attacks locusts. It can take 8-18 days to have an effect so should only be used to treat immature locusts, early in their lifecycle. It is not suitable for treating adult locusts.
- Biopesticides include fungi, bacteria, neem extract and pheromones. The effectiveness of many biopesticides equals that of conventional chemical pesticides, but there are two distinct differences. Biopesticides in general take longer to kill insects, plant diseases, or weeds, usually between 2 and 10 days.

- There are two types of biopesticides - biochemical and microbial. Biochemical pesticides are similar to naturally occurring chemicals and are nontoxic, such as insect pheromones used to locate mates, while microbial biopesticides like Green Muscle come from bacteria, fungi, algae or viruses that either occur naturally or are genetically altered. Entomopathogenic fungi generally suppress pests by mycosis: causing a disease that is specific to the insect.
- **Guaiacol** is the pheromone produced in the gut of Desert locusts by the breakdown of plant material. This process is undertaken by the gut bacterium *Pantoea (Enterobacter) agglomerans*. Guaiacol is one of the main components of the pheromones that cause locust swarming.

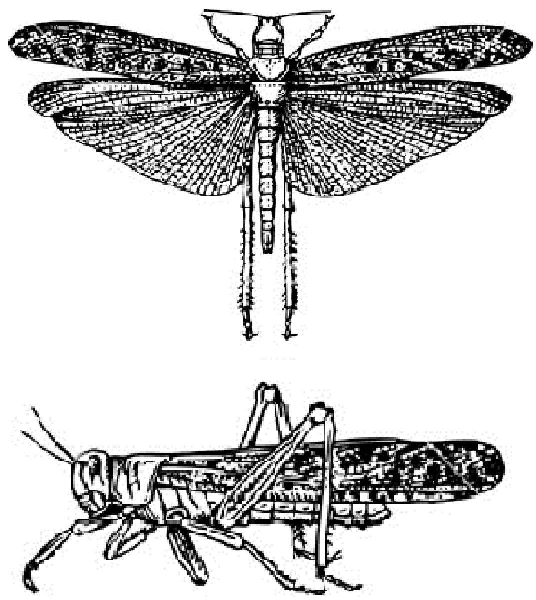


Figure – *Schistocerca gregaria*

6.6 Locusta Migratoria (Migratory Locust)

Systematic Position

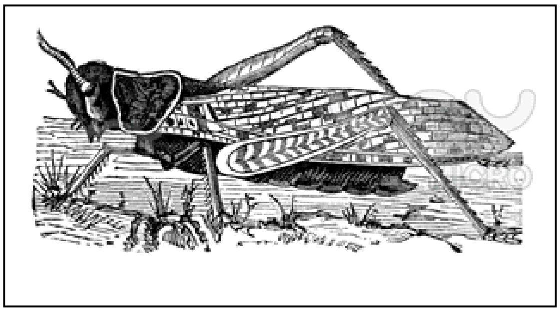
Phylum: Arthropoda

Class: Insecta

Order: Orthoptera

Suborder: Caelifera

Family: Acrididae



Subfamily:	Oedipodinae
Genus:	*Locusta*
Species:	*migratoria*(Linnaeus 1758)

The **migratory locust** (*Locusta migratoria*) is the most widespread locust species, and it is the only species of the genus *Locusta*. These are species that can breed rapidly under suitable conditions and subsequently become gregarious and migratory. They form bands as nymphs and swarms as adults both of which can travel great distances, rapidly stripping fields and greatly damaging crops. Locusts are an edible insect and are considered a delicacy in some countries and throughout history.

Locusta migratoria is a polyphenic species, that is, its pigmentation and size vary according to its "phase" (gregarious or solitary form) and its age. When population densities grow high the migratory locust appears in its smaller gregarious form, which is yellow to orange with black spots. In contrast, solitary form adults are brown or green, and tend to match the vegetation around them. *Locusta migratoria* in large population numbers can be economically devastating, as both larvae and adults eat huge quantities (adults daily eat their weight in food), and adults, as strong fliers, are highly mobile

Distribution

Migratory Locust has the largest world distribution area among all locusts and grasshoppers, comprising practically all temperate and tropical parts of the eastern hemisphere, i.e. Europe, Africa including Madagascar, Arabian and Indo-Pakistan peninsulas, Caucasus, Central and South-eastern Asia, Australia, Papua New Guinea and New-Zealand. The northern limit of this huge distribution area corresponds roughly with the southern edge of the coniferous forest zone of Europe and Asia. Southern extension reaches New-Zealand. The western limit corresponds to the Azores, in the Atlantic Ocean, and the eastern one to at least the Fiji, in the Pacific Ocean. The altitudinal distribution of the species is also amazingly wide, from sea-level to mountains. Therefore, the species is present in a wide range of habitats presenting very different climatic and environmental conditions; this results in different biological responses fitting with local conditions and a number of geographical subspecies. In case of India usually it breeds during spring in Baluchistan and the resultant adults migrate to the desert areas of India where they breed in summer.

Host Plants

Solitary hoppers and adults can damage various vegetable crops, rice, cotton, as well as plantations of volatile oil bearing plants in India. During years of mass outbreaks, grain and other crops are severely damaged as well as hayfields and pastures. It is also the case for many tree species. Gregarious hoppers and adults of Migratory Locust can strongly harm wheat, rye, barley, oat, maize, rice, sorghum, millet, alfalfa, clover, peas, legumes, string bean and other *Fabaceous* crops, red and sugar-beet, potato, tobacco, cabbage, rutabaga, cucumbers, watermelons, melons, and other cucurbits, sunflower, althaea, cotton, flax, castor-oil plant, vegetable and other crops, young plants of many fruit, vines, fruit, forest and bush trees, haylands and pastures. Damage on trees concerns stem, fruit and branches broken by the weight of locusts.

Insect Biology

Life Cycle

There are three breeding seasons for locusts

(i) Winter breeding [November to December]
(ii) Spring breeding [January to June]
(iii) Summer breeding [July to October]

India has only one locust breeding season and that is Summer breeding. The neighboring country Pakistan has both spring and summer breeding.

Eggs

Female locusts lay eggs in batches, called **pods**, in the soil, usually at a depth of 2–10 cm. Each pod will contain 30–60 pale yellow banana-shaped eggs 5–6 mm long. An individual female may lay up to four pods. Each pod is sealed with a froth plug which protects the eggs from extreme temperature and ensures adequate moisture is available for development. A collection of egg pods laid by a number of locusts is termed an **egg bed**. Egg beds occur typically in bare patches of compact soil, as distinct from self-mulching soils. Egg beds may vary from a few square meters to several hundred square metres and be scattered irregularly throughout a region.

Eggs need warmth and moisture to develop and will suspend development if these needs are not met. In summer, eggs may hatch within 14–16 days, while eggs laid in autumn will probably remain dormant by process of diapause through winter and resume development and hatch the following spring. These egg pods will normally be laid closer to the surface than summer-laid eggs (non-diapause).Eggs in a single egg bed may hatch together or over several weeks if conditions for hatching are marginal. Hatching normally occurs from spring through to autumn, with two to three generations hatching through that period if conditions are favourable.

Green feed is required to provide fuel for flight and for egg development. Depending on conditions an adult locust if once sufficient fuel is available for flight they may leave or migrate from an area. If conditions are ideal, however, the adult female may lay eggs in the same area in which she developed.

Nymph / Hopper

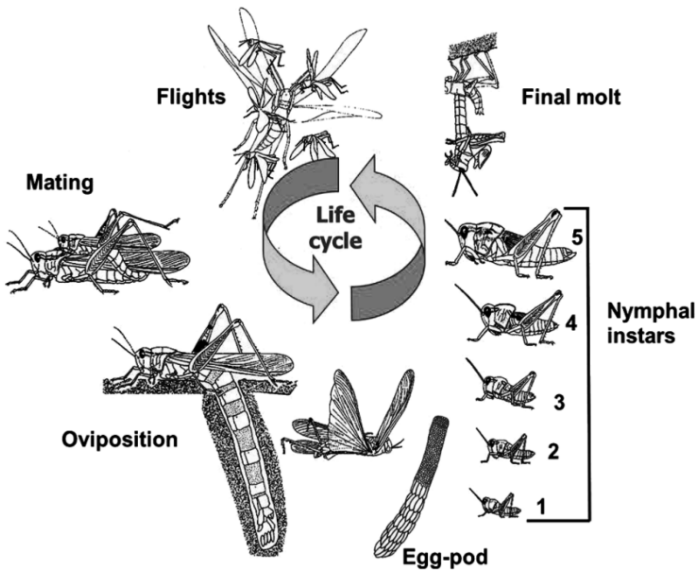
An immature locust is called a **nymph** or **hopper**. After hatching from the egg, a locust goes through five growth stages called **instars**, moulting at each stage. The developing wings become more noticeable at each stage until the locust becomes a fledgling adult and then a mature adult capable of sustained flight. Normally, the nymphs take 4–8 weeks to complete this development.

Locusta shows different phases in its life cycle. Usually it is in the solitary phase, in which body colour is from brown to green. The thorax is slightly domed above the head and crested. A dark stripe starts at the antenna, goes up through the eye at a 45 degree angle and becomes horizontal before fading into the thorax, which has a small but prominent dark spot. Rear femur has two oblique darker bands. The other phase is gregarious phase in which body colour is red to orange with very contrasting darker to almost black markings. The thorax is not domed but saddle-shaped and even lower than the head. A dark stripe starts at the antennae, goes up through the eye at a 45 degree angle and becomes horizontal as it continues across the thorax. In later instars this becomes a prominent stripe along the entire body.

Adult

After the final moult, the adult locust emerges with fully formed wings. At first the body and wings of the locust are still soft and they can't sustain flight for about a week until the wings harden. After full development the body length varies from 35 to 50 mm for males and from 45 to 55 mm for females. Adults are slightly smaller than the desert locust. Though the female and the male look alike, they can be distinguished by looking at the end of their abdomens. The head is slightly lower than the thorax but both are raised above the line of the wings. The thorax has a central ridge which is partly lost in the swarm phase. The mouth is dark. The male has a boat-shaped tip, while the female has two serrated valves that can be either apart or kept together. These valves aid in the digging of the hole in which an egg pod is deposited. Mandibles are blue in colour. Elytra are shining and long, exceeding clearly the abdominal extremity.

Wings are colourless with smoky tint and black veins. The bottom of internal side of hind femora is brownish, bluish to black. The length of hind femur is of 22.0-26.0 mm in males and 20.0-32.0 mm in females. There is a dense pilosity of the inferior face of thorax. The colour can vary but is usually green, brown, yellowish-green or grey. The pronotum is curved for solitary adults and saddle-shaped for gregarious ones, with convex or straight to slightly concave median keel respectively. The transversal furrow is well marked for gregarious individuals. The hoppers also differ, being green in solitary phase but grey in the 1st instar, then darkening and becoming orange and black in the later instars when gregarizing.



Polyphenism

The migratory locust is polyphenic. It transitions between two main phenotypes in response to population density; the solitary phase and the gregarious phase. As the density of the population increases the locust transforms progressively from the solitary phase towards the gregarious phase with intermediate phases-

Solitaire = solitary phase ⟶ transienscongregans (intermediate form) ⟶ gregarious phase ⟶ transiensdissocians (intermediate form) ⟶ solitaire = solitary phase.

A few differences between solitary and gregarious phase are as under:

Characteristics	Solitary phase	Gregarious phase
Behavior	-Do not form groups or swarms -Roost, bask, feed and move as individuals -Hoppers move short distance, adults fly as individuals at night	-Form persistent and cohesive groups, bands and swarm -Roost, bask, feed and move together -Very mobile, fly as swarms by day. Hoppers move in band.
Colour	-Hoppers uniformly green in early instars but may be brown in last two instars. -Adult pale grayish brown, buffer peach coloured. Males change to pale yellow on sexual maturation. -Female show no colour change on maturation at low density.	-Hoppers have black pattern on yellow or orange background -Adults rosy pink on fledging, darkens with age to grayish or brownish red then to yellow on sexual maturation. Males are brighter.

6.7 Nature of Damage

Locusts have probably been an enemy of man ever since he began to grow crops. Locusts are still a great enemy of the farmer and in some countries they are the determining factor between sufficient food for the people and starvation. Damage is sometimes diffuse and not very obvious, but it can be very severe in many more restricted areas. This depends on whether the swarms are moving about quickly or whether they stay for several days in one area. An adult locust can consume its own weight (about 2 grams) in fresh food per day. For every million locusts, one ton of food is eaten.

Sugarcane, palms, pineapple and less frequently pigeon pea, cabbage, carrot, cassava, coffee, cotton, groundnut, kidney bean, hyacinth bean, lettuce, Lima bean, pea, potato, turnip etc are badly affected by locust attack. Bulrush millet (*Pennisetum americanum*) is a staple grain crop along the southern edge of the Sahara and in the Indo-Pakistan desert. It is much liked by the *Locusta migratoria* as a food plant and since it is grown extensively in areas which are highly frequented by this locust for breeding, considerable damage is caused; both leaves and ripe grain are destroyed.

Wheat and barley are the staple food crops in the spring breeding areas of the Locust where they can be severely damaged, especially when they are approaching harvest. At this stage locusts bite through the last remaining moist part of the plant, the section of stem just below the ear, causing complete loss of grain, often without attacking the ear itself.In case of rice crop comparatively little damage is done to irrigated rice even in areas highly frequented by the Locust, probably because the artificially wet conditions in which it is grown are not liked by this locust. The effect of damage varies according to the stage of sugarcane growth and the variety.

Cotton crop can be severely attacked. The effect of damage on yield is great if it occurs just before flowering but less if it occurs afterwards. In the Locust summer-breeding zone the start of cotton flowering generally coincides with the fledging of adult locusts and as the young adult is the stage at which most feeding takes place, this increases the danger to cotton in these areas. Fruit trees are particularly vulnerable to attack by immature swarms which have a preference for roosting in trees. Serious damage has occurred on oranges, lemons, pawpaw, dates and grapevines. Once damaged by locusts, the trees are liable to have their fruit yield affected for more than one year.

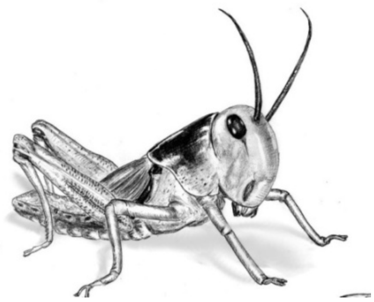
The Migratory Locust feeds on grasses also. During recessions it feeds on wild grasses and cereal crops in and around the flood plains of the Middle Niger that form its main outbreak area.

Control

- The chief aim of locust control is to destroy the locust in all its' stages.
- For destruction of eggs first the egg laid areas are located, then trench them round, so as to entrap the young hoppers as they move out after hatching. Even actual destruction of eggs on organised scale may be carried out by ploughing, harrowing and hand digging.
- For Hopper Control the mechanical methods included entrapping making hopper bands in 2' x 2' trenches and burrying. The chemical method includes use of poison baits and dusting of insecticides.
- Various types of poison baits can be used like 5% BHC or pairs green or sodium fluosilicate & 2 Dusting 5 to 10% BHC against hoppers 25 to

30kg/ha has seen found to bring a complete control of the pests. Aldrin 4% dust can also be effectively use.

- In order to control of adults or winged locust swarms 5% or 10% BHC or 4% aldrin may be used to achieve better control when swarms are resting on the bare ground at night or in early morning can be beaten or swept up and destroyed. If they are resting on bushes or hedges, they can be easily burnt with help of flame throwers. When flying locusts are about to descend in large swarms in cultivated areas, the best way to tackle them is to prevent then alighting by all possible methods, such as waving a white cloth, or creating a cloud of smoke, by burning refuse, etc., spraying with neem kernel suspension as a deterrent to the crop, has also been tried with success.
- Recently with the introduction of aerial application of insecticide like aldrin, the control of locust swarms has become easier. Once locusts have fledged or are 'flying', aerial spraying of agricultural chemicals is the only efficient method of control.
- Natural enemies of locusts are birds, mammals and insects.



Locusta migratoria

6.8 Comparison Account of Locust and Grasshoppers

Grasshopper

- Locusts and grasshoppers are the same in appearance but differ in the way they behave.
- The grasshopper belongs to the order Orthoptera and suborder Caelifera.
- This insect contains 28 families.
- It is usually referred to as the short-horned grasshopper so as to distinguish it from crickets.

- They are equipped with short ovipositors and antennae which are shorter compared to their bodies.
- They usually have wings, and the females are larger than the males.
- They have long back legs used for leaping.
- Their mandibles are very strong.
- The adults have two wings in the front and two membranous wings in the back which are all fully developed.
- The females have short ovipositors and two pairs of valves which are used to dig in sand when egg laying, and these are located at the end of the abdomen.
- The males have one plate at the end of the abdomen which is not paired.

Locust

- On the other hand, locusts are a species of the grasshopper but change behavior and color at high population densities.
- The locust belongs to the order Orthoptera and suborder Acrididae.
- This insect has one family only.
- They are the swarming phase of the grasshoppers.
- In suitable conditions, they breed rapidly and become migratory and gregarious.
- When they form swarms, they can travel at high speeds, and they are responsible for most of the damage to crops as they rapidly strip them.
- The causes of the behavioral changes are not fully understood
- The locust is a type of a grasshopper which is short horned. The grasshopper is not a type of a locust.

Comparison

- Both belong to the order Orthoptera.
- The grasshopper belongs to the suborder known as Caelifera while the locust belongs to the suborder Acrididae.

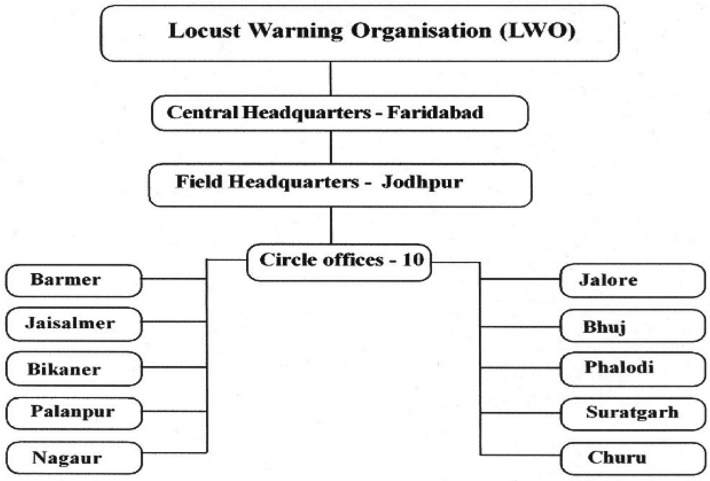
- The grasshopper has 28 distinct families while the locust has only 1 family.
- Both are short horned and have short ovipositors, two, short antennae, long back legs used for leaping, and mandibles are strong.
- Both adults of the locusts and grasshoppers have two wings in the front and two membranous wings in the back which are all fully developed.
- Both are regarded as delicacies in certain parts of the world.
- Locusts can exist in two different behavioral states which are migratory and gregarious while grasshoppers do not.
- Locusts may change their body shape and color, fertility, and survival behavior while grasshoppers generally do not.
- Locusts can form dense swarms and bands while grasshoppers generally do not.
- Locusts can migrate over large distances while grasshoppers cannot.

6.9 Locust Warning Organisation (LWO)

In India, the scheme Locust Control and Research is responsible for control of Desert Locust and is being implemented through Organisation known as **"Locust Warning Organisation (LWO)"** established in 1939 and later amalgamated with the Directorate of Plant Protection Quarantine and Storage in 1946. Locust Warning organization is responsible to monitor and control the locust situation in Scheduled Desert Area mainly in the States of Rajasthan and Gujarat while partly in the States of Punjab and Haryana by way of intensive survey , surveillance, monitoring and control operations where required.

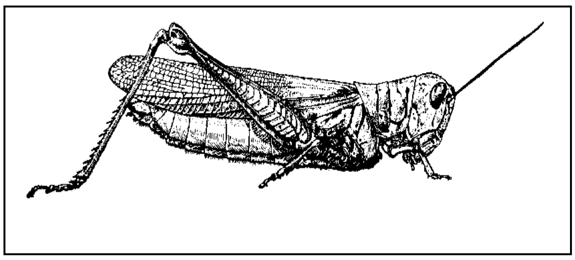
Locust Warning Organisation is aimed to detect the local breeding in Scheduled Desert Areas and incursion of exotic locust swarms into India. LWO keeps itself abreast with the prevailing locust situation at National and International level through monthly Desert Locust Bulletins of FAO issued by the Desert Locust Information Service, AGP Division Rome, Italy. Survey data are collected by the field functionaries from the fields which are transmitted to LWO circle offices, field HQ Jodhpur and Central HQ Faridabad where these are compiled and analyzed to forewarn the probability of locust outbreak and upsurges. The locust situation is appraised to the State Governments of

Rajasthan and Gujarat with the advice to gear up their field functionaries to keep a constant vigil on locust situation in their areas and intimate the same to nearest LWO offices for taking necessary action at their end.



6.10 Hieroglyphus Spp. (Rice Grasshopper)

Systematic Position



Phylum – Arthropoda

Class – Insecta

Order – Orthoptera

Suborder- Caelifera

Family – Acridiidae

Genus – *Hieroglyphus*

Distribution

In India different species of *Hieroglyphus* are widely distributed and is considered to be a major pest of paddy. They are polyphagous pests. *Hierogiyphus banian* is sporadic pest of rice and other kharif cereals in the Punjab, another species, *Oxya nitidula* Walker, which is smaller, also appears in pest proportions on the paddy crop in certain years. The other important species in northern India are *Aelopus tumulus* and *Acrida exaltata* Walker.

6.12 Host Plants

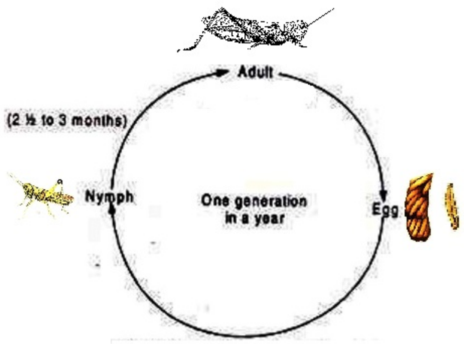
They are polyphagus and feed on leaves of rice, maize, millets, sugarcane, grasses, sunn hemp, arhar, etc. and minor pest of millets and fodder crops. *H. banian* is a sporadic pest of rice and other kharif cereals in Punjab.

Insect Biology

Life Cycle

The *Hieroglyphus* spp. have one generation in a year and pass the winter and dry part of summer in the egg stage. The female starts laying eggs by inserting her abdomen in the soil. The eggs are laid 5-8 cm deep, in pods, each containing 30-40 eggs. The eggs are found in the soil and they hatch in June or in early July, a few days after the first shower of the monsoon. On emergence, the nymphs or hoppers start feeding actively and complete their development in seven stages, within 3 weeks. The gregarious form of the fifth- and sixth-instar hoppers are generally an orange-brown colour with a black facial mask and antennae and black spots all over the thorax, pronotum and legs; the abdomen is yellow on top with a black stripe each side, brown on the sides with darker brown spots and black underneath. They measures about 5 cms in length. There is also a black stripe on the hind femora. Their fledging occurs from August to November. Gregarisation occurs at high population densities. They feed on the leaves of paddy or the grasses on the bundh.

The hoppers take 70 days in case of male and 80 days in case of females to become sexually mature. The adults are somewhat like locusts but are smaller. The adults are 40-50 mm long and are shining greenish yellow, having three black lines running across the pronotum. The adults are seen feeding voraciously during August and September. When they are two months old, they mate. The adult Rice Grasshoppers shows Polymorphism, usually they occur in two forms: a fully winged form and a flightless form with much reduced wings. Under normal circumstances, the flightless form is more common, but in upsurges more flying types occur-flight being an aid to dispersal. *Heiroglyphus banian* and *H. nigrorepletus* are somewhat like locusts but are smaller.



Nature of Damage

The greatest amount of damage is caused during August – September when both adults and nymphs feed on paddy and other crops, causing defoliation. They also cut off the ear heads. In certain years, they cause extensive damage, moving from field to field over large areas. Milky stage of rice crop specially attracts the surface grasshoppers. On cereal crops, feeding damage is generally concentrated near field margins as the hatchlings are not very mobile. The enormous loss to the crop is done by chewing and cutting various plant portion like leaves, flowers and grains. They completely defoliate the plants leaving only the mid ribs and the plant growth is affected. Their feeding damage includes leaf notching and stripping, but as they mature they can consume an entire plant. They can fly and move around easily in search of a wide variety of food sources

Control

Cultural Control

- Grasses and weeds in the fields, bunds and surrounding areas should be removed and cleaned area should be maintained.
- Proper ploughing of the fields in the beginning of summer to check the emergence of hoppers, and scrap bunds to destroy the eggs .
- Flood the stubbles, shave bunds, sweep along the bunds and pick adults directly from the foliage at night when they are sluggish.

Mechanical Control

- In early stages of infection, bagging and netting of the hoppers can be done to check their population.
- Half grown nymphs and hoppers are driven to one corner of the field and are beaten to death.

Biological Control

- Encourage biological control agents: scelionid wasps, parasitic flies, nematodes, and fungal pathogens, birds, frogs, and web-spinning spiders, and a certain species of an entomophthoralean fungus; and platystomatid fly and mite (eggs of oriental migratory locust), ants, birds, bats, field rats, mice, wild pigs, dogs, millipedes, fish, amphibia, reptiles, and monkeys.
- The egg masses are destroyed by ploughing the field and exposing them to birds.

Chemical Control

- Dusting the crop with to 10% BHC or 5% Aldrin is very much effective.
- Poison baiting is useful both against nymphs and adults.
- Dust the crop with 5-10% BHC (or) methyl parathion 2% or lindane 2 D 25-30 kg/ha (or) malathion 5 D 20 kg/ha
- Spray dichlorvos 76 EC 500 ml/ha (or) malathion 50 EC 2.5 lit/ha.

Termites

Systematic Position

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

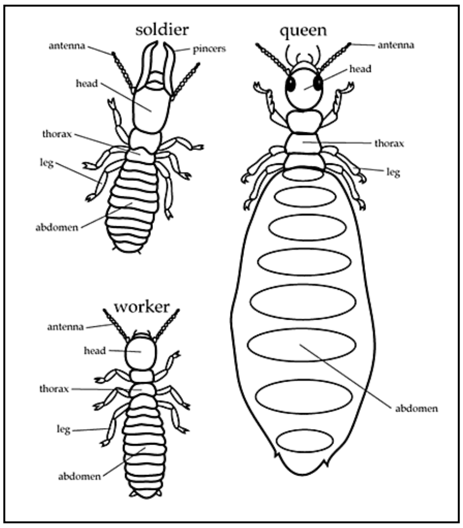
Subclass: Pterygota

Infraclass: Neoptera

Superorder: Dictyoptera

Order: Blattodea

Infraorder: Isoptera



Termites are a group of eusocial insects which is recently kept in the taxonomic rank of order Isoptera but are now accepted as the infra order Isoptera, of the cockroach order Blattodea.

There are mainly two groups of harmful termites that causes structural damage to wood inside buildings. These two groups are **subterranean** and **drywood** termites, and are so named because of their mode of nesting. These two groups comprise many species altogether, and both groups feed on wood, but they are fundamentally different as far as nest building is concerned. This is but one of the major characteristics that set them apart.

Subterranean termites live in the ground and are the most commonly observed termite. Most instances of termite damage are due to subterranean termites. They construct nests below the soil surface and tunnel their way from the soil into nearby homes and houses. The ones that cause massive structural damage can build nests that number into the millions of individuals and affect more than one building. Many kinds of subterranean termites usually constructs mud covered shelter tubes. The mud covered tubes is a characteristic sign of presence of subterranean termites.

Drywood termites constructs nest in wood and their nests are only a fraction of the size of the more notorious subterranean termites. Drywood termites do not cause as much damage as subterranean termites because they are usually present in small colony size. Drywood termites frequently produce and send out tiny winged future kings and queens to form new nests. They are abundant in coastal areas.

The key differences between subterranean termites and drywood termites are as follows.

Subterranean termites	Drywood termites
• Nests below ground level; requires contact with soil • Many species may develop large colonies • More advanced caste system, with physogastric queen and true workers • Secondary reproductives are not as readily produced, although some species do have this ability. Workers are infertile • Many species build shelter tubes when traversing exposed terrain; chief indicator of presence • Damage progression in wood is rapid, depending on colony size • Control methods involve soil/wood treatment and/ or baiting	• Nests inside wood; does not require contact with soil • Most species have small colonies • More primitive caste system, and minimal physogastry in queen and "false" workers • Most species easily produce secondary reproductives, also called pseudergates, from workers which are actually "stunted" reproductives • Chief indicator is the presence of small pellets or frass; these are their droppings • Damage progression in wood is slow, often taking years to become obvious • Control methods involve spot treatment on infested wood which harbor their nests

6.12 Distribution

The termites are found all over the world and popularly known as white ants. *Odontotermes obesus* (Rambur) is widely distributed in, India, Bangladesh and Pakistan.

In India, termites are widely distributed in red, sandy loams, lateritic and red loam soils. In Gujarat and Rajasthan there is need of study on the isopteran fauna over certain types of diverse ecosystems varying from the arid region in the east up to the salty marsh land of Rann of Kutch in the west and over and above, the Aravallis. About 253 species under 54 genera of seven families have been documented from the Indian region and about 35 species have been reported to damage agricultural crops and timber in buildings. Most are soil inhabiting, either as mound builders or as sub-terranean nest builders.

Major mound-building species in India are:

a) *Odontotermes obesus*

b) *O. redemanni*

c) *O. wallonensis*

Major sub-terranean species in India include:

a) *Heterotermes indicola*

b) *Coptotermes ceylonicus*

c) *C. heimi*

d) *Odontotermes homi*

e) Microtermes obesi

f) M. beesoni

g) *Trinervitermes biformis*

6.13 Host Plants

The main host plants of termites are cotton, sugarcane, upland rice, potatoes, sweet potatoes, groundnuts, soyabean, coffee, wheat, barley, sugarcane, pea, sorghum, pearl millet, maize, groundnut., tea, cocoa, rubber, oil palm, coconut, kapok, some vegetables, some fruit trees like; mango, papaya, citrus, nutmeg, etc.

Insect Biology

Termites shows division of labor among castes, produce overlapping generations and take care of young collectively like ants, bees and wasps. As eusocial insects, termites live in colonies that, at maturity, number from several hundred to several million individuals. Colonies use decentralised, self-organised systems of activity guided by swarm intelligence which exploit food sources and environments unavailable to any single insect acting alone. A typical colony contains nymphs (semimature young), workers, soldiers, and reproductive individuals of both sexes, sometimes containing several egg-laying queens.

Life Cycle

In a new established colony, 7-10 days after nuptial flight the female lays the first batch of eggs numbering 25-100. These eggs hatch in 40-42 days depending on the climatic conditions. The female termite then swells to become queen and lays upto 3000 eggs per day. When these hatched, the infants are fed by the gastric juices of the queen. As the colony expands, the eggs are laid singly or in double rows of 16 - 24 eggs glued together by a gelatinous secretion, depending on the species. The larva undergoes seven nymphal instars but this again varies according to the species and the environmental conditions. These are fed and cared for by the workers. They mature over a period of 2 - 6 months, depending on their species Adult termites are small, 4 -15 mm long, and vary in color from white to tan and even black, depending on the species.

Termites can be identified according to the caste they belong. There are four castes in the colony namely; the queen, king, soldier, and the worker. The queen is the largest termite in the colony. Her role is to lay eggs to increase the size of the colony. She can lay a thousand of eggs in a day. The king is always beside her ready to mate her. The soldiers have large onion-like heads and powerful jaws. They emit liquid when disturbed. The workers are the majority in a termite colony. They gather the food, feed the queen, take care of and feed the larvae, as well as build and maintain the nest. Unlike ants, the male and female termites can be workers. The nymphs with fully developed wings will be the future kings or queens

Nature and Damage

Of about 2,858 described species of termites, fewer than 185 are considered pests. They are known primarily for their destruction of wooden structures; termites can also be agricultural pests. Termites are known to damage major field crops such as wheat, maize, sugarcane, cotton, groundnut, pulses, and forest plantation trees such as eucalyptus, silver oak, and all kinds of timber in buildings. Termites attack the roots of crops at all stages of plant development, seed sets, newly planted seedlings, tree trunks and also wooden logs. Termite damage starts soon after sowing and continues till the growing stage. The leaves of damaged plants becomes wither and dry and later on drop down. Such plants are easily uprooted.

Termites mostly feed on dead plant material, surface debris such as twigs, bark fragments, dry leaves and grasses, soil, or animal dung, and about 10% of the estimated 3,000 species are economically significant as pests that can cause serious structural damage to buildings, crops or plantation forests.

In natural ecosystems, termites feed an organic matter too. They are responsible for reducing soil fertility by removing both plant and animal debris and locking them in their underground nests, thus making them unavailable for plant growth. They are also litter consumers in forest ecosystems and contribute to the breakdown of dead wood and decomposition of organic matter on the forest floor. Losses due to termites run to several millions of rupees in agricultural crops alone. About 10-25 per cent loss is estimated in most field and forest crops. Severe losses due to termites have been recorded on wheat and sugarcane in northern India, maize, groundnuts, sunflower and sugarcane in southern India, tea in north-eastern India and cotton in western India.

In general, damage by termites is greater in rain-fed than irrigated crops, during dry periods than periods of regular rainfall, in lowland rather than highland areas, and in plants under stress like lack of moisture, disease or physical damage, than in healthy and vigorous plants. In particular, exotic crops are more susceptible to termite attacks than indigenous crops. The extent of termite damage to agricultural crops, the nature of loss they cause, and the plant species they infest, are very much related to the geographic region.

The food of termites is primarily cellulose and it can be obtained from both living and dead wood vegetation. The termites, however, are not self-sufficient in digesting this cellulose because they are not able to synthesize cellulase, the enzyme that breaks down cellulose into oligosaccharides or monosaccharides. They are dependent for the digestion of cellulose on the microscopic fauna, which inhabit their intestines. The fauna exhibit a symbiotic association with the termites, and consist of microscopic protozoa: flagellates or protozoans with whip-like appendages, amoebae, spirochaetes, and fungi. Some of these protozoans contain enzymes, which digest the cellulose present in the wood, for termites. Thus, the termites and the protozoans have symbiotic relationship and they cannot survive without each other.

CONTROL

Non chemical Control (Cultural &Mechanical Control)

Termite control still relies heavily on chemical control. Alternative control measures to control an active infestation are limited. Long term, non-chemical approaches to termite to termites focuses on prevention. Some non-chemical approaches that may eliminate, an active termite infestation

- Mud Tube Removal -Removing mud tubes helps to assess the effectiveness of a termite treatment and reappearance of termite infestation. The tubes are an indication that termites are active around the house.
- Debris Removal - Reduction of food resources by removing cellulose debris is a direct control measures implemented when termites are found infesting the house.
- If the moisture is completely removed than termites can't live.
- Replace old, rotted wood with fresh timbers.
- Heating & Extreme cold will also kill termites.

Biological Control

- Various pathogenic organisms can be used to control termites. Termites live in an environment that is filled with microorganisms, including many that are pathogenic to the insects. One pathogenic fungus, *Metarhizium anisopliae* has been developed commercially into a product called Bioblast. Nematode-containing products have been used for many years against a variety of other pests, most notably in turf against soil-inhabiting white grubs and some caterpillars.

Chemical Control

- Where the pest is of regular occurrence the soil should be mixed with endosulfan 4D or quinolphos1.5 D or chlorpyriphos 5 D BHC or 10 D @ 35 kg/ha at the time of sowing.
- If the incidence of pest is noticed in standing crop dilute 2.5 L of endosulphan35 EC or chlorpyriphos 20EC in 5 L of water and mix it with 50 kg of soil and broabcast even in 1 ha followed by light irrigation
- Fumigation can also be applied to kill all the termites.

Odontotermes obesus

The *Odontotermes* genus belongs to subfamily Macrotermitinae and there are many species of *Odontotermes*, which are either subterranean or mound building. The *Odontotermes* range from Africa to Asia. They are so named from a small characteristic "tooth" which appears as a crenulation on the soldier's left mandible. In some species, this "tooth" is rather prominent, but in other species quite obscure, only visible when the soldier opens its mandibles.

A particular species, *Odontotermes obesus*, happens to be one of the species of termites is a subterranean species, also it is one of the largest *Odontotermes* termite, the soldier is approximately 12 mm in length, from the mandibles to the rear of the abdomen.

Odontotermes consumes wood left in the open and favors dead tree stumps or fallen branches and are quite common in urban areas, but quite rare in forested areas. This particular species, can be readily found in public parks where there are many old trees and subsequently, fallen branches that it can feed on. Its alates typically fly after dusk, although they do not form dense swarms and the flights are short-lived. As a whole, *Odontotermes* are very important decomposers of wood in tropical forests, and there are many species in existence.

Microtermes obesus

Microtermes is a genus of subfamily Macrotermitinae that is so named because it is the opposite of *Macrotermes*, being pretty small in size, but still recognizably one of the *Macrotermitinae*, as can be inferred from the appearance of the workers. There is a wide ranging of *Microtermes* species found in India. They are highly common in agricultural estates.

They nest in wherever is convenient for them, and this includes other termite mounds or their own improvised little hillocks usually at the base of trees, stumps, logs and bushes. When they nest in other termite mounds, they will excavate their nests within the walls of the mound itself. The extremely hard and thick walls of the mounds of *Macrotermes obesus* provide an ideal nesting habitat for *Microtermes obesus*, allowing them to hollow out chambers and construct their fungus gardens within them.

Generally, *Microtermes* species constructs beautiful fungus combs . Workers are dimorphic, but soldiers may or may not be, depending on species. *Microtermes obesus* has dimorphic soldiers, although it is hard to tell the small sized soldiers apart at first glance. Usually workers are larger than the soldiers.

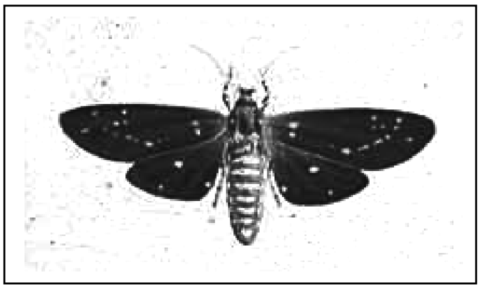
6.14 Role of Termites in ecosystem

- Termites are major detritivores, particularly in the subtropical and tropical regions, and their recycling of wood and other plant matter is of considerable ecological importance.

- Termites contribute significantly to most of the world's ecosystems. They help to recycle the woody and other plant material. Their tunnelling action helps to aerate soils. Termite activity causes patchy changes that improve the soil composition and fertility. Compacted and encrusted soils cannot absorb water and hence can no longer support plant life. Termite tunnelling helps to reclaim greatly damaged soils, which has been successfully demonstrated in the African Sahel zone. Termites also contribute significantly to atmospheric gases.

- It has been recently investigated that a fungus cultivated by some harvester termites has cultured an antibiotic producing bacterium. This finding may provide new insight into the identification, production and use of new antibiotics.

***Amsacta moorei* Butler (The Hairy Caterpillars, The Red Hair Caterpillar)**



Phylum-	Arthropoda
Class-	Insecta
Order-	Lepidoptera
Superfamily-	Noctuoidea
Family-	Arctiidae
Genus-	*Amsacta*
Species-	*moorei*

Distribution

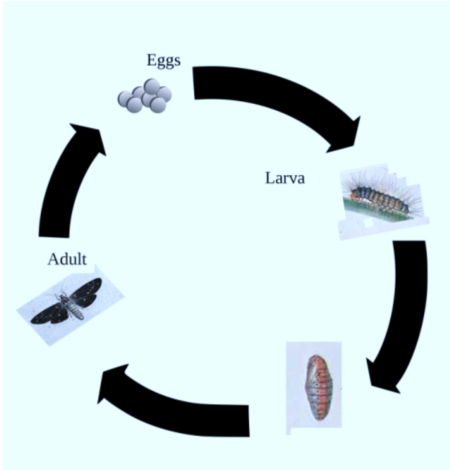
Host Plants

It is a polyphagous insect and feeds practically on all kinds of vegetation growing during the kharif season. Its attack is particularly serious on Groundnut, Pigeon Pea, Watermelon, Sunn Hemp, Melons, Cucumbers, Guar, Finger Millet, Soyabean, Cotton, Pearl Millet, Castor Bean, Sesame, Sorghum, Moth Beans, Black Gram, Mung Bean, Cowpea, Maize etc.

Insect Biology

Life Cycle

This pest is active from mid-June to the end of August and passes rest of the year in pupal stage in the soil Moths, from these pupae, appear usually with the first shower of the monsoon. They are nocturnal in habit and lay light-yellow spherical eggs in clusters of 700-850 each on the under surface of the leaves of host plants. A single female may lay up to 1,500 eggs, which hatch in 2-3 days. The young caterpillars feed gregariously and, as they grow older, they march in bands destroying field after field of various kharif crops. The caterpillars grow through six stages and complete their development in 15-23 days. They enter the soil, shed their hair, and make earthen cocoons at a depth of about 23 cm. Here they pupate and remain in this stage for many months till they emerge next year from the cocoons. In a given populations, probably more than one generation is completed in a year. The moths are stoutly built and have white wings with black spots. The outer margins of the fore wings, the anterior margin of the thorax and the entire abdomen are scarlet red. There are black bands and dots on the abdomen.



Nature of Damage

The young kutra caterpillars prefer to eat the growing-points of plants. The older ones feed voraciously on all vegetation resulting in severe crop damage finally resulting into disaster. The insects eat away entire foliage of plants leaving skeleton only. Field after field is infested by the moving army of caterpillars. In the years of severe infestation, there may be a complete failure of the kharif crops. Crop losses caused by *A. moorei* during different years vary from minor damage to complete crop failure in the endemic. Arctiidae is a family which apparently reacts according to climatic influences, pest outbreaks, and hence heavy crop losses, are likely to occur in years of substantial and frequent or intermittent rains during the first 25-30 days after start of moth emergence, i.e. from end June to July.

Control

Cultural & Mechanical Control

Some cultural methods, such as deep ploughing after harvest or destruction of weeds growing on embankments, fence lines and on nearby uncultivated land, may help in reducing some pest damage. Marching bands of caterpillars can be destroyed by digging trenches around the fields and burying them. Additionally, collection and destruction of egg masses and young larvae in the gregarious phase of the pest have been recommended. Young larvae are gregarious. They can be destroyed by pulling out the infested plants and bury them under-ground.

The moths are nocturnal in behaviour and are strongly attracted to artificial light. So, light traps of electric or petromax lamps placed just above a broad flat basin full of kerosenized water, should be put up on the night following throughout the period of emergence for about one month.

Biological Control

Some bio-agents such as *Trichogramma* and nuclear polyhedrosis virus, Entomopoxvirus of *A. moorei*, which is infectious to the Lepidopteran insects, are used as a biological insecticide.

Chemical Control

The grown up caterpillars can be controlled by spraying in one acre ½ litre of Thiodan 35 EC (endosulfan) or Ekalux 25 EC (quinalphos) or 1 litre of Anatox 80 EC (toxaphen) or 200 ml of Nuvan 100 (dichlorvos) in 100-200 litres of water or by dusting 15 kg of 5 percent Aldrin Diptrex per acre.

6.15 Pests of Maize and Millets

Maize (*Zea mays* L.) occupies an important place in world agriculture. More than half the maize of India is produced in four states : Madhya Pradesh, Andhra Pradesh, Karnataka and Rajasthan. It is estimated that by the year 2020, demand for maize in developing countries will surpass demand for both wheat and rice. Maize in India ranks fifth in total area and third in total production and productivity. This level of production has to be substantially raised to meet growing demand of maize for human food, animal and poultry feed, as well as industrial processing by the wet and dry millers to produce value added products. Maize can be successfully grown in rainy (kharif), winter (rabi) and summer spring (zaid) crop seasons. Because of its divergent types, it is grown over a wide range of climatic conditions, ranging from near sea-level to several thousand meters above sea-level (2,700 m msl). Maize can be grown in tropical, subtropical and temperate climates, however tropical and sub-tropical occupy a higher percentage of corn production. It can also be grown in all types of soils ranging from sandy to heavy clay. Deep heavy soils are considered more suitable in view of their better water holding capacity. Saline and alkaline soils should be avoided since these adversely affect crop growth and development. The requirement of fertilizers depends upon the status of the soil, previous cropping history and duration of the variety to be grown. However, a balanced application of 60-120 kg N, 40-60 kg P and 40 kg K is recommended for various ecosystems. A population of 65,000-70,000 plants/ha is optimum for realizing high maximum yield.

Among the factors adversely affecting productivity, ubiquitous prevalence of diseases and insect pests in the pre harvest stage are prominent. The total economic loss of the crop in India due to insect pests and diseases has been estimated to be of the order of 13.2%. Since there is practically no possibility of increasing maize area, the productivity can only be raised by providing seed of improved cultivars, better agronomic practices and protection against diseases and pests. Hence, this document aimed to provide comprehensive integrated pest management practices to reduce crop losses caused by diseases and insect pests of maize.

Millets

The term "millet" is applied to various grass crops whose seeds are harvested for human food or animal feed. Sorghum is called millet in many parts of Asia and Africa, and broomcorn is called broom millet in Australia. Compared to other cereal grains, millets are generally suited to less fertile soils and poorer growing conditions, such as intense heat and low rainfall. In addition, they require shorter growing seasons. Millets are generally considered minor crops except in parts of Asia, Africa, China, and the Soviet Union. The millets are considered to have been cultivated in India from pre-historic times. Their importance as an article of human food can be realized from the fact that about 30 million acres in India fall under millets. As a group, millets are used for both forage and grain. Millets are generally grown as mixed crops in regions of low rainfall, the other crop grown with them being usually one of the legumes. Most of the millets grown in our country are of short duration, taking, three to four months from sowing to harvesting. Some of India are sorghum pearl millet and finger millet.

Millets are important crops in the semiarid tropics of Asia and Africa specially in India, Nigeria, and Niger with 97% of millet production in developing countries. It is grown and consumed in Rajasthan, Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra and Goa. Millets are a group of highly variable small seeded grasses, widely grown around the world as cereal crops or grains for fodder and human food. The crop is favored due to its productivity and short growing season under dry, high temperature conditions.

Millet is very famous, rich in iron, phytochemicals that lower cholesterol, folate, magnesium, copper, zinc, and vitamins E and B-complex. It packs an additional punch since it contains all 13 essential amino acids. It is good for bones and has higher energy content than other flours. It is also rich in calcium and unsaturated fats which are good for the body. It is low in saturated fat, very low in sodium, no sugar, high in manganese and can prevent heart failure if it is eaten daily.

Stem borer, earworm and millet midge are the most problematic pests, but the crop may also be attacked by various species of grasshoppers, locusts, white grubs and various butterflies.

6.16 Chilo Zonellus (Swinhoe) / *Chilopartellus* (Swinhoe, 1885)

The Spotted Stemborer

Phylum: Arthropoda

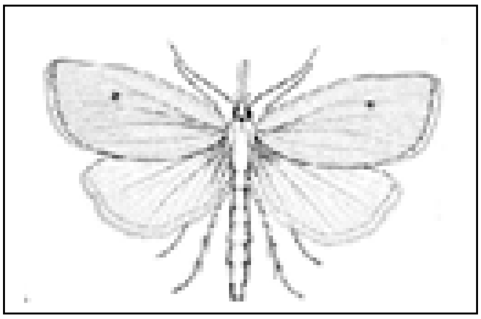
Class: Insecta

Order: Lepidoptera

Family: Crambidae

Genus: *Chilo*

Species: *partellus*



Distribution

The spotted stem borer is found in India, Pakistan, Ethiopia, Lesotho, Madagascar, Malawi, South Africa, Sudan, Tanzania, Uganda and on Mayotte. It is native to Asia where it is a pest of maize and sorghum. It was first reported from Africa in the 1930s and became established in East Africa in the 1950s. After arriving in Africa, it has spread to nearly all countries in Eastern and Southern Africa, and it is assumed that it is spreading to Western Africa. *C. zonellus* is indigenous to Asia and became established in Eastern Africa in the early 1930s. It occurs in low to mid-altitude areas. It was described by Swinhoe in 1885.

Chilo zonellus has rapidly spread over a wide geographical range and due to this expansion they have proven to be a very efficient colonizer and devastating pest wherever they may occur. In general, *C. zonellus* occurs in low to high latitudes and warmer areas.

Host Plants

The main host plants of *Chilo zonellus* are Maize, Sorghum, Bulrush millet, Sugarcane, Rice. It is a major pest of Maize, Sorghum and minor pest of

Wheat. It is a generalist herbivore that feeds on several species of cultivated and wild plants. The spotted stemborer attacks several wild grass species as alternative pest. Wild hosts include many species of wild grasses such as: elephant grass (*Pennisetum purpureum),* reeds *(Phragmites* species) and vossia (*Vossia cuspidate*).

Insect Biology

Life Cycle

The whole life cycle takes about 3-4 weeks, varying according to temperature and other factors. Five or more successive generations may develop in favourable conditions. In regions where there is sufficient water and an abundance of host plants, the spotted stemborer can reproduce and develop all year-round.

When larvae are fully grown, they pupate and remain inside the maize stem. After 7-14 days adults emerge from pupae and come out of the stem. They mate and lay eggs on maize plants again and continue damaging the crop. During the dry season, larvae may enter a state of suspended development (diapause) for several months and will only pupate with the onset of rains. Adults emerge from pupae in the late afternoon or early evening. They are active at night and rest on plants and plant debris during the day. They are rarely seen, during the day unless they are disturbed.

Eggs

The eggs are laid on the underside of a leaf near the midrib in 3-5 rows, in groups of 50-100. They are flattened, ovoid, scale-like, creamy-white and about 0.8 mm long. Eggs are laid in overlapping batches of 10-80 eggs on the upper and underside leaf surfaces, mainly near the midribs. Hatching takes place after 7-10 days.

6.17 Larvae (Caterpillar)

In general appearance the spotted stem borer larvae are creamy-white to yellowish-brown in colour, with four purple-brown longitudinal stripes and usually with very conspicuous dark-brown spots along the back, which give the larvae a spotted appearance. When fully grown the larva has a prominent reddish-brown head. It has a prothoracic shield which is reddish-brown to dark-brown and shiny. The head capsule is brown. When mature they are about 25 mm long. The caterpillars can be distinguished from the presence of hooks on its prolegs. In *C. zonellus* these hooks are arranged in a complete circle. Young caterpillars initially feed in the leaf whorl. Older caterpillars tunnel into stems, eating out extensive galleries, within which they feed and the larval period takes 28-35 days to grow.

Pupa

During dry seasons, larvae may enter a state of diapause or a period suspended development for several months and will pupate once it the dry season is over and there is an onset of rain. Pupation takes place in a small chamber in the stem. Pupa is up to 15 mm long, slender, shiny and light yellow-brown to dark red-brown in colour. The pupal period takes 7 10 days.

Adult

Adult moths have a wingspan of 20-30 mm. Males are smaller and darker than females. The forewings of males are pale brown. The forewings of the females are much paler and the hind wings are almost white.

Nature and Damage

Larvae (caterpillars) eat through leaves when young and as they grow older, eventually bore into the stem causing it to break or die resulting in a condition called 'deadheart'. Vegetative stage or before harvest the younger plants less than two months old are more often attacked than older plants. Younger larvae usually feeds in leaf whorls. Older larvae tunnel into the stem, and may also eat into the cob in older plants. Yield losses are variable across regions, seasons, plant species and varieties and management regime on farms. Yield losses may exceed 20% on maize and 50% on sorghum.

The Damage caused by *Chilo zonellus* occurs as a series of small holes in lines in younger leaves and patches of transparent leaf epidermis in older leaves. Sometimes the early stages mine in the leaves, causing yellow streaks. The larvae forms tunnel into the stem can result in holes, broken stems or drying and eventual death of the growing point of the maize called as deadheart.

In young plants the shoot can be killed, causing a "dead heart". In older plants the upper part of the stem usually dies as a result of the boring of the caterpillars.

Control

Detection methods

Spotted Stemborer infestations may be detected by walking through young crops looking for characteristic feeding marks on funnel leaves, the presence of dead hearts and holes in tunnelled stems. Samples of affected stems can be cut open to find caterpillars and pupae. It is best to rear them until they reach the adult stage to identify the species as it is very difficult to identify the species from the larvae and pupae. Spotted stemborers may be detected in older crops and in crop residues by taking random samples of stems to dissect to find caterpillars and pupae.

Cultural practices

Intercropping maize with non-hosts crops like cassava or legumes like cowpea can reduce spotted stemborer damage. Alternatively, maize can be intercropped with a repellent plant such as silver leaf desmodium (*Desmodium uncinatum*) and a trap plant, such as Napier grass (*Pennisetum purpureum*), molasses grass (*Melinis minutiflora*) as a border crop around this intercrop to protect maize from stemborers. The trap plant draws the adult female away from the crop. More eggs are laid on the trap plant than on the crop but the larvae develop poorly or not at all on the trap plant. This practice is known as "push-pull".

Good crop hygiene through the destruction of maize residues by burning to get rid of the larvae and pupae within the stems, and removal of volunteer crop plants and/or alternative hosts, prevents carry-over populations. This helps in limiting the initial establishment of stemborers that would infest the next crop.

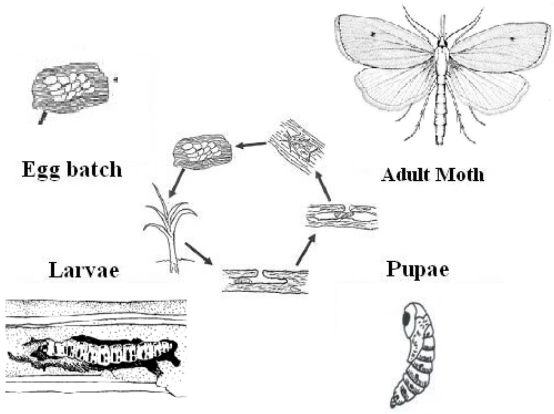
Early slashing of maize stubble and laying it out on the ground where the sun's heat destroys the larvae and pupae within can also be utilised.

Biological control

Biological control by two parasitic wasps, *Cotesia flavipes* and *Xanthopim plastemmator*, that attack the spotted stemborer, has shown good results. *Cotesia flavipes* locates the stemborers while they are feeding inside the plant stems. The wasp lays about 40 eggs into a stemborer. Upon hatching the larvae of the parasitic wasp feed internally in the stemborer, and then exits and spin cocoons. *Xanthopim plastemmator* operates similarly but attacks the pupae. Habitat management practices that conserve these parasitoids and predators like ants and earwigs can help in the control of the spotted stemborer.

Chemical control

Chemical control can be achieved by applications of granules or dusts to the leaf whorl early in crop growth to kill early larval instars. This method has limited effectiveness once the larvae bore into the stem. Neem products (powder from ground neem seeds) are reportedly effective and may be applied to the leaf whorl in a 1:1 mixture with dry clay or sawdust. Pesticides are poisons so it is essential to follow all safety precautions on labels.Furadan 3G proved significantly more effective in the reduction of per cent dead hearts, pest infestation and in increase of stalk and cobs weight, average number of cobs/plant and grain yield followed by Ripcord 100g/l EC and Tamaron SL 600. High dose of all the three insecticides gave better control of maize stem borer than medium and low doses. However, medium and low doses of insecticides were also found significantly better compared to the check.



***Sesamia inferens* (The Pink Stem borer)**

Phylum: Arthropoda

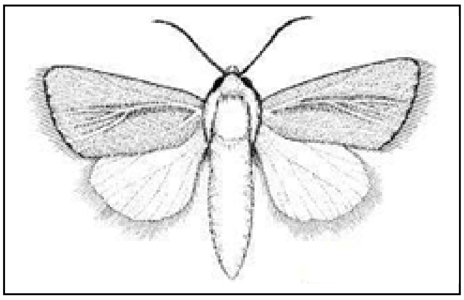
Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Sesamia*

Species: *inferens*



Distribution

The Asiatic pink stem borer, Gramineous stem borer, Pink borer, Pink rice borer, Pink rice stem borer, Pink stem borer, Pink stem borer, Purple borer, Purple stem borer or Purplish stem borer (*Sesamia inferens*) is a moth of the Noctuidae family. It is found from Pakistan to Japan and the Solomon Islands. This pest is found all over Asia, from western Iran to China, Japan, Burma, Taiwan, Malaysia, Solomon Is. and New Guinea. Indo-Australian tropics to Solomons. The species is found from the lowlands to about 1700m, but is commoner in the former, particularly in disturbed and open habitats.

Host Plants

This is a polyphagous pest that attacks oats, citronella grass, goose grass, barley, rice, pearl millet, finger millet, sugarcane, sorghum, wheat, maize, maize and several wild grasses. The larvae mostly feed on Gramineae species including *Coix*, *Echinochloa*, *Oryza*, *Panicum*,*Saccharum*,*Setaria*, *Triticum*,

Zea and *Zizania*. Many of the food plants are of economic importance.

Insect Biology

Life Cycle

The pink stem borer breeds throughout the year and has no period of suspended development i.e. diapause. However, it is less abundant during the dry season when it is limited to mature grasses elephant grass, *Setaria* species and itchgrass among others, as a food source. Life cycle is completed in about 40-70 days, depending upon the climatic conditions. There are 4-6 generations in a year.

Eggs

The eggs are laid in clusters in several rows within the cover of the leave sheath. The eggs are hemispherical, about 1 mm in diameter and slightly flattened with radial ridges. They are creamy-white when laid but darken as they develop. Eggs are inserted between the lower leaf sheaths and the stem in batches of 10-40 and arranged in two to four contiguous rows. On average, each female lays around 300 eggs in a period of five days. Eggs are laid usually when plants are two weeks old until flowering. The most serious damage, however, occurs at early plant stages.

Larvae

The larva of the African pink stalkborer looks smooth and shiny and lack obvious hairs or markings. Their colour is variable but they are usually creamy-white with a distinctive pink suffusion. The head and prothoracic shield are brown; the dorsal part of the last abdominal segment bearing the anus is yellow-brown. Setae are present on small, inconspicuous pinacula which is hardened or sclerotized area that indicate points of muscle attachment and the spiracles are elongated oval with black surrounds. The crochets of the larval abdominal prolegs are arranged in lines as is the case for noctuid stem borers. This contrasts with pyralid borers whose crochets are arranged in circles. Mature larvae are between 30-40 mm long, pink with buff and pink dorsal markings and a brown head .

Most larvae penetrate the stem shortly after they emerge from their eggs. Larval feeding might result in dead hearts and the tunnelling and girdling activity of the larvae often results in stalk breakage. During the ear filling period, the majority of the larvae occur in the ears. Development of the larvae takes four to six weeks. Most larvae pupate within the stem or cobs.

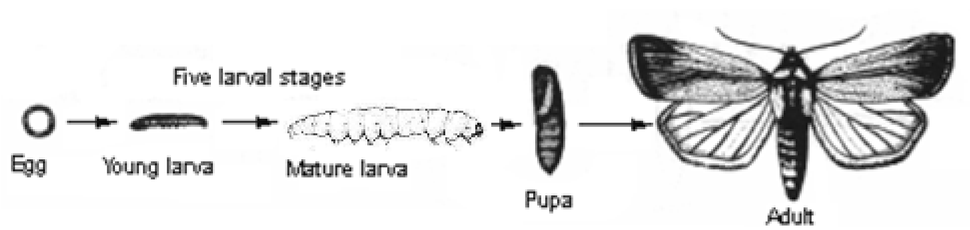
Pupae

Pupation normally takes place inside the stem and sometimes outside in hidden places such as between leaf sheath and stem. There is no cocoon formation. Pupa is 18 mm long, dark brown with purple tinge on the head region with a wrinkle. The frontal region and a terminal tail is with four large and two small spines.

Adult

Adult moths are strong, fast flying insects. They are straw coloured with hairy body The wingspan in females of the pink stem borer is 20-30 mm and in males a little less. The forewings are pale-brownish, with variable but generally inconspicuous darker markings along the margin and an overall silky appearance. Hind wings are white.

This species superficially resembles *Mythimna* species but has smooth, rather than hairy, eyes. The forewing is much less striate than in *Mythimna,* with a diffusely darker central streak, and darker brown at the margin. The hindwings are almost pure creamy white.



Nature and Damage

S. inferens is extreme polyphagous in nature. It is the least destructive borer pest among the rice stem borers. Outbreaks in rice usually result from a population overspill from adjacent sugarcane fields or other alternative hosts. Its incidence in rice seems to have decreased with the intensification of rice cultivation during the past 30-40 years. *S. inferens* is generally more prevalent in areas where its alternative hosts are cropped such as surrounding sugarcane or maize or in rotation with wheat. It also generally attacks the rice crop during its intermediate or late growth phases.

Stem borers are ubiquitous in rice fields. *S. inferens* is usually most often found in association with other stem borers attacking a rice crop. It belongs to a different family than other pyralid stem borers and is larger in size. Wider stemmed rices favour *Chilo* species and *S. inferens*.

All the stem borer species attacking a crop must be considered together and their damage as additive, as there is little or no difference in damage potential between species. Larva bores into the stem and hollows it out which results in dead heart. White heads are a greater contributor than deadhearts to yield loss. Hybrid or other high-tillering rices can tolerate high infestation rates if the crop is well managed and there is a lack of other stresses. The tunnelling caused by the larvae severs the vascular tissue but there are many conduits in a stem and reduction in nutrient and assimilate flow can normally be shunted to undamaged vascular bundles unless the stem is completely severed. Stem borer tunnelling has a greater impact on yield loss than defoliation and damage can act synergistically with other stresses.

Control

Cultural Control

The community-wide cultural practices act to prevent colonization and build-up, and have the greatest potential to minimize *S. inferens* infestation. These include planting cultivars each season with the same maturity class and planting synchronously between fields. Rice cropping intensity is limited to two crops per year over the area and if irrigation allows a third crop it should be a non-host species such as field legume. Harvesting has a devastating effect on stem borers particularly if the straw is destroyed and the remaining stubble ploughed under.

Early planting within a contiguous area such as an irrigation turnout generally escapes damage. Increasing plant density allows maximum compensation from damage. Using well timed and optimal levels of nitrogen and balanced fertilizer also helps a crop to compensate from damage even though it may increase the overall stem borer density. Good crop husbandry such as thorough land preparation, prompt weeding, and vigilant water management ensure vigorous crop growth and ability to tolerate stem borer damage.

6.18 Mechanical and Physical Control

The traditional and more labour intensive practices used against stem borers are not particularly effective against *S. inferens*. Hand picking of egg masses is conceivable if labour is cheap, against *Scirpophaga* rice borers which lay egg masses in the open but is impractical against *S. inferens* which oviposits behind leaf sheaths. Roguing deadhearts is time consuming and often the larvae have already left the affected tiller.

Biological Control

All life stages of *S. inferens* is vulnerable to attack by natural enemies. Once the eggs have been laid behind the leaf sheaths, the factors that will most reduce the stem borer population are natural enemies. Because of their fecundity, *S. inferens* populations will increase even if 90% of the population dies during the crop season. For a population to decline, more than 99% of the eggs laid must fail to reach the reproductive stage.

Classical biocontrol has been carried out in Taiwan and the Philippines with the introduction of the tachinid parasitoid *Sturmiopsis inferens* from India. Even though the species became established, this method has not been highly successful as studies have shown that there are already many natural enemies of *S. inferens* in paddy fields and the effect of one more, even as effective as *Sturmiopsis*, will not be noticed against this indigenous pest.

6.19 Host-Plant Resistance

The type of plant can have a broad effect on all stem borers. Short-stature, high tillering, early-maturing (110-125 days) plant types offer the greatest reduction to population build-up and damage. The levels of resistance, however, are only quantitative and high levels of resistance have not been found. Short-stature cultivars reduce the highly susceptible periods of tiller and panicle elongation. Deepwater rice cultivars which elongate several meters are therefore highly susceptible. First-instar larvae need to bore into tillers and panicles in order to survive and they have the greatest chance during elongation when silica, the plant's natural defence, is less densely packed. The longer it takes first-instar larvae to bore into a tiller the more chance natural enemies have in finding it. The larvae may also die of starvation if it cannot enter. First-instar larvae of *S. inferens* are a little larger than other stem borers and therefore take a shorter time to bore into a tiller. If one panicle is severed, the assimilate can be diverted to other panicles which still have unfilled grains.

Recent advances in biotechnology have raised hopes for the development of a highly resistant transgenic rice variety against stem borers. The incorporation of an insecticidal proteinase inhibitor gene into rice plants has been used for this purpose. The fifth generation of transgenic japonica rice plants containing the potato proteinase inhibitor II gene showed increased resistance against *S. inferens.*

Chemical Control

- Seed treatment with Carbofuran 35 ST having 1/3 a.i.
- Seed treatment with Carbofuran (40F) 5% W/W @ 2.5g/kg of seed was also found effective against *S. inferens*.
- 1st Foliar application of Endosulfan 0.1% 15 days after sowing
- 2nd application of 4% granules al 15 kg/ha a fortnight

IPM

Management of *S. inferens* and other rice stem borers should first address preventative measures. These include a combination of cultural practices and selection of a tolerant plant type which will have the greatest effect in bolstering the crop's ability to tolerate normal levels of damage. A vigorously growing rice crop planted to a high tillering variety has been shown to tolerate up to 20% dead hearts and 10% whiteheads with no yield loss. Stressing non-chemical preventative measures also ensures conservation of natural enemies which will further protect the crop. Chemical control is costly and disruptive to parasitoids and predators and should be contemplated as a last resort.

6.20 Summary

A pest is any living organism which is invasive or prolific, detrimental, troublesome, noxious, destructive, a nuisance to either plants or animals, human or human concerns, livestock, human structures, wild ecosystems etc. Pest refers to any animal or plant causing harm or damage to people or their animals, crops, or possessions, even if it only causes annoyance.

India is facing crop losses and problem of food security as agricultural pests, such as insects, viruses, bacteria, fungi, and weeds are spreading. Pests belong to a broad spectrum of organism which causes annoyance, harm or damage to people, animals, crops or possessions. In India there is a need of raising awareness for management of the vast range of pest that threaten agricultural crops. The causes of pest outbreaks and crop losses are due to different factors creating changes in the agricultural ecosystem. The most direct economic impact of agricultural pest is the reduced efficiency of agricultural production may it be crops or animals, which reduces farmers' income. The efforts are broadly classified as integrated pest management, low external input sustainable agriculture and organic agriculture. Integrated Pest Management is the most commonly recommended and widely adopted.

6.21 Self Assessment Questions

1. Define pest with some examples of insect pests.
2. Describe the life cycle of termites.
3. What do you mean by monophagous, oligophagous and polyphagous pests? Give suitable examples.
4. What are the main host plants of Locusts?
5. What are the control measures for Desert Locust**?**
6. Explain the life cycle of *Locusta migratoria* in details.
7. Differentiate between the solitary phase and gregarious phase of *Locusta migratoria*.
8. Write an essay on Pests of maize and millets.
9. Give a comparison account of locust and grasshoppers
10. What is LWO (Locust Warning Organisation)? Where it is located in Rajasthan?
11. Explain the Biology, nature, extent of damage and control of *Hieroglyphus* ?
12. Describe the Biology, nature, extent of damage and control of *Chilo zonellus*.
13. Explain the caste differentiation in social insects - termites.
14. Differentiate between subterranean termites and drywood termites
15. Define Polyphenism

6.22 References

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Unit 7

Agricultural Pests – II

Structure of the Unit

7.1 Objectives

After completing the unit, you will be able to understand about-

- Brief idea about pulses crops and its importance
    - Biology, nature of damage and control of Pests of Pulses - *Heliothis armigera / Helicoverpa armigera* (The Gram Pod Borer), *Agrotis ipsilon* (The black cutworm), *Prodenia litura / Spodoptera litura* (Oriental leaf worm moth)
- Brief idea about Oil seed crops
    - Biology, nature of damage and control of - *Lipaphis erysimi* (Mustard Aphid/ Turnip Aphid), *Athalia lugens proxima* (The Mustard Sawfly), *Bagrada cruciferarum* (The painted Bug), *Holotrichia (Lachnosterna) consanguinea* (White Grub), *Achaea janata* (The Castor Semilooper), *Euproctis lumata* (Castor hairy caterpillar)

- Brief idea about cotton crop and its importance in India.
  - Biology, Life Cycle, Nature of Damage and different types of control measures of Pests of Cotton crops - *Earias insulana* (Spotted Boll-worms), *Pectinophora gossypiella* (Pink ballworm), *Oxycarenus laetus* (Dusky Cotton Bug), *Dysdercus koenigii* (Cotton Stainer), *Utetheisa pulchella* (Sunnhemp Hairy Caterpillar)

7.2 Pests of Pulses

Pulses Crops

The term "pulse" comes from the Latin word "puls," which means a thick soup. Pulses are the edible seeds of legumes which includes peas, beans, lentils, and chickpeas. These pulse crop species are a part of the larger plant family known as the Fabaceae or legume family. The Fabaceae family includes about 600 genera and 13,000 species, making it the third largest family within the plant kingdom.

Pulses are considered environmentally friendly because of their reduced dependence on fossil fuels. Instead of requiring fertilizer applications, they are able to obtain much of their nitrogen requirement from the atmosphere by forming a symbiotic relationship with *Rhizobium* bacteria in the soil. Low crop residues and low carbon-to-nitrogen ratios of pulse crops eliminates the need for burning and make rotating to the next crop using reduced tillage very easy.

7.3 Importance of Pulse Crops in India

Pulses are rich in proteins and found to be main source of protein to vegetarian people of India. It is second important constituent of Indian diet after cereals. They can be grown on all types of soil and climatic conditions. They give ready cash to farmer. Pulses being legumes fix atmospheric nitrogen into the soil. They play important role in crop rotation, mixed and intercropping, as they help maintaining the soil fertility. They add organic matter into the soil in the form of leaf mould. Pulses are generally not manured or requires less manuring. They are helpful for checking the soil erosion as they have more leafy growth and close spacing. They supply additional fodder for cattle. Some pulses are turned into soil as green manure crops. Majority pulses crops are short durational so that second crop may be taken on same land in a year. They provide raw material to various industries.

Insects pests can be a serious problem on pulses crops. These insects pests can damage crops by reducing their yielding and having a negative impact on their quality. Farmers use synthetic pesticides to combat pests. Besides being hazardous to the farm workers' health and leaving toxic residues on crops, the uses of these pesticides have other negative consequences.

Heliothis armigera, **Hubner /** ***Helicoverpa armigera,*** **Hubner (The Gram Pod Borer)**

Systematic Position

Phylum: Arthropoda

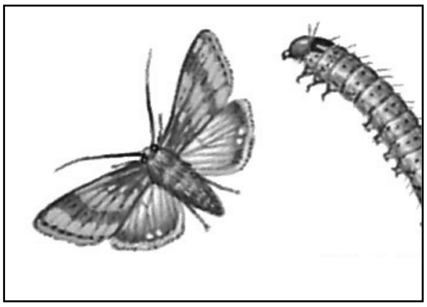
Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Helicoverpa*

Species: *armigera*



Nearly 60 insect pestspecies are known to feed on different pulses crops, of which the pod borers *Helicoverpa armigera* is one of the major pests. It is a major pest of pulses crops in Asia, Africa, and Australia. *Helicoverpa* causes losses to legume crops in the semi-arid tropics are estimated at over US $328 million annually. Pod borers rarely become a serious pest on lentil. Worldwide, losses due to *Heliothis*/*Helicoverpa* in cotton, legumes, vegetables, cereals, etc., exceed $2 billion, and the cost of insecticides used to control these pests is over $1 billion annually. There are several common names for pod-borers, namely cotton bollworm, corn earworm, African cotton bollworm, native budworm, old world bollworm, legume pod borers, gram pod borer, and tomato fruit worm.

Distribution

Helicoverpa armigera is widely distributed in Asia, Africa, Australia, and the Mediterranean Europe, Additionally, there are reports of *H. armigera* outbreaks in Hungary, Italy, Romania, Slovakia, Spain, Sweden, Switzerland, and the United Kingdom also.

Host Plants

Helicoverpa armigera is a major pest of cotton, pigeonpea, chickpea, sunflower, tomato, maize, sorghum, pearl millet, okra, *Phaseolus* spp., vegetables, tobacco, linseed, a number of fruits (*Prunus, Citrus,* etc.), and forest trees. In recent years, *H. armigera* damage has been reported in carnation, grapevine, apple, strawberries, finger millet, etc.

Insect Biology

Life Cycle

Egg

The oviposition period lasts for 5 to 24 days, and a female may lay up to 3,000 eggs, mainly at night on leaves, flowers, and pods. The spherical eggs are 0.5 mm in diameter. They are first yellow, later turning brown. The egg incubation period depends on temperature, and varies between 2 to 5 days, usually 3 days.

Larva

The colour of the larvae is greenish or brown, but colouration is very variable. The body has longitudinal dark and pale bands. Head, prothoracic plate, and legs are brownish. Spiracles are black. The length of a fully grown caterpillar is 40 mm. There are 6 larval instars. The total larval period is usually 14 to 24 days, but up to 50 days at low temperatures. Excreta may be seen on the plant or under it. On maize the caterpillars are feeding with the forepart of the body inside the ear while the hind part remains outside. A similar behaviour is observed on pulses. Duration of larval development depends not only on the temperature, but also on the nature and quality of the host plant, and varies between 15.2 days on maize to 23.8 days on tomato.

Pupa

The shiny brown pupa is about 16 mm long. Pupation takes place in the soil. The pre-pupal period lasts for 1 to 4 days. The larvae spin a loose web of silk before pupation. In non-diapausing pupae, the pupal period ranges from about 6 days at 35°C to over 30 days at 15°C. The diapausing period for pupae may last several months. The pupal period takes 2-4 weeks according to the temperature.

Adult

A stout bodied light brown nocturnal moths with a wingspan of 32-40 mm are produced from pupae when exposed to temperatures exceeding 30°C. The body length is 16-18 mm. The forewings are yellowish brown or greyish to brown, with a broad slightly darker band and a small dark spot. The hind wings are pale with a broad dark grey or brown marginal band with two lighter spots on it. In captivity, longevity varies from 1 to 23 days for males and 5 to 28 days for females.

Helicoverpa armigera exhibits a facultative diapause, which enables it to survive adverse weather conditions in both winter and summer. The winter diapause is induced by exposure of the larvae to short photoperiods and low temperatures. In China and India, *H. armigera* populations are comprised of tropical, sub-tropical, and temperate ecotypes. In subtropical areas, *H. armigera* undergoes diapause during winters when the temperatures are low. High temperatures can also induce diapause. It enters a true summer diapause when the larvae are exposed to very high temperatures (43°C for 8 h daily), although the proportion of females entering diapause is nearly half compared to that of males. At these temperatures, non-diapausing males are sterile.

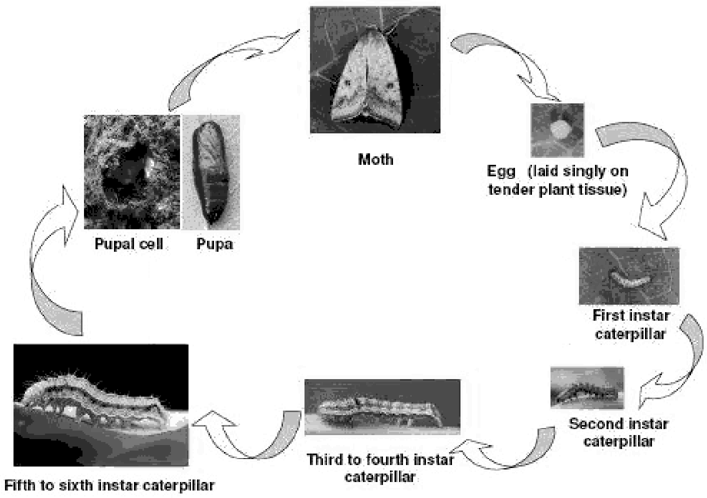


Figure: Life cycle of *Helicoverpa armigera*

Nature of Damage

Caterpillars cause a variety of damage to different crops. They feed on leaves and tender shoots and bore into the fruits. In pulses, they bore into the pod to feed on seeds, sometimes half of the body remains outside the pod if the pod is small. Fungus and other diseases follow in the damaged fruits. One larva may feed on several fruits before completing development. *Helicoverpa* females lay eggs singly on leaves, flowers, and young pods. The larvae initially feed on the foliage in legume crops, but mostly on flowers and flower buds in cotton, pigeon pea, etc. The young seedlings of legume plants may be destroyed completely, particularly under tropical climates in southern India. Larger larvae bore into pods/bolls and consume the developing seeds inside the pod.

Control

Monitoring of *Helicoverpa* populations is necessary to determine if threshold has been exceeded and control measures are required. Action thresholds based on egg numbers have been used to make control decisions. One larva per meter row in chickpea causes economic loss. A simple rule of thumb based on monsoon rains and November rainfall has been developed to forecast *H. armigera* populations in India. Mainly three crops, cotton, tomato and maize, have high risk levels of *Helicoverpa* attack and require multiple sprays of pesticides.

Cultural Methods

A number of cultural practices such as time of sowing, spacing, fertilizer application, deep ploughing, interculture, and flooding have been reported to reduce the survival and damage by *Helicoverpa* species. Inter-cropping or strip-cropping with marigold, sunflower, linseed, mustard, or coriander can minimize the extent of damage to the main crop. Strip-cropping also increases the efficiency of chemical control. Hand-picking of large larvae can reduce *Helicoverpa* damage. However, the adoption of cultural practices depends on the crop husbandry practices in a particular agro-ecosystem. The chickpea trap crop is planted after the commercial crops to attract *H. armigera* emerging from winter diapause. The trap crops are destroyed before larvae commence pupation. As a result, the overall *H. armigera* pressure on summer crops is reduced, resulting in greater opportunity for adoption of soft control options, reduced insecticide use, and greater activity of the natural enemies.

Natural Enemies

The importance of biotic and abiotic factors on the seasonal abundance of *H. armigera* is poorly understood. *Trichogramma* egg parasitoids are seldom present in high numbers in legume crops in India. The ichneumonid wasp, *Campoletis chlorideae* is an important larval parasitoid of *H. armigera* on chickpea in India. The dipteran parasitoids *Carcelia illota*, *Goniophthalmus halli*, and *Palexorista laxa* have been reported to parasitize up to 54% of the larvae on chickpea. Predators such as *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp., and *Polistes* spp. are common in India. Provision of bird perches or planting of tall crops that serve as resting sites for insectivorous birds such as Myna (*Acridotheris tritis)* and Drongo (*Dicrurus macrocercus)* helps to reduce the numbers of *H. armigera* larvae.

6.4 Biopesticides and Natural Plant Products

The use of microbial pathogens such as *H. armigera* nuclear polyhedrosis virus (HaNPV), entomopathogenic fungi, *Bacillus thuringiensis* (*Bt*), nematodes, and natural plant products such as neem, custard apple, and karanj (*Pongamia pinnata)* kernel extracts have shown some potential to control *H. armigera*.

HaNPV has been reported to be a viable option to control *H. armigera* in chickpea in India. The entomopathogenic fungus *Nomuraea rileyi* (10^6 spores per ml) resulted in 90 to 100% mortality of the larvae. Another entomopathogenic fungus, *Beauveria bassiana* (2.68×10^7 spores per ml) resulted in 10% reduction in damage by *H. armigera* over the control plants. *Bt* formulations are also used as sprays to control *Helicoverpa*. Spraying *Bt* formulations in the evening results in better control than spraying at other times of the day.

Chemical Control

Management of *Helicoverpa* in India in legume crops and other high-value crops relies heavily on insecticides. Different types of insecticides like Endosulfan, cypermethrin, fenvalerate, methomyl, thiodicarb, profenophos, spinosad, and indoxacarb have been found to be effective for controlling *H. armigera*. Spray initiation at 50% flowering has been found to be most effective. Development of resistance to insecticides is a major problem in *H. armigera. Helicoverpa armigera* populations in several regions have developed resistance to pyrethroids, carbamates, and organophosphates. Introduction of new compounds such as thiodicarb, indoxacarb, and spinosad has helped in overcoming development of resistance in *H. armigera* to conventional insecticides.

6.5 Integrated Pest Management (IPM)

Crop cultivars with resistance to *Helicoverpa* produced through conventional plant breeding or biotechnological approaches can play an important role in its control. Cultural practices such as deep ploughing, interculture, flooding, and intercropping could potentially reduce the intensity of *Helicoverpa*. Although the role of natural enemies as biological control agents is unclear, their impact could be improved by reducing pesticide applications, and adopting cropping practices that encourage their activity. Most studies have shown that insecticide applications are more effective than neem kernel extracts, *Bt*, HaNPV, or augmentative releases of natural enemies. However, biopesticides and synthetic insecticides, applied alone, together, or in rotation, are effective for *Helicoverpa* control in chickpea. Moreover, scouting for eggs and young larvae is critical for initiating timely control measures. Insecticides with ovicidal action, and/or systemic action are effective against *Helicoverpa* during the flowering stage. The development of transgenic plants with different insecticidal genes, molecular marker assisted selection, and exploitation of the wild relatives of *Cicer* and *Lens* species are very much effective for *Helicoverpa* management on chickpeas and lentils.

Host Plant Resistance

The development of crop cultivars resistant or tolerant to *H. armigera* has considerable potential for use in integrated pest management, particularly under subsistence farming conditions in developing countries. Several chickpea germplasm accessions (ICC 506EB, ICC 10667, ICC 10619, ICC 4935, ICC 10243, ICCV 95992, and ICC 10817) with resistance to *H. armigera* have been identified, and varieties such as ICCV 7, ICCV 10, and ICCL 86103 with moderate levels of resistance have been released for cultivation.

Genetically Modified Crops

In recent years, genetic engineering has enabled the introgression of genes from distantly related organisms (i.e., *Bacillus thuringiensis*) into crops such as cotton, corn, pigeonpea, and chickpea. Chickpea cultivars ICCV 1 and ICCV 6 have been transformed with *cry IAc* gene. Insect feeding assays indicated that the expression level of the *cry IAc* gene was inhibitory to the development and feeding by *H. armigera*. Efforts are underway to develop transgenic legume crops for resistance to pod borer.

Agrotis ipsilon **(Hufnagel) (The black cutworm)**

SYSTEMATIC POSITION

Phylum: Arthropoda

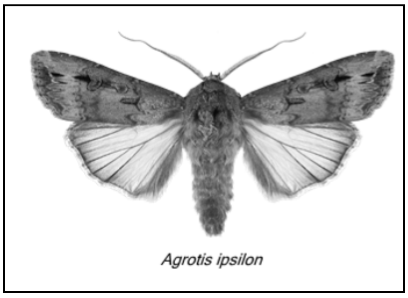
Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Agrotis*

Species: *ipsilon*



Distribution

The origin of *Agrotis ipsilon* (black cutworm) is uncertain, though it is now found in many regions of the world, being absent principally from some tropical regions and cold areas. *Agrotis ipsilon* is widely distributed world over in Europe, North Africa, Syria, Japan, China, Indonesia, Australia, New Zealand, Hawaii, Sri Lanka, Myanmar, and India. In Europe, it is found in almost all countries extending from Ireland and Portugal in the west to Bulgaria and Romania in the east, and from Norway and Finland in the north to Sicily in the south. It is widespread, and more damaging in the northern hemisphere than in the southern hemisphere. It annually reinvades temperate areas, overwintering in warmer or subtropical regions. Long distance dispersal of adults has long been suspected in Europe, China, and North America. These are the pests of several crops in different agro-ecosystems.

Main Host Plants

The black cutworm, *Agrotis ipsilon*, has a wide host range, feeding on nearly all vegetables and many important grains. Black cutworm has a wide host range. Nearly all vegetables can be consumed, and this species also feeds on alfalfa, clover, cotton, rice, sorghum, strawberry, sugarbeet, tobacco, and sometimes grains and grasses. In the mid western USA it is considered to be a serious corn pest. Among the weeds suitable for larval development are bluegrass, *Poa pratensis*; curled dock, *Rumex crispus*; *lambs quarters*, *Chenopodium album*; yellow rocket, *Barbarea vulgaris*; and redroot pigweed, *Amaranthus retroflexus*. The black cutworm prefers for weeds sometimes and crops will be attacked only after the weeds are consumed. Adults feed on nectar from flowers. Deciduous trees and shrub such as linden, wild plum, crabapple, and lilac are especially attractive to moths.

Insect Biology

Life Cycle

Egg

The egg is white in color initially, but turns brown with age. It measures 0.43 to 0.50 mm high and 0.51 to 0.58 mm wide and is nearly spherical in shape, with a slightly flattened base. The egg bears 35 to 40 ribs that radiate from the apex; the ribs are alternately long and short. The eggs normally are deposited in clusters on foliage. Females may deposit 1200 to 1900 eggs. Duration of the egg stage is three to six days.

Larva

There are five to nine instars, with a total of six to seven instars most common. Head capsule widths are about 0.26-0.35, 0.45-0.53, 0.61-0.72, 0.90-1.60, 2.1-2.8, 3.2-3.5, 3.6-4.3, and 3.7-4.1 mm for instars one through eight, respectively. Head capsule widths are very similar for instars one through four, but thereafter those individuals that display eight or nine instars show only small increments in width at each molt and eventually attain head capsule sizes no larger than those displaying only six or seven instars.

Larval body length is reported to be 3.5, 5.3-6.2, 7, 10, 20-30, 30-45, 50, and 50 mm for instars one through eight, respectively. Duration of the larval stage is normally 20 to 40 days. Mean duration of instars one through six was reported to be 6.0, 5.0, 4.6, 4.3, 5.6, 4.0 days, respectively, at 22°C. Larval development is strongly influenced by temperature, with the optimal temperature about 27°C. Humidity is less important, but instars one through five thrive best at higher humidity.

In appearance, the larva is rather uniformly colored on the dorsal and lateral surfaces, ranging from light gray or gray-brown to nearly black. On some individuals, the dorsal region is slightly lighter or brownish in color, but the larva lacks a distinct dorsal band. Ventrally, the larva tends to be lighter in color. Close examination of the larval epidermis reveals that this species bears numerous dark, coarse granules over most of its body. The head is brownish with numerous dark spots. Larvae usually remain on the plant until the fourth instar, when they become photo-negative and hide in the soil during the daylight hours. In these latter instars they also tend to sever plants at the soil surface, pulling the plant tissue below ground. Larvae tend to be cannibalistic.

Pupa

Pupation occurs below ground at a depth of 3 to 12 cm. The pupa is 17 to 22 mm long and 5 to 6 mm wide, and dark brown. Duration of the pupal stage is normally 12 to 20 days.

Adult

The adult cutworm is large in size, with a wingspan of 40 to 55 mm. The forewing, especially the proximal two-thirds, is uniformly dark brown. The distal area is marked with a lighter irregular band, and a small but distinct black dash extends distally from the bean-shaped wing spot. The hind wings are whitish to gray, and the veins marked with darker scales. The adult preoviposition period is about seven to 10 days. Moths select low-growing broad leaf plants preferentially for oviposition, but lacking these will deposit eggs on dead plant material. Soil is an unsuitable oviposition site.

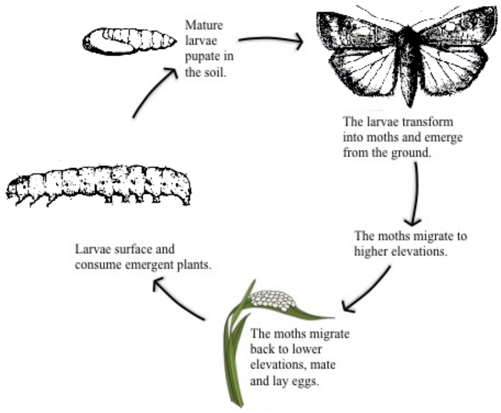


Figure : Life cycle of *Agrotis ipsilon*

Nature Of Damage

- The larvae feed on leaves, stems, and roots of many field crops. Approximately up to 10% plant damage has been recorded at 40 days after crop emergence. The older larvae cut the plant above the root crown. Most of the plant is not consumed after cutting, and larvae move to another plant leaving the earlier one to wither and dry. Some species feed on the upper leaves before moving to the soil surface. Heavy damage of cutworms occurs in areas that remain flooded during the rainy season. The caterpillars can migrate over short distances. The moths have a flight range of 1.5 km during a period of 4 hours overnight, facilitating dispersion and oviposition on different hosts. They can accordingly fly quite long distances.
- This species occurs normally in many crops and is one of the best-known cutworms. Black cutworm is not considered to be a climbing cutworm, most of the feeding occurring at soil level. However, larvae will feed above ground until about the fourth instar. Larvae can consume over 400 sq cm of foliage during their development, but over 80% occurs during the terminal instar, and about 10% in the instar immediately preceding the last. Thus, little foliage loss occurs during the early stages of development. Once the fourth instar is attained, larvae can do considerable damage by severing young plants, and a larva may cut several plants in a single night. Plants tend to outgrow their susceptibility to injury. Corn at the one-leaf stage is very susceptible to damage, but that by the 4 or 5-leaf stage plant yield was not reduced by larval feeding. Leaf feeding and cutting above the soil line are less damaging to corn than cutting at the soil surface. Subterranean damage is very injurious.

Control

Cultural and Mechanical.

- Black cutworm larvae feeds readily on weeds, and destruction of weeds can force larvae to feed exclusively on crop plants, causing severe crop damage. Thus, it is often advised that weeds not be tilled or treated with herbicide until larvae have matured. Timing is important, however, because prolonged competition between crop and weed plants can reduce crop yield. Presence of flowering weeds also can be beneficial by supporting prolonged survival of parasitoids.

- Black cutworm populations is generally high in wet or flooded areas of fields. Black cutworm has been known, at times, as "overflow worm," due to its tendency to be abundant and damaging in fields that have been flooded by overflowing rivers.

Trapping.

- Adult cutworms populations can be trapped with both black light and sex pheromone traps. Light traps are most effective in the summer and autumn, but the late season generations generally pose little threat to crops. Pheromone traps are more effective during the spring flight, when larvae present the greatest threat to young plants. Trap color affects moth capture rate, with white and yellow traps capturing more than green traps.

Chemical Control

- Persistent insecticides are commonly applied to plants and soil for black cutworm suppression, but surface rather than subsurface soil applications are desirable. Larvae readily accept insecticide-treated bran and other baits Application of systemic insecticides to seeds also provides some protection against larval injury. *Bacillus thuringiensis* is not usually recommended for cutworm control.

- As cutworms tend to be primarily nocturnal, insecticide application may be applied in the evening to maximize exposure to the cutworms and to minimize effects on beneficial insects. Commonly used insecticides are Pyrethroids, Pyrinex; Nufos; Organophosphates, Chlorpyrifos etc.

Biological Control

Natural Enemies

- Numerous natural enemies species of cutworms have a significant control on cutworm populations. Among the wasps known to attack this cutworm are *Apanteles marginiventris* (Cresson), *Microplitis feltiae* Muesebeck, *Microplitis kewleyi* Muesebeck, *Meteorus autographae* Muesebeck, *Meterorus leviventris* (Wesmael) (all Hymenoptera: Braconidae); *Campoletis argentifrons* (Cresson), *Campoletis flavicincta* (Ashmead) , *Hyposoter annulipes* (Cresson), and *Ophion flavidus Brulle* (all Hymenoptera: Ichneumonidae). Larvae parasitized by *Meteorus leviventris* (Wesmael) consume about 24% less foliage and cut about 36% fewer seedlings, so considerable benefit is derived from parasitism in addition to the eventual death of the host larva.

- Other parasitoids known from black cutworm include flies often associated with other ground-dwelling noctuids, including *Archytas cirphis* Curran, *Bonnetia comta* (Fallen), *Carcelia formosa* (Aldrich and Webber), *Chaetogaedia* monticola (Bigot), *Eucelatoria armigera* (Coquillett), *Euphorocera claripennis* (Macquart), *Gonia longipulvilli* Tothill, *G. sequax* Williston, *Lespesia archippivora* (Riley), *Madremyia saundersii* (Williston), *Sisyropa eudryae* (Townsend) and *Tachinomyia panaetius* (Walker) (all Diptera: Tachinidae).

- Predatory ground-dwelling insects such as ground beetles (Coleoptera: Carabidae) apparently consume numerous larvae.

- According to recent researches it was observed that 75 to 80% of cutworms can be killed by a granulosis virus, there is surprisingly little information on epidemiology and of natural pathogens. Rather, such pathogens as viruses, fungi, bacteria, and protozoa from other insects have been evaluated for black cutworm susceptibility; in most cases only relatively weak pathogens have been identified.

- An entomopathogenic nematode, *Hexamermis arvalis* (Nematoda: Mermithidae), is known to parasitize up to 60% of larvae. Entomopathogenic nematodes (Nematoda: Steinernematidae and Heterorhabditidae) will infect and kill black cutworm larvae, but their populations normally need to be supplemented to realize high levels of parasitism. Their effectiveness is related to soil moisture conditions.

Prodenia litura / Spodoptera litura (Oriental leaf worm moth)

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Prodenia (Spodoptera)*

Species: *litura*

Distribution

Spodoptera litura is one of the most important insect pests of agricultural crops in the Asian tropics. It is widely distributed throughout tropical and temperate Asia, Australasia and the Pacific Islands. It is found in the Indo-Australian tropics. It is also established on most Polynesian islands, where it occurs in a variety of island forms. *Spodoptera litura*, the Oriental leaf worm moth, is a noctuid moth which is also known as the cluster caterpillar, cotton leafworm, tobacco cutworm, Taro caterpillar, Tobacco budworm, Rice cutworm, and Cotton Cutworm and tropical armyworm.

Main Host Plants

It is a major pest of many crops. The host range of *S. litura* covers at least 120 species. The larvae feed on a wide range of plants. It has a very wide host range including: lettuce, cabbage, beetroot, peanuts, geranium, cotton, banana, fuchsias, acacia, African oil palm, amaranth, alfalfa, strawberry, sorghum, sugarcane, tomatoes, asparagus, apple, eggplant, beet, beans, broccoli, elephants ear, horsetail she oak, corn, flax, lantana, papaya, orange, mango, leek, among many others.

Insect Biology

Life Cycle

Eggs

S. litura eggs are laid in clusters of several hundreds, usually on the upper surface of the leaves. Females lay spherical, somewhat flattened eggs in masses of 200 to 300 eggs that are approximately 4-7 mm in diameter and cream to golden brown in color. Egg masses are usually covered with body hair scales and laid on the underside of the host plant leaf. Eggs usually hatch between three to four days.

Larva

The larva is hairless, variable in colour, young larval stages are light green, the later instars are dark green to brown on their backs, lighter underneath, sides of body with dark and light longitudinal bands; dorsal side with two dark semilunar spots laterally on each segment, except for the prothorax; spots on the first and eighth abdominal segments larger than others, interrupting the lateral lines on the first segment. Though the markings are variable, a bright-yellow stripe along the length of the dorsal surface is characteristic of *S. litura* larvae. Larval instars can also be distinguished on the basis of head capsule width, ranging from 2.7 to 25 mm. Body length ranges from 2.3 to 32 mm. Feeding is initially by skeletonizing, or leaving the outline of the leave veins on the plant. As growth continues, caterpillars eat entire leaves, and even flowers and fruits.

Pupa

The Caterpillar burrows into the soil several centimeters deep and then pupates without a cocoon. While pupating, it produces large amounts of fluid. The pupa is 15-20 mm long, red-brown; tip of abdomen with two small spines. The pupal stage lasts either a few weeks or several months depending upon climatic conditions of year.

Adult

Adult moths measure between 15-20 mm in length and have a wingspan of 30-38 mm. Forewings are gray to reddish-brown, with a complex pattern of creamy streaks and paler lines along the veins. Hind wings are grayish-white with grayish-brown margins. Males have a blue-grey band from the apex to the inner margin of each forewing.

Nature Of Damage

It is believed to have potentially high economic impact in terms of its direct pest damage and trade implications.

Control

- Pheromone traps can be used to detect the presence of armyworm adults. Regular monitoring of crops is recommended because adult moths frequently invade the crops from adjacent crops and weeds. Pheromones can also be used to disrupt mating and inhibit or eliminate reproduction.

Sweep-netting of larvae will establish the presence of larvae in agricultural crops and a sex attractant for trapping male could potentially be used to monitor male flights in legume crops.

Chemical Control

- In the recent years populations of many pests including *S. litura* have developed resistance to many commercially available pesticides. It has been observed that the *S. litura* is developing resistance against cypermethrin, fenvalerate and quinalphos, by 197-, 121-, 29- and 362-fold, respectively. The control of arthropod pests is therefore becoming increasingly difficult and it is vital that all biological alternatives to insecticides need to be given greater priority, both in research and application.
- New insecticides have been tested to deal with resistant strains of this moth and some promising results are coming forward. Neem oil microemulsion proved significantly superior than macroemulsion.
- New molecules such as chlorantraniliprole, spinosad and emamectin benzoate have shown promising results against *S. litura*
- Plant oils and insecticides mixtures (synthetic pyrethroids) gave a higher mortality rate on 8-day-old larvae of *S. litura* than the synthethic pyrethroids alone.

Biological Control

- Egg parasitoids - *Chelonus heliopae, T. remus, etc.*
- Larval parasitoids- Six parasitoid species, *Apanteles ruficrus*, *Cotesia marginiventris*, *Apanteles kazak*, *Campoletes chloridae*, *Hyposoter didymator* and *T. remus* etc.
- Predators- *Canthoconidia furcellata, Conocephalus* sp.etc.
- Pathogens - *Serratia marcescens, Bacillus thuringiensis,* green muscardine fungus *Nomuraea rileyi,* egg parasitoid, *Telenomus preditor*, entophytic fungi (*Khuskia oryzae* and *Cladosporium uredinicola*), nuclear polyhedrosis, *Splt*MNPV etc.

Integrated Pest Management

- Recently the use of several combinations of chemicals as an integrated approach is developed which is based on cultural and biocontrol with efficient monitoring using pheromones has been developed. The IPM technology that has been developed and implemented in irrigated groundnut where *S. Litura* is endemic has the following components:
- Clean cultivation to expose *Spodoptera* pupae to natural enemies and weather-related factors
- Sunflower, taro and castor like plants that can attract *Spodoptera* must to be sown as trap crops both around and within fields
- Pheromone traps to predict *Spodoptera* egg laying
- Mechanical collection of egg masses and larvae from trap plants on alternate days following the 'warning' from the pheromone traps
- Application of fungicide (chlorothalonil) at the appearance of the first leaf spot lesions, and again after 10 days
- An application of neem kernel extract during the early stages of crop growth if necessary
- *Pongamia glabra* oil treatment on tomato plants gave significant reductions on the populations of *S. Litura* while no adverse effects againsts it natural enemies
- Application of nuclear polyhedrosis virus at 500 larval equivalents per hectare in the evening if needed.

7.6 Oil Seed Crops

Oilseeds constitute a very important group of commercial crops in India. India has the largest area and production of oilseeds in the world. Major Indian oil seeds crops are groundnut, sesamum, rapeseed, mustard, linseed, soyabean, castor seed, cotton seed, sunflower, safflower and nigerseed. The oil extracted from oilseeds form an important item of our diet and are used as raw materials for manufacturing large number of items like paints, varnishes, hydrogenated oil, soaps, perfumery, lubricants, etc. Oil-cake which is the residue after the oil is extracted from the oilseeds, forms an important cattle-feed and manure.

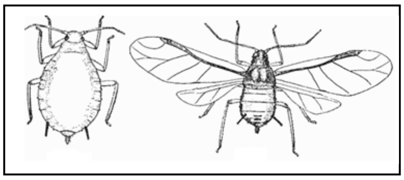
Recently it was noted that the production of oilseeds has always fallen short of our demand and there has always been a need to import oilseeds or their products for meeting the demand of our ever-growing population. With limited scope of bringing additional area under oilseeds, increase in oilseed production will have to come primarily from pest management, land saving to technologies highlighting a combination of high yield plant type, standard crop management practices and balanced crop nutrition.

Insects pests are the serious problem on oilseeds crops. These insects pests can damage crops by reducing their yielding and having a negative impact on their quality. There have been large scale regional variations in area, production and productivity changes in oilseeds. Only a few states like Haryana, Madhya Pradesh, Rajasthan and West Bengal increased their oilseed production both through area expansion and productivity improvement. States like Maharashtra, Tamil Nadu and Himachal Pradesh increased their oilseed output mainly through productivity improvement. In some states like Orissa, area productivity and production is not satisfactory.

Pests Of Oil Seeds

***Lipaphis erysimi* (Mustard Aphid/ Turnip Aphid)**

Systematic Position



Phylum:	Arthropoda
Class:	Insecta
Order:	Hemiptera
Suborder:	Sternorrhyncha
Superfamily:	Aphidoidea Latreille, 1802
Families:	Aphididae
Genus:	*Lipaphis*
Species:	*erysimi* Kaltenbach, 1843

There are over 400 species and varieties of aphids but around 250 species are serious pests for agriculture and forestry as well as an annoyance for gardeners. Aphids are known as plant lice, greenflies, blackflies, or whiteflies, (not jumping plant lice or true whiteflies). These are small sap-sucking insects and are among the most destructive insect pests on cultivated plants in tropical, subtropical to temperate regions. The damage they do to plants has made them enemies of farmers and gardeners the world over. From a zoological standpoint they are a highly successful group of organisms. Their success is due in part to the asexual parthenogenetic reproductive capability.

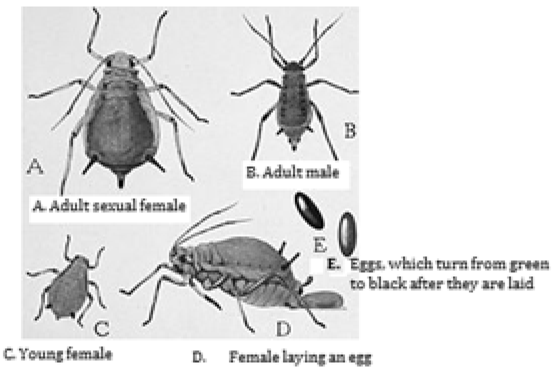
Lipaphis erysimi has an incomplete metamorphosis, there being no pupal stage but a series of moults in which the nymph gradually becomes a mature adult.

Distribution

Aphids are distributed worldwide, but are most common in tropics and sub tropics. In contrast to many taxa, aphid species diversity is much higher in the tropics than in the temperate zones. Aphid are with a complex lifecycle found widespread throughout cold, temperate, and warm climates across Europe, Asia, Africa and the American continents. They can migrate great distances, mainly through passive dispersal by riding on winds. Aphids have also been spread by human transportation of infested plant materials.

Main Host Plants

Lipaphis erysimi attacks on several crops like Crucifer (*Brassica*),Watercress, carrot, kohlrabi, lettuce, tomato ,Rape seed, broccoli, cabbage, Chinese broccoli, Chinese cabbage, daikon, mustard, cabbage, radish and zucchini.



Insect Biology

- Mustard aphids have soft bodies, generally pale greenish in colour. Aphids have antennae with as many as six segments. The mouth parts of *Lipaphis erysimi* are modified to form piercing and sucking tubes, the insects obtaining their food by sucking plant juices. Aphids feed themselves through sucking mouthparts called stylets, enclosed in a sheath called a rostrum, which is formed from modifications of the mandible and maxilla of the insect mouthparts. They have long, thin legs and two-jointed, two-clawed tarsi

- *L. erysimi* have a pair of cornicles or "siphunculi", abdominal tubes through which they exude droplets of a quick-hardening defensive fluid containing triacylglycerols, called *cornicle wax*. Other defensive compounds can also be produced by some types of aphids. They have two compound eyes, and an ocular tubercle behind and above each eye, made up of three lenses called as triommatidia.

- When host plant quality becomes poor or conditions become crowded, some aphid species produce winged offspring, "alates" that can disperse to other food sources. The mouthparts or eyes are smaller or missing in some species and forms.

Life Cycle

- Mustard aphid has two modes of reproduction: fertilization of females by males resulting in the production of eggs by sexual reproduction, and the birthing of live female nymphs by adult females without fertilization by males by process of parthenogenesis. Reproduction through parthenogenesis seems to be the norm as males are very rare and females are almost exclusively viviparous throughout the year and males have only been observed in the cooler months.
- Temperature is a crucial factor in the longevity of the turnip aphid. Within the viable temperature ranges, high temperatures shorten the life span and cooler temperatures increase longevity. Adults live for 15 - 18 days during the summer while lifespan is considerable longer at winter temperatures and varied from 31 - 61 days. The number of nymphs produced is also influenced by temperature. On different rape and mustard species, fecundity is influenced by the species and variety of the host plant.

Eggs

- Eggs are laid along the veins of leaves. In October the females lay eggs usually on the stems of trees or shrubs. The eggs are black, with thick shells and can withstand extremes of temperature. It is in the egg form only that aphids pass the winter.

Nymphs

- There are four nymph instars stages. The general appearance of each stage is similar except for increase in size during subsequent instars. The first, second, third and fourth nymphal stages last 1-2, 2, 2, and 3 days respectfully, giving the nymphal stage a length of 8-9 days total. Minor variations in these durations occur between winged and wingless forms when raised on cabbage, cauliflower, mustard and radish.

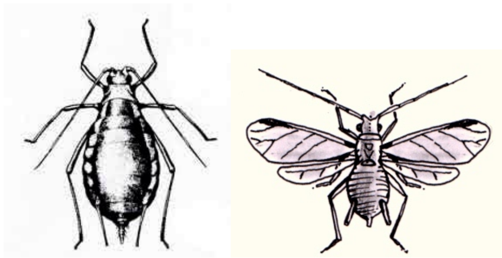


Figure – Aphids : (Apterae) Wingless and (Alate) Winged form

Adults

- Wingless, female, aphids called apterae are yellowish green, gray green or olive green with a white waxy bloom covering the body. The waxy coating is denser under humid conditions. The winged, female, adult aphids called alate have a dusky green abdomen with dark lateral stripes separating the body segments and dusky wing veins. Antennae are dark in color except at the base. The apterae females are about 3/50-1/10 inch long and the alate forms are about 3/50-1/12 inch long.
- After emerging from the last moult, 1-2 days pass before the adult females begin producing young. They continue producing young for 13-20 days followed by a 2-3 day post reproductive stage. The total duration of the adult stage is 26-37 days. Wingless females produce 70-87 young in their lifetime, while winged females produce 31-40 young.
- Male aphids are olive-green to brown in color. They are considerably smaller than the females and measure approximately 3/50 inch in length.

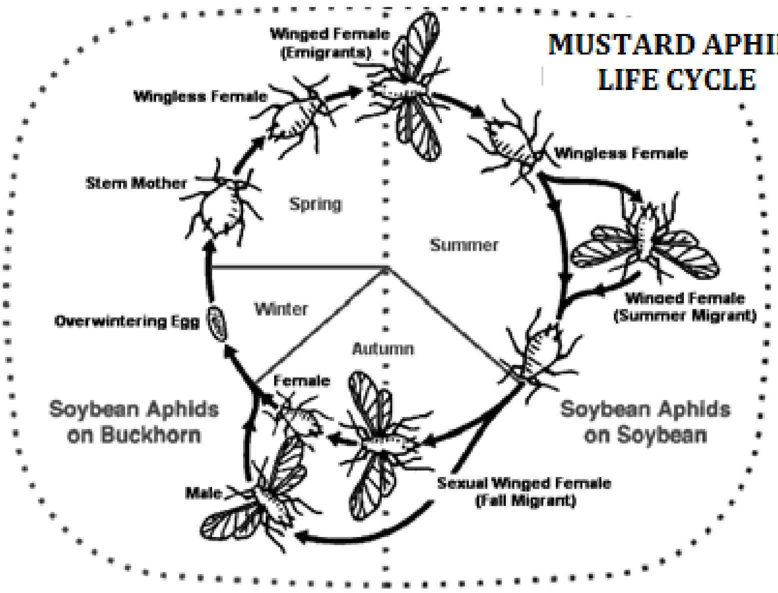


Figure – Generalized Life cycle of Mustard Aphid

Nature of Damage

- Mustard aphid lives on the undersides of leaves, young shoots, inflorescences, growing points and rhizomes, causing rolling, chlorosis, yellowing and patches on young leaves, shortening of the internodes of young shoots, distortion, lesions on growing points and inflorescences, and dwarfing of whole plants. Often *L. erysimi* prevents Chinese cabbages and wild cabbages from hearting up or causes gall formation; oil-seed crops, vegetables and Chinese herbal medicine plants cannot normally head, bloom or bear seeds.
- The *L. erysimi* can cause economic damage to plant crops as a result of its direct feeding activity. In high enough densities it can remove plant nutrients which can potentially cause a reduction in the number of heads, the number of grains per head, and a reduced seed weight. It may cause yellowing to upper leaves and ears, symptoms which are common to many aphid species and plant pathogens. Indirect damage can be caused by excretion of honeydew, and as a vector for viruses. It is found on many widely cropped species throughout the world.
- *L. erysimi* is a major pest of *brassica* crops in areas with sub-tropic and tropic climates. Aphids feed by sucking sap from their host-plants. Large colonies form on the under-sides of leaves, leading to leaf curling, shrivelling and yellowing. In severe infestations, both sides of the leaf

are infested, along with inflorescences. Large aphid populations can affect leaf size and yield.

- *L. erysimi* is a serious pest of mustard in India. Infestations of L. erysimi on Indian mustard (*Brassica juncea*) were responsible for reductions in plant height, number of branches per plant, siliqua per plant, grains per siliqua, seed yield, oil content, and oil yield. The aphid damages the crop from the seedling stage through to maturity, with the highest populations occurring during the flowering and podding stages. On rape, *L. erysimi* caused direct injury to leaves and stems, and reduced yield by between 2 and 39%
- The development of *L. erysimi* on various plant parts and growth stages of *toria* was studied in the laboratory. On the basis of duration of the various stages of the pest, pest fecundity and number of individuals reaching the adult stage, the pod was the most favourable part for the development of L. erysimi, followed by the stalk and tender leaves. Hard leaves were the least favourable part.
- Like other soft bodied insects such as leafhoppers, mealybugs and scales, aphids produce honeydew. This sweet and watery excrement is fed on by bees, wasps, ants and other insects. The honeydew serves as a medium on which a sooty fungus, called sooty mold, grows. Honeydew gives cabbage plants a dirty appearance that reduces their market value.
- Aphids vector many plant diseases that cause greater losses than caused by direct feeding injury. This is often the greatest impact of an aphid infestation. The turnip aphid is a vector of about 10 non-persistent plant viruses, including cabbage black ring spot and mosaic diseases of cauliflower, radish and turnip

Control

Non-Chemical Control

- In India, the turnip aphid is preyed upon by three species of lady-bird beetles and their grubs and parsatized by two wasp parasites (a *Chalcid* and an *Ichneumonid*) . Natural enemies include predatory ladybirds, hoverfly larvae, parasitic wasps, aphid midge larvae, crab spiders, lacewings and entomopathogenic fungi .

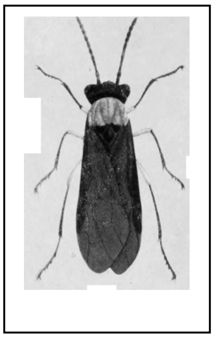
- There are many plant extracts and plant products that are eco-friendly and control aphids as effectively as chemical insecticides. Use of neem products and lantana products to protect plants against aphids. Integrated pest management of various species of aphids can be achieved using biological insecticides based on fungi such as *Lecanicillium lecanii* or *Beauveria bassiana* or *Paecilomyces fumosoroseus*. Synthesized neuropeptide analogues are another form of biological control Neuropeptides are chemical signals that regulate and control body functions such as digestion, respiration and water intake.

Chemical Control

- There are various chemical insecticides that can be used to control mustard aphids. The chemical treatments with methamidophos and quinalphos offered the best protection against the turnip aphid on cabbage. It was also found that endosulfan, ethiofencarb and pirimicarb are also significantly effective against this pest. However, their tests were inconclusive in regard to the efficacy of synthetic pyrethroids, fenvalerate and permethrin.

***Athalia lugens proxima* (The Mustard Sawfly)**

Systematic Position



Phylum:	Arthropoda
Class:	Insecta
Order:	Hymenoptera
Families:	Tenthredinidae
Genus:	*Athalia*
Species:	*lugens proxima* (Klug)

Distribution

The mustard sawfly is widely distributed in Indonesia, Formosa, Burma, Myanmar and the Indian Subcontinent. The taxonomy of sawflies has been studied in the Asian region. *A. proxima* occur only sporadically on vegetable crops and do not cause economic losses.

Main Host Plants

This is winter season pest which feeds on various cruciferous plants like mustard, toria (*Brassica compestris*), rapeseed, cabbage, cauliflower, knol-khol, turnip, radish, etc.

Insect Biology

Life Cycle

The mustard sawfly breeds from October to March and the larvae rest in their pupal cocoons in the ground during summer. The adults emerge from these cocoons early in October. They live for 2-8 days and lay 30-35 eggs singly, in slits made with saw-like ovipositors along the underside of the leaf margins. The eggs hatch in 4-8 days and the larvae feed exposed in groups of 3-6 on the leaves during morning and evening. The larva is dark green and has eight pairs of abdominal prolegs. The full grown larva measures 16-18 mm in length. There are five black stripes on the back, and the body has a wrinkled appearance. They remain hidden during the day-time and when disturbed, fall to the ground and pretend to be dead. They pass through seven stages and are full-grown in 16-35 days. The full-fed larvae descend the plant and enter the soil to a depth of 25-30 mm. There, they pupate in water-proof oval cocoons made of silk and emerge as adults in 11-31 days. Thus, the life-cycle is completed in 31-74 days. The pest completes 2-3 generations from October to March. The adults are small orange yellow insects with black markings on the body and have smoky wings with black veins.

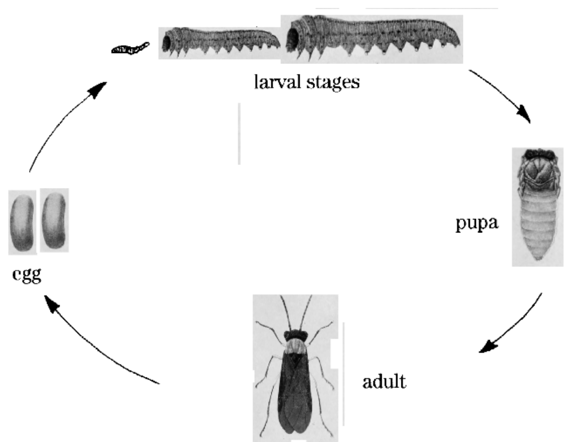


Figure –Life cycle of mustard saw fly

Nature of Damage

The larvae, alone, are destructive. The major damage is done by them . They bite holes into leaves, preferring the young growth, and skeletonise the leaves completely. Sometimes, even the epidermis of the shoot is eaten up. Larval feeding cause the edges of older leaves to become frayed and with holes. The Larvae are generally crepuscular .

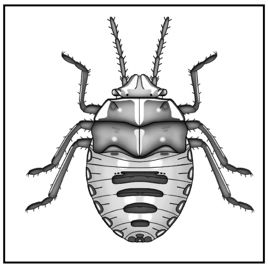
A. proxima in large numbers causes serious damage to the crop. It has a great potential to defoliate the crop at seedling stage. Adults inflict damage by act of laying eggs with the help of their saw like ovipositor.

Control

- Hand picking of larvae and their destruction.
- First irrigation 3-4 weeks after sowing as it reduces the bug population significantly because flooded condition by irrigation results in drowning of the larvae.
- Use of neem is also effective.
- Bt formulations @ 0.05- 0.2 per cent exhibits excellent control
- Application of quinalphos (0.025%) or malathion (0.05%) or dichlorvos (0.05%) or 625 ml of endosulfan 35 EC once in October and again in March-April is effective in controlling this pest.
- Conserve larval parasitoid *Perilissus cingulator* Morby (Ichneumonidae) and the bacterium, *Serratia marcescens* Bizio (Enterobacteriaceae) parasitizes the larvae.

Bagrada cruciferarum **Kirkaldy (The painted Bug)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Hemiptera

Families: Pentatomidae

Genus: *Bagrada*

Species: *cruciferarum* Kirkaldy

Distribution

The painted bug is a serious pest of cruciferous crops and is widely distributed in Pakistan, Afghanistan, Burma, Sri Lanka, India, Iraq, Arabia, South East Asia and East Africa.

Main Host Plants

The painted bugs are important pests of cruciferous crops at flowering and podding stage. Besides cruciferous crops, it has also been observed feeding on Maize, Bajra, Black gram, *Vigna mungo*, rice, sugarcane, indigo and coffee etc.

Insect Biology

Life Cycle

The *Bagrada cruciferarum* shows their peak activity from March to December and during this period all the stages can be seen. It passes the winter months of January and February in the adult stage under heaps of dried oilseed plants lying in the fields. These bugs lay oval, pale-yellow eggs singly or in groups of 3-8 on leaves, stalks, pods and sometimes on the soil. Eggs may be laid during day or night.

A female bug may lay 37-102 eggs in its life-span of 3-4 weeks. The eggs hatch in 3-5 days during summer and in 20 days during December. The nymphs develop fully in five stages. The full-grown nymphs are about 4 mm long and 2.66 mm broad. They have their dorsum with a number of brown makings. Nymphs transform themselves into adults in 16-22 days during the summer and in 25-34 days during the winter. The adult bugs are 3.71 mm long and 3.33 mm broad. They are sub-ovate, black and have a number of orange or brownish spots. Mating is started immediately after final nymphal moult. The incidence is negatively correlated with RH and positively correlated with temperature. The entire life-cycle is completed in 19-54 days and it passes through 9 generations in a year.

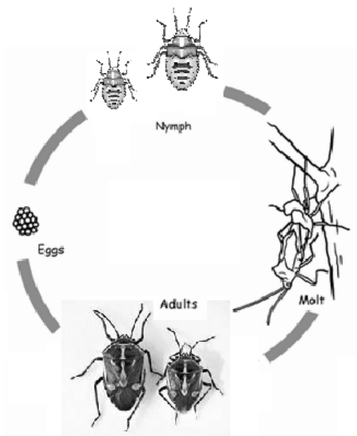


Figure –Life cycle of *Bagrada cruciferarum*

Nature of Damage

Both nymphs as well as adults stages are harmful. Nymphs and adults suck cell-sap from the leaves and developing pods, which gradually wilt and dry up. The nymphs and adult bugs also excrete a sort of resinous material which spoils the pods. On leaves palish or whitish markings appear and later on these leaves turn brown. In case of severe infestation, the seed formation is reduced.

Control

Cultural Control

- Removal of weed hosts in and near planting areas. *Bagrada* bug adults, eggs, and nymphs in the soil or container media can be controlled by steam or chemical treatment before planting. Removal of plant residue after harvest can reduce carryover between crops.

- In gardens where the *Bagrada* bug is present in very high densities, it may be advisable to remove very attractive host plants Sweet alyssum can attract bugs into the garden and also serve as a source of infestation for other plants in the garden or landscape.

Mechanical Control

- Hand picking of the bugs from plants is only feasible if pest populations are very low. When infestations are heavy, it may be possible to vacuum the bugs with a portable vacuum cleaner. It is often easier to tap the plant onto a sheet and collect or vacuum the bugs rather than removing them individually.

- Pyramid traps baited with crushed sweet alyssum, inside polypropylene bags, can also be used to catch and destroy bugs, particularly when numbers are high. These traps are available commercially as stink bug traps.

Biological Control

- Research is in process to evaluate the efficacy of entomopathogenic fungi against the bagrada bug. *Beauveria bassiana*, *Metarhizium anisopliae*, and *Paecilomyces fumosoroseus* are examples of entomopathogenic fungi that attack different types of insects, and are being evaluated for use against the bagrada bug.

- General natural enemies or predators including spiders may attack bagrada bugs. Parasitoids that attack the eggs of bagrada bug include flies (Families: Sarcophagidae and Tachinidae) and wasps (Family: Scelionidae).

Chemical Control

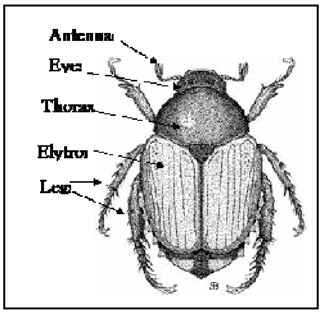
- In case of *Bagrada* bugs contact foliar insecticides applications are the most effective during the afternoon and early evening during the height of insect activity on plants Field trials in India demonstrated that sowing imidacloprid-treated seed provided higher productivity and reduced plant damage. Further bio-efficacy evaluations in India gave positive results using pyrethroids, pyrethrins, neonicotinoids, and organophosphate insecticides to control bagrada bugs and increase yields

- If insecticides are used, check the pesticide label to make sure the product is registered for use on home gardens and landscape plants.

- Pyrethrum may suppress adults while azadirachtin and insecticidal soaps may reduce populations of nymphs.

Holotrichia (Lachnosterna) Consanguinea **(White Grub)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Scarabaeidae

Subfamily: Melolonthinae

Genus: *Holotrichia (Lachnosterna)*

Species: *consanguinea*

Distribution

Holotrichia consanguinea is the most serious scarab pest in India, well known as white-grubs for their white larvae that are found under the soil where they feed on the roots of plants.. It finds loose, sandy well drained soil to be quite suitable for its survival and multiplication. It is a dominant whitegrub species in the states of Rajasthan, Gujarat, Haryana, Punjab, U.P. and Bihar. It feeds on all kharif crops but the damage is more evident on plants having tap roots and so in many parts of the country, it is the main constraint in groundnut cultivation.

The beetles of *Holotrichia consanguinea* emerge from the soil during dusk after good pre monsoon or monsoon rain in mid May or later, Any rain received prior to mid-May does not initiate emergence of beetles as they are not sexually mature. If there is good premonsoon rain, two peaks of beetle emergence are observed, Once active, the beetles follow the daily rhythm of emergence, congregation on host trees at dusk, and return to soil, at dawn. Particularly well known species include *Holotrichia serrata* which is a serious problem in sugarcane cultivation and *Holotrichia consanguinea* which is a problem in groundnut cultivation

Main Host Plants

The beetles are polyphagous in nature, they feed on the foliage of a wide variety of host trees and bushes found in the close vicinity. *Jujube* (ber), *Prosopis cineraria* (khejri) neem, Cluster Fig (gular), jambolana (Jamun) and drumstick (sainjana). In some situations, large number of beetles settles on a non-host tree, only for mating and just after, shift for feeding to nearby preferred hosts. The host preference depends on the combination of hosts available in a particular locality.

Insect Biology

Life Cycle

After emergence, *Holotrichia consanguinea* usually do not fly long distances in the evening but try to avail the short twilight hour for mating and selecting a suitable host as they are unable to see clearly in dark. First female beetle comes out of soil and settle down on a host. After this it secretes a pheromone which attracts the male for mating. If a female fails to mate in first 10 to 15 minutes of setting on the host tree, she tries mating next evening. The process of congregation of beetles on host continues every evening for a period of about three weeks to ensure mating of all females. After mating females return to soil in early morning and start egg laying within 2 to 3 days of mating. The female prefer light sandy soil for egg-laying. The longevity of the emerged beetles varies from 35 to 49 days, during the period daily host visits are made for feeding.

20 eggs are laid by female beetles in instalments, starting from third day after mating. The eggs are laid inside the soil at the depth of 6 to 10 cm. Freshly laid eggs are white, elliptic, about 3.2 mm in length and 1-2 mm in width. Before

hatching the eggs become brownish black and globular, and measure about 3.27 mm in length and 2.73 mm in width. The incubation period under laboratory conditions ranges from 7 to 13 days. The newly hatched grubs are creamy white in colour and may feed on organic matter for some time till they come in contact with living roots. On an average, the first instar grub measures 15.1 mm in length; while, the head length and width are 4 mm and 3 mm, respectively. The average duration of first instar grub is 16 days. The average duration of second instar grub is 32 days. The average duration of third instar is 49.5 days. Total grub duration ranges from 82 to 113 days. For feeding, the grub makes chamber by compressing the surrounding soil particles and then eats the rootlets exposed into the chamber; thereafter it moves vertically, a little, to eat more of the same root. After this, the grub moves horizontally making chambers and feeding on the exposed roots. The grubs continue active feeding from July to mid - October.

Pupation starts by the beginning of November. Before pupation the grubs enter deep into the soil to the depth of 40 to 70 cm or more in search of suitable moisture Zone. The average pupal length and width is 27.3 mm and 14.2 mm, respectively. A short prepupal period is spent before entering into pupation, during which, the grub prepares and earthen chamber for pupation. The average pupal period is 14.2 days.

The freshly emerged adult is whitish in appearance but with the lapse of time it becomes dull brown with light brown abdomen and dark brown legs. The average beetle length and width is 21.3 mm and 11.8 mm, respectively. The beetles remain in the soil in inactive state upto middle of May at a depth of about one meter. The average duration of one life cycle is 122 days and there is only one generation in a year.

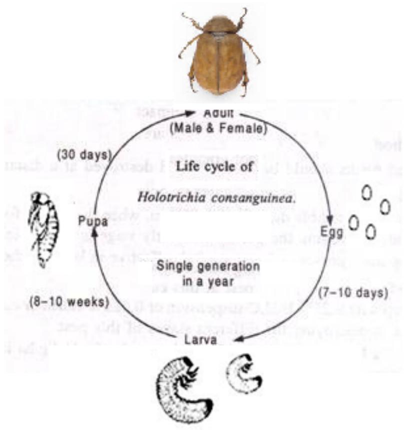


Figure –Life cycle of *Holotrichia consanguinea*

Nature of Damage

The white grubs cuts roots of standing crops and as a result several plants die. It bores
and damages groundnut pods. White grubs are pests of national importance in India and are a serious constraint to production of kharif crops. It causes 100% losses in sorghum, sugarcane, paddy, groundnut, chillies, tobacco, bajra etc. The damage to groundnut ranges from 20 to 100%; in groundnut the presence of one grub per m2 may cause mortality of 80 to 100%.

Control

Prevention and control

Entomologists all over the world have made attempts to control white grubs by adopting mechanical, biological, cultural and chemical control methods. Some of them are as follows-

Cultural control

By means of different cultural practices, such as ploughing, harrowing, hoeing, flooding and fallowing of fields, trap cropping and crop rotation, flooding for a long period to obtain some control on white grub. Crop rotation with sugarcane-paddy-sugarcane in endemic areas as a means of control. Fallowing of land for 2 years consecutively helped in reducing the pest. Raising of resistant crops such as sunflower also checks the build-up of grub populations. Sowing of trap crops such as sorghum, maize, onion etc. to reduce white grub infestation. The soil should be ploughed twice during May and June at or before sowing to expose white grubs in the soil to harsh weather.

Mechanical control

Hand collection of beetles after emergence is one of the cheapest, simplest and best control method to control the white grub population. Beetles from host trees can be collected by hand picking or the host trees, which can bee jerked with the help of a hooked bamboo pole. The beetles that fall on the ground are picked up in the petromax light and put into a kerosene-water mixture to be killed. The time of collection should be between 8.30 and 11.20 PM in night. Mechanical collection should be done for 4-7 days, depending on the beetle population after each day's emergence. Uprooting and destruction of infected plant is also one of the mechanical control method for white grubs.

Chemical control

White grubs are subterranean in habit and therefore it is very difficult to control. Different chemical substances are used for their control. Soil application of insecticides such as quinalphos dust before sowing kharif crops gave satisfactory control of the pest. Soil drenching with chlorpyriphos effective for control of the pest. Spraying of carbaryl and fenitrothion on host trees for the control of beetles. Heptachlor emulsion can be applied at the base of young shoots also.

Biological control

A number of biocontrol agents, viz. parasites, predators and the micro-organisms of this pest, have been reported by various workers None of them, however, could bring down grub populations to non-pest levels in a short time.

***Achaea janata* Linnaeus (The Castor Semilooper)**

Systematic Position

Phylum: Arthropoda

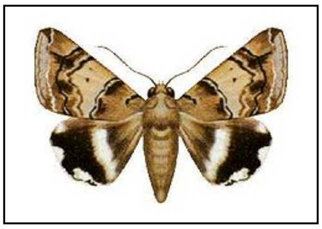
Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Achaea*

Species: *janata* Linnaeus



Distribution

This is a serious pest of castor which is distributed in the whole of Indian subcontinent and Pakistan and has also been reported from Sri Lanka, Thailand, Malaysia, Philippines and Indonesia. The caterpillars are termed 'semi-loopers' due to their specific mode of locomotion. Due to its uniqueness, the pest has been often confused with others and given a variety of names, viz. *Ophius melicerta, Noctria tigrina, Achaea catella, Catocala traversa*.

Main Host Plants

A. janata is a pest of *Arachis hypogaea* (groundnut), orchorus (jutes), *Dalbergia sissoo, Glycine max* (soyabean), *Lagenaria siceraria* (bottle gourd), *Punica granatum* (pomegranate), *Ricinus communis* (castor bean), *Rosa chinensis* (China rose), *Solanum lycopersicum* (tomato), *Tamarindus indica* (Indian tamarind), *Theobroma cacao* (cocoa), *Vigna mungo* (black gram), *Ziziphus mauritiana* (jujube), *Euphorbia, Tridax, Cardiospermum, Ficus,* mango etc.

Insect Biology

Life Cycle

Detailed studies on the morphology of *A. janata* have been carried out by John and Muraleedharan (1989) and John (1991).

Eggs

The eggs of castor semilooper are small, spherical of 0.85-0.95 mm diameter, with a greenish colour, convex on the dorsal side with ridges and furrows on the surface radiating from a circular depression at the apex and concave on the ventral side. They are deposited in a scattered manner, singly and in clusters, on the undersurface of small tender leaves.

Larva

First-instar larva

The first-instar larvae are thread-like, having a feeble brown colour with a transparent integument, through which the green contents of the alimentary canal are visible. Distinct black dots are seen on the transparent body in a longitudinal row on either side of the midline and laterally. Brown, bristle-like hairs are seen scattered on the body. The larva is 0.48-0.67 cm long, 0.49-0.67 mm wide. The first two pairs of prolegs are undeveloped, hence they have the gait of a looping caterpillar. The third and fourth pairs of prolegs are well developed. On the XIth segment, two black spots, which later became tubercles, are seen, and behind it lie two other black dots which gave rise to the black patches in the subsequent instars.

Second-instar larva

The body becomes spongy and the larvae slowly change in colour to grey with a whitish bloom. Black dots are seen on the mid-dorsal line as well as laterally on each segment from this instar onwards. The second pair of prolegs now develop but the first pair still remains as a stump. From this instar onwards, the head capsule appears in a black and white design. The second-instar larva is 1-1.2 cm long, 1.16-1.34 mm wide. Two black small tubercles and two black patches are seen on the anal end.

Third-instar larva

The larvae grow, become evidently longer and greyish-white. The second pair of prolegs are small and the first still remains as a stump, hence they retain the semiloop gait. At the anal end, the two black tubercles and black patches become larger. The larvae are 1.7-2.1 cm long, 1.95-2.07 mm wide.

Fourth-instar larva

These larvae are larger than the third-instar larvae of length of 2.8-3.6 cm, 3.05-3.66 mm width. They have a black streak running longitudinally along the mid-dorsal line of the body. Two conspicuous, white spots become evident on the tergum of the Vth segment of the body, lying on the longitudinal white streak on either side. The first pair of prolegs remain as a stump and the second pair are smaller. Prolegs are seen on the VIth segment, but are very small, so the mid-ventral sternum with its white coloration appears like an inverted 'V' form. The two larger, tubercle-like projections on the XIth segment are black, behind these are two black patches. On each segment, black spots are seen on the mid-black streak.

Fifth-instar larva

The fifth-instar larvae are fairly large: 5.5-6.1 cm long, 4.94-5.06 mm wide. The body has a spectacular, beautiful, velvety, appearance with a mid-dorsal black streak running longitudinally on a black background with noticeable anal tubercles. On either side of the mid-black streak, two narrow, yellow and orange streaks run longitudinally. On the tergum of the Vth segment, two white spots on the midline with an orange base can be recognized flanked by two white patches on the longitudinal orange streak. Just above the patches on the VIth segment are two white dots. On the tergum of the VIth segment on the midline are two small orange patches. At the intersegmental area of the sternum, short, vertical, white bars can be distinguished running longitudinally to the end of the body. On the first and IV-XIth segments, laterally placed oval-shaped, light-orange stigmata can be seen. On the dorsal side of the XIth segment, there are two prominent, red, tubular projections, each with a hair on them. The thoracic legs are chitinous and horny.

Prepupa

The feeding phase of the fifth-instar larva is followed by a non-feeding prepupal stage. The larva shrinks, turns black and the body wall becomes thicker (3.8-4.8 cm long, 5-6.5 mm wide). The body gradually forms a comma-shape and enters the prepupal stage. They remain in the comma-shape for 1 day.

Pupa

The pupa is whitish-green. The body is very soft, gradually tanned to a dark brown, with a hard cuticle coated with white dust. Pupae are spindle-shaped, with a tapering posterior end armed with cremastral setae of four different sizes, in pairs numbering eight in both the sexes, which are twisted firmly into the strands of silk. The pupa is 2-2.5 cm long, 5-7 mm wide and weighs 706 mg. During the entire pupal lifespan (8-10 days), the weight decreases gradually, with a sudden decrease at adult emergence.

Adult

Wet imago stage emerges out of the pupa. The soft, crumpled wings become dry after a period of rest, and they start fluttering. Adult moths are light brown, with characteristic black and white patterns in the posterior region of the hind wings and dry brown scales all over the body. The length of the forewing is 1.65-2.75 cm and that of the hindwing is 1.23-2.25 cm. The moth is 1.8-2.3 cm long, 5-6.5 mm wide. An increase in weight is seen on the second day and thereafter declines as mating and egg laying starts.

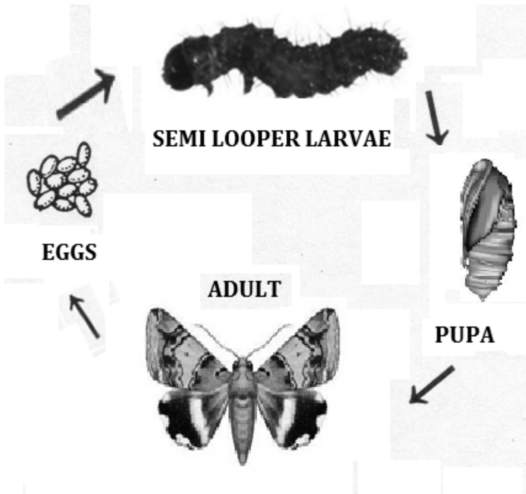


Figure –Life cycle of *Achaea janata*

Nature of Damage

The caterpillars feed voraciously on castor leaves, starting from the edges inwards and leaving behind only the midribs and the stalks. Damage is maximum in August-September, with the excessive loss of foliage, the seed yield is reduced considerably. Although the semilooper feeds on a variety of plants, it seems to prefer castor.

Larvae defoliate plants quickly by feeding gregariously and voraciously. Midribs and veins are left intact and other parts of the leaves eaten up. Being larger in size, their capacity to cause damage is enormous. Young plants cannot sustain damage and die.

CONTROL

- Sudden outbreaks of *A. janata* on castor (*Ricinus comunis*) or other hosts often make it difficult to apply natural control methods. However, hand picking of larvae is effective to a certain extent. The construction of open spaces around and across fields attracts birds, which attack the larvae when they attempt to cross the open spaces.
- Chemical control can be achieved by spraying endrin 0.02%, parathion 0.025% or by spraying 0.02% of diazinon, toxaphen, carbaryl, endosulfan and methyl parathion.
- Biological control involves conservation of the following parasitoids: Egg parasites: *Trichogramma evanescens.* Larval parasite: *Apanteles sundanus, A. ruidus, Microplitis maculipennis, M. ensirus, M. similes, Euplectus leucostomus, Paniscus ocellaris, Zamesochorus orientalis, Tetrastichus ophiusae, Rogas percurrens* and *Enicospilus* sp.

Euproctis lunata **Walker (Castor hairy caterpillar)**

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Lymantriidae

Genus: *Euproctis*

Species: ***lunata*** **Walker, 1855**

Distribution

Euproctis lunata is widely distributed in different regions all over India, Pakistan, Australia, Burma, Sri Lanka, China, Indonesia, the Malay Peninsula and Malaysia. A lymantriid, *Euproctis* is a serious pest in India and is occasionally sporadic . Among several species of *Euproctis*, the most injurious is *E. lunata* Walk. are of considerable economic importance in the Punjab, where the castor-bean is an important crop.

Main Host Plants

Host range: *Lagerstomia indica, Punica granatum, Hibiscus rosasinensis*, Castor, linseed, groundnut, pigeonpea, grapevine, cotton, mango, coffee, pear and rose.

Insect Biology

Life Cycle

The adult *Euproctis lunata* moth is yellowish with pale transverse lines on fore wings. It lays egg in groups on lower surface of the leaves. The female moth lays its eggs in clusters on the under-sides of leaves and covers them with pale brown hairs. The egg period is 4-10 days. The newly hatched larvae feed gregariously and after a few days feed on the leaves independently. The caterpillar possesses red head with body covered with long dense, reddish brown hair arising on warts, anteriorly and posteriorly black broad bands enclosed a reddish area in the middle and a long pre- anal tuft. There are six larval instars. The larval periods last for 13-29 days. It pupates in a silken cocoon in leaf folds for 9-25 days. The larva over-winters during winter season. The pupal period is about 7 to 20 days. The pest is active throughout the year and several generations have been observed. The peak period of activity is August-September.

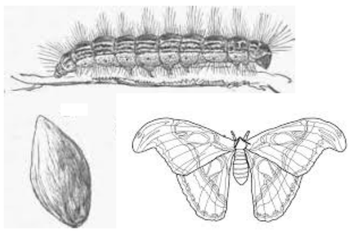


Figure – Life cycle stages of *Euproctis lunata*

Nature Of Damage

Young *Euproctis lunata* larvae eat the leaf margins of the host plants. After its full growth the larvae starts feeding on the entire leaf lamina. The caterpillars of this pest cause serious damage to the crop by completely defoliating the leaves during the kharif season. Defoliation of leaves is the main symptom and in heavy infestation even it consume the small twigs and green cell layers of the stems. The pest is active throughout the year but its activity is reduced in winter. Major damage is caused by migrating caterpillars. Usually there is more destruction caused to young crop. When the soft foliage has been exhausted, they even turn to the bark to satisfy their insatiate appetite.

Control

Cultural control

- By use of light traps of approximately 250 watts mercury bulbs on community basis with the first monsoon rains to attract the moths and kill them.
- By sowing cucumber along with castor and by placing the twigs of *Ipomoea*, *Jatropha* and *Calotropis* to attract the migrating caterpillars and kill them mechanically.

Biological control

- One scelionid egg parasite, *Aholcus euproctiscidis* and two larval parasites, *Apanteles enproctisiphagus, Helicospilus merdarius, H. horsefieldi, Disophrys* sp. and *Glyptomorpha deesae* have been recorded. Heavy infestation is controlled by *Apanteles* and this parasite population should be conserved in the field.

Chemical control

- Dust the infested crop with parathion 2 D @ 20-25 kg per ha or malathion 5 D 25-30 kg/ha (or) carbaryl 10 D @ 20 kg/ha.
- Trenching around the field 2ml and dusting with endosulphan 4% or Methylparathian 2% or Quinolphos 1.5% to control migrating larvae.
- Spray monocrotophos 1.6ml or fenvalerate (0.02%), Quinalphos 2ml, or Methyl Parathion (0.02%) or Dimethoate 2ml

7.7 Pests of Cotton (Fibre Crops)

Cotton Crop

Cotton is one of the principle crop in India. It plays a vital role in the Indian Economy by providing employment to substantial number of countrymen. Cotton provides direct employment to 60 Lakh farmers of the country and provides indirect employment in cotton related industry to around 4-5 Crore People. India has the distinction of having the largest area under cotton cultivation at around 9 million hectares and constitutes around 25% of the total area under Cotton Cultivation in the world. The main cotton producing states of India are Punjab, Haryana, Rajasthan, Gujarat, Maharastra, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu and Orissa etc.

Cotton is one of the largest foreign exchange earner commodities for India. Apart from providing one of the basic necessities of life, the textile industry also plays a pivotal role through its contribution to industrial output, employment generation and the export earnings of the country. It contributes about 14% to the industrial production, 4% to the GDP and 14.42% to the country's export earnings.

7.8 Importance of Cotton Crop

The cotton plant is unique among major agricultural crops. It is a woody perennial that has been adapted and bred to react as an annual. Cotton production requires some soil management practices typically by means of physical adjustments, fertilization, and crop rotation with a culture of leguminous plant and one of cereal. Seedling emergence can occur between one week and a month after planting. During this phase (germination, emergence and seedling growth), the plant needs warm temperature and much moisture. Flowering generally starts one month and a half to two months after the crop is planted. Blooming will continue regularly for several weeks, even months. After flowering, the inner part of the bloom gradually develops into a fruit called as cotton boll. Cotton bolls keep growing until full size of approximately 2 to 3 cm width. It will take about two months between the blooming of the flower and the first opening of the bolls. Cotton bolls burst open upon maturity, revealing soft masses of fibres which is commercially used as cotton.

7.9 Common Cotton Pests

Cotton pests are the principal cause of yield losses of about 15% of world annual production. More than 1300 different species of insect pests attack the crop. Among the most common and endogenous pest species found in cotton fields are: Cutworms, Thrips, Plant Bugs, Cotton Fleahoppers, Clouded Plant Bugs, Cotton Aphids, Cabbage Loopers, Armyworms, Whiteflies, Boll Weevils, Bollworms, Tobacco Budworms

Earias insulana. **Boisduval 1833 (Egyptian stemborer**, **Egyptian bollworm**, **spiny bollworm** or **Spotted Boll-worms)**

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Arctiidae

Genus: *Earias*

***Species**:* ***insulana* Boisduval 1833**

Distribution

Earias insulana boll-worms are the serious pests of cotton which are widely distributed in North Africa, India, Pakistan and other countries like Algeria, Burundi, Congo, Egypt, Eritrea, Ethiopia, Gambia, Kenya, Libya, Madagascar, Malawi, Mauritius, Morocco, Namibia, Nigeria, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe etc.

Main Host Plants

Earias insulana causes heavy damage mainly to *Gossypium* (cotton), okra (*Abelmoschus esculentus* L.) and *Hibiscus* (rosemallows) but also damages other crops like *Abutilon* (Indian mallow), *Oryza sativa* (rice), *Saccharum officinarum* (sugarcane), Sida, *Zea mays* (maize), *Malva parviflora* (sonchal), and some other malvaceous plants.

Insect Biology

Life Cycle

The *Earias insulana* usually breed throughout the year but during the winter only the pupae are found hiding in plant debris. The moths that appear in April live for 8-22 days and lay 200-400 eggs at night, singly on flower-buds, brackets and tender leaves of okra or cotton plants. The hairy parts of the plants are preferred for oviposition. In warm weather, the eggs hatch in 3-4 days and the caterpillars pass through six stages, becoming full-grown in 10-16 days. The full-grown dull-green caterpillars are 20 mm long having tiny stout bristles and a series of longitudinal black spots on the body. They pupate either on the plants or on the ground among fallen leaves and the moths emerge in 4-9 days. The life-cycle is completed in 17-29 days during the summer. In winter, the eggs hatch in about one week and the pupal stage is greatly prolonged, taking 6 to 12 weeks. Several overlapping generations are completed in a year. The roots of cotton plants sprouting in early spring and the fruits of neglected okra left in the field, are the two important sources of early infestation and multiplication of this pest. After pupation adults emerge. The adult moths are yellow green and measure about 25 mm across the wings.

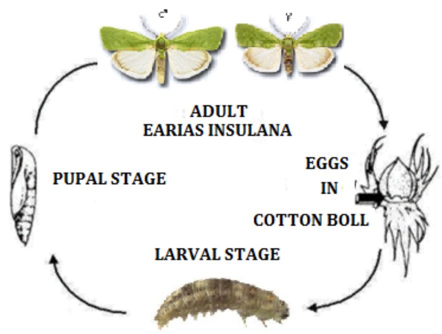


Figure: Life cycle of *Earias insulana*

Nature of Damage

Cotton infestation by *Earias* spp. generally starts with shoot boring in the young crop. *Earias insulana* enters the terminal bud of the vegetative shoot and make channels downwards from the growing point, or directly penetrates the internode. Only soft growing tissue is attacked. Extensive tunnelling results in wilting of the top leaves and the collapse of the apex of the main stem. The whole apex turns blackish-brown and dies. The result is bunched growth in young plants and death of the growing point in the mature plant.

As the buds and flowers appear they wither and are shed; they usually have a conspicuous hole where the larva has entered. The shedding of minute buds is often blamed on mirids but may be caused by very young *Earias*. The bolls are also attacked, but only when they are unripe. The larvae usually bore deeply, filling the tunnel opening with excrement. The tunnel often enters the bolls from below, at a slight angle to the peduncle. Small bolls, up to 1 week old, turn brown, rot and drop. Larger bolls, 2-4 weeks old, may not drop, but open prematurely and may be so badly damaged they cannot be harvested. The infested bolls open prematurely and produce poor lint, resulting in lower market value.

Secondary invasion by fungi and bacteria may conceal the *E. insulana* infestation. *Earias spp*. can transmit *Xanthomonas malvacearum*, causing bacterial blight of cotton or black fungus infection which is caused by *Rhizopus nigricans* present in a cotton crop. Young bolls or those without larval feeding holes rarely became infected.

Control

Cultural Control

Eradication of alternative host plants may be helpful in control of *Earias.* Cotton crop should be inspected regularly and all wilted shoots should be

removed, thus removing the larvae of *Earias*. Some farmers allow livestock to graze cotton during the vegetative stage with the same effect. The benefits of topping are controversial, although it is claimed that the removal of the topmost few centimeters of the cotton plant at the beginning of the season reduced infestation and encouraged lateral branches, increasing the yield, without affecting the quality of the fibre.
Other suggested practices are deep ploughing and close spacing of plants. High doses of nitrogen fertilizers have been found to increase infestation. Earlier sowings helps to reduce bollworm infestation.

Host-Plant Resistance

Considerable resistance to *Earias* has been recorded in several wild species of *Gossypium*. Numerous trials have tested the resistance of various cultivars and reduced susceptibility has been found in many of them. Those with high levels of tannin and gossypol, frego-bract and okra-leaf characters and red pigmentation have been found to be less susceptible than many commercial cultivars. Tall plants with larger top leaves and bolls in clusters carried more bollworm attack. Conversely, dwarf varieties with early flowering habits have been found to escape the damage of spotted bollworm.

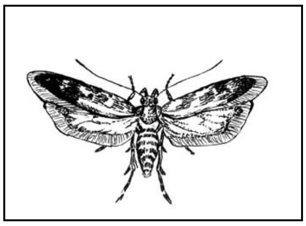
Biological Control

A number of parasitoids have the potential against *Earias* spp. *Bracon greeni*, is efficient as a biological control agent. The rains, by lowering the temperature and enhancing relative humidity, benefited *B. greeni* at the expense of *Earias* and enabled the parasitoid to keep the host under check. *Trichogramma australicum* and *B. greeni, T. brasiliensis* also increased the cotton yield. The use of natural enemies could be incorporated into an integrated control programme for *Earias* like cotton pests but the excessive use of pesticides reduced the numbers of predators, resulting in a reduction in seed cotton yields.

Bacillus thuringiensis has been used with some success. *Trichogramma chitonis* Ishii (Hymenoptera; Trichogrammatidae) an egg parasite, *Trichogramma bresiliensis* Ashmead (Hymenoptera; Trichogrammatidae), the exotic parasitoid is being used as biological control agent in many cotton growing areas. *Brachymeria nephantidis* Gahan (Hymenoptera; Chalcididae) has been recorded recently parasite against pupae of *Earias* sp.

***Pectinophora gossypiella* Saunders (The Pink Boll Worm)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Gelechiidae

Genus: *Pectinophora*

***Species*: *gossypiella* Saunders, 1844**

Distribution

The pink boll-worm is one of the most destructive pests of cotton in the world and is found in America, Africa, Australia, Europe and the former USSR, Oceania and Asia. It is highly destructive in the Punjab, Haryana and Pakistan. The most severe infestations of *Pectinophora gossypiella* have occurred in Africa and India, it has been recorded in nearly all cotton-producing countries and is a key pest in many of these areas.

Main Host Plants

The main host plants of pink boll worm are *Gossypium* (cotton), *Gossypium arboreum* (cotton, tree), *Gossypium herbaceum* (short staple cotton), *Abelmoschus esculentus* (okra), *Abutilon* (Indian mallow), *Abutilon indicum* (country mallow), *Althaea* (hollyhocks), *Hibiscus* (rosemallows), *Hibiscus cannabinus* (kenaf), *Hibiscus sabdariffa* (Jamaica sorrel),Malvaceae, *Medicago sativa* (lucerne) etc.

Insect Biology

Life Cycle

The yearly life-cycle begins with the emergence of moths in the summer. The emergence takes place at two distinct times- in May-June, and then in July-August.

Egg

The females lay whitish flat eggs singly on the underside of the young leaves on new shoots, on flower-buds and on the young green bolls singly or more commonly in small groups. Eggs are white when first laid but then turn orange, and later the larval head capsule is visible prior to hatching. The eggs are small and difficult to see without some magnification. Eggs hatch in about three to four days after they are laid. Eggs of the first field generation in the spring are often laid on vegetative cotton plants near cotton squares and sometimes on squares. Second and subsequent generation eggs are usually laid under the calyx of bolls.

Larva

The eggs hatch in one week and the caterpillars grow older. Soon after emergence, the larvae enter the flower-buds, the flowers, or the bolls. After hatching larvae immediately begin to bore into squares or bolls. In squares, larvae complete most of their development before blossoming occurs and often cause rosetted blooms. While moving from seed to seed, the larva causes damage by cutting through the lint with its mouth parts. Lint is also damages as the larva tunnels out of the boll. Larvae are white with a brown head when they hatch. They have four instar stages during development and finally begin to turn pink in the fourth instar. The holes of entry close down, but the larvae continue feeding inside the seed kernels. Final development is completed in the blossom. They become full-grown (8-10 mm) in about two weeks They generally require 12-15 days to complete development and come out of the holes for pupation on the ground, among fallen leaves, debris, etc.

Pupa

It is in pupation that the pink boll worm makes the drastic transformation from a larva to an adult moth. Most pupation occurs in the top layer of soil beneath cotton plants. The pupa is brown and approximately one half inch long. It does not feed or move about during the pupal period of seven to eight days.

Adult

Adult pink bollworms are mottled brown to gray moths and are about one half inch long. They emerge from pupae in an approximately 1:1 male to female ratio. There is a time period of two to three days after emergence during which the female mates and prepares to lay eggs. After this preoviposition period the female lays most of her eggs in about ten days. Both male and female adults feed primarily on nectarines located on the bottom of cotton leaves and may live for one to two months. The female produces a sex pheromone that aids the male in locating her for mating purposes.

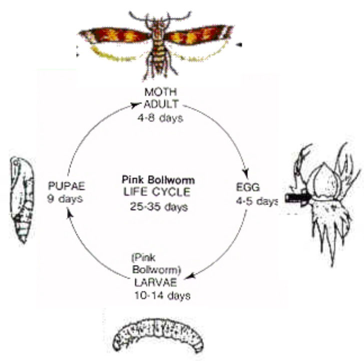


Figure: Life cycle of pink boll worm

Nature of Damage

The pink bollworm withdraws nutrients from the inside of the cottonseed and may cause serious yield losses. The damage is caused in different modes. There is excessive shedding of the fruiting-bodies. Of the total shedding 52.4 to 88.8 per cent is caused by all the boll-worms collectively, one-half may be due to the attack of pink boll-worm. The attacked bolls fall off prematurely and those which do mature do not contain good lint. The damaged seed-cotton gives a lower ginning percentage, lower oil extraction and inferior spinning quality. It is considered that by controlling the pink and spotted boll-worms the cotton yield can be increased up to 50 per cent. The destruction of off-season cotton-sprouts, alternative host plants or the burning of plant debris from cotton fields, minimize the incidence of this pest.

The damage is caused by the caterpillars only. They are pink and are found inside flower-buds, panicles and the bolls of cotton or the fruits of okra and other allied plants. In the adult stage, the insect is a deep-brown moth, measuring 8-9 mm across the spread wings. There are blackish spots on the fore wings, and the margins of the hind wings are deeply fringed.

Control

Cultural Control

- The use of *Bt* cotton will help prevent damage by pink bollworm. A recently developed transgenic cotton, Bollguard II, offers suppression of cotton bollworm, along with beet armyworms, pink bollworm, and tobacco budworm.
- By cutting off irrigation the food supply for pink bollworm can be eliminated early enough to stop production of green bolls by early September. When the crop is terminated, immediate shred of the cotton

plants following harvest can destroys some larvae directly and promotes rapid drying of unharvested bolls.

- Populations can be reduced by winter irrigations which can reduce overwintering pink bollworms by as much as 50 to 70%; flooding in December is more effective than flooding in November or January. Take advantage of pink bollworm mortality afforded by winter irrigations and rotate to small grains or newly seeded alfalfa.
- In spring, irrigations of the crop should be done to prevent even slight moisture stress and to promote maximum emergence of moths in advance of susceptible squares.
- Deep ploughing with alfurrow turning plough by the end of February is also helpful in reducing the carryover of this pest to the next season. Infestations may be reduced by the heating of cottonseeds at about 55°C, as well as by other management tactics, including plantation treatment and destruction of the infested crop.

Integrated Pest Management

- Combinations of biological and chemical controls have also proved successful. Combine application of *Trichogramma brasiliense* in combination with chemical insecticides gave a good control of pink bollworm in India, and *Bacillus thuringiensis* has been found to be effective in combination with chemical insecticides also.
- The release of sterile insects, cultural controls, intensive monitoring with pheromone baited traps for adult males and boll sampling, pheromone applications for mating disruption, very limited use of pesticides and the widespread use of genetically engineered cotton.

Chemical Control

- Beta-cyfluthrin, Chlorpyrifos, Esfenvalerate, Gamma-cyhalothrin, Lambda-cyhalothrin, Zeta-cypermethrin, Zeta-cypermethrin, bifenthrin etc chemicals can be used to control pink boll worm.

Biological Control

- Parasitoids like *Bracon kirkpatricki* can be used as biological control agents for *P. gossypiella.* Biological control agents were first obtained from India, in the belief that it was the origin of the pest. Recently nematodes have been used also as control agents *Trichogramma achaeae* Nagaraja and *Nagarkatti* Hymenoptera (Trichogrammatidae) parasitizes the eggs of this pest throughout India. *Apanteles angaleti* Muesebeck (Hymenoptera; Braconidae) parasitizes 1-17 per cent of the larvae of the host. It is widely distributed in India and the parasitoid is associated with the host throughout the year.

- The other hymenopterous parasitoids associated with larvae of the pink boll-worm are *Bracon greeni* Ashmead (Braconidae) *Chelonus pectinophorae* Cushman (Braconidae), *Elasmus johnstoni* Ferriere (Elasmidae), *Goniozus sp*. (Bethylidae), *Rogas aligharensis* (Braconidae) etc. The anthocorid bug *Triphles tantilus* Motsch. (Hemipt., Anthocoridae) also feeds on eggs and first instar larvae.

***Oxycarenus laetus* Kirby (The Dusky Cotton Bug)**

Systematic Position

Phylum:	Arthropoda
Class:	Insecta
Order:	Hemiptera
Family:	Lygaeidae
Genus:	*Oxycarenus*
Species**:**	*laetus* Kirby

Distribution

Oxycarenus laetus ***is*** distributed all over the Indian subcontinent as a minor pest of cotton.

Main Host Plants

The Dusky Cotton Bug is a minor pest of cotton in India and its chief importance lies in the fact that the adults and nymphs get crushed at the time of ginning, thus staining the lint and lowering the market value of cotton. Besides cottons, it also feeds on okra, hollyhock and other malvaceous weeds.

Insect Biology

Life Cycle

The insect is active practically throughout the year, but during winter, only adults are found in the unginned cotton. The cigar-shaped eggs are laid in the spring on *Hibiscus* and then on okra and finally on cotton during the monsoon. Initially, they are whitish turning pale and finally becoming light pink before hatching. The eggs are usually laid in the lint of half-opened bolls, either singly or in small clusters of 3 to 18 each. The egg stage lasts for 5-10 days and the nymphs, on emerging, pass through seven stages, completing the development in 31-40 days. The young nymphs have a rotund abdomen and, as they grow older, they resemble the adults, except for being smaller and having prominent wing pads instead of wings. The life-cycle lasts 36-50 days and a number of generations are completed in a year.

The body of dusky cotton bug is dark brown and have dirty white transparent wings. and is very small insect of about 4-5 mm in length, legs are deep brown and wings are faded transparent with black spots. The adults are picked up with picking of seed cotton and crushed during ginning resulted in stained lint and also produce bad smell.

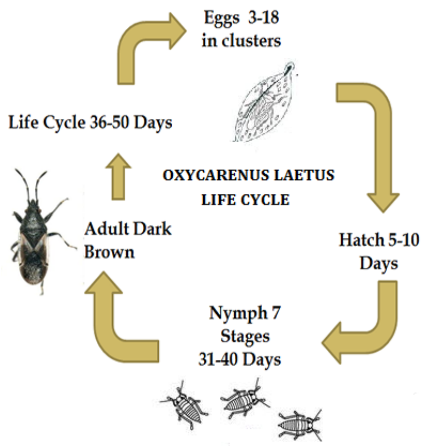


Figure: Life cycle of *Oxycarenus laetus*

Nature of Damage

The nymphs and adults suck the sap from immature seeds, whereupon these seeds may not ripen, may lose colour and may remain light in weight. The adults found in the cotton are crushed in the ginning-factories, thus staining the lint and lowering its market value.

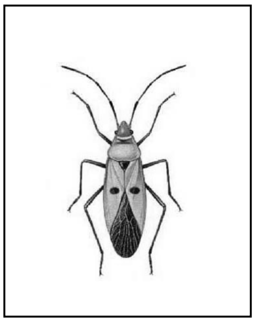
Control

Triphleps tantilus Motsch (Hemipters; Anthocoridae) feeds on the nymphs of this bug and no other parasitoids are known.

*** Other control measures same as above cotton pests**

***Dysdercus koenigii* Fabricius (Cotton Stainer)**

Systematic Position



Phylum:	Arthropoda
Class:	Insecta
Order:	Hemiptera
Family:	Pyrrhocoridae
Genus:	*Dysdercus*
Species**:**	*koenigii ,* Fabricius

Distribution

Dysdercus koenigii is distributed all over Asia, Australia, Central and South America, and Africa as a major pest of fibre crops. This insect is widely distributed in India and is a minor pest of cotton in the Punjab and Uttar Pradesh.

Main Host Plants

This Cotton Stainer bug is present throughout the year on the cotton crops and it also feeds on okra, hollyhock, kapok, sorghum, millet, jute and other malvaceous plants. The alternate hosts are falsa, rohan and eggplant. This insect also has been a severe pest of oranges on occasions. Some other hosts of *Dysdercus* include tangerines, okra pods, ripe fruit of papaya, pods and blossoms of oleander, eggplant, nightshade, and guava.

Insect Biology

Life Cycle

Eggs

Dysdercus eggs are pale yellow, small, and are laid singly or in small, loose clusters in sand, debris, or decaying vegetable matter or under soil and plant debris, or in the cotton plant in batches of about 7-100 eggs. Incubation period is about 4-13 days depending upon the temperature and the species. *Dysdercus* eggs look very much like microscopic hens' eggs.

Nymphs

There are five nymphal stages or instars. The nymphs are generally red. The first usually is spent underground. They hatch in 7-8 days and the young nymphs have a flabby abdomens, but, as they grow older, they become more slender and develop black markings on the body. The duration of each of the first four stages typically averages four to five days during midsummer, but the fifth stage commonly takes about twice as long. Nymphs are found together in the area where the eggs had been laid and later disperse to look for food. Then they tend to meet again while feeding on seeds and while resting. They look similar to their adult counterparts but without wings. All five stages require from 21 to 35 days to complete. The fourth and fifth instars have dark wing pads, and the dividing lines between abdominal segments become very distinct as maturity is approached. Their development stages depend upon the temperature and their nutrition.

Adult

The adult cotton stainers are true bugs with piercing and sucking mouthparts. Their colors vary from bright red, yellow, and orange depending on the species. They are about 1-1.5 cm long. This adult is long legged, has a bright red thorax, and brown wings crossed with yellow. Adults can tolerate a wide range of climatic conditions and can disperse and fly up to 15 km. There are several generations a year. The life cycle can vary from about a month to three and a half months, depending primarily upon temperature differences. The various species are attracted to lights.

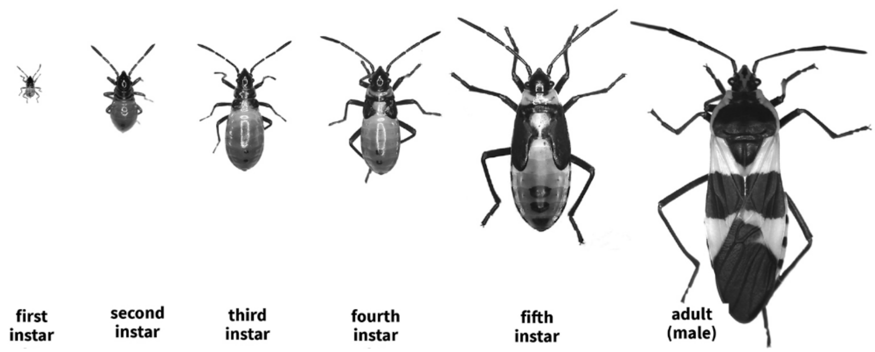


Figure: Developmental stages of *Dysdercus koenigii*

Nature of Damage

The cotton stainer is the most destructive cotton pest. Cotton stainers feed both on immature and mature seeds. Cotton stainers generally attacks on maturing cotton bolls and seeds. Feeding by puncturing flower buds or young cotton bolls usually causes reduction in size, or the fruiting body may abort and drop to the ground. Their penetrations into the developing cotton bolls transmit fungi on the immature lint and seed, which latter on stain the lint with typical yellow color, hence the name 'cotton stainers'. Heavy infestations on the seeds affect the crop mass, oil content, and the marketability of the crop. The feeding activities of cotton stainers on cotton produce a stain on the lint which reduces its value. A few researchers have reported that the stain comes from excrement of the bugs. However, most says that the stain primarily is a result of the bug puncturing the seeds in the developing bolls causing a juice to exude that leaves an indelible stain.

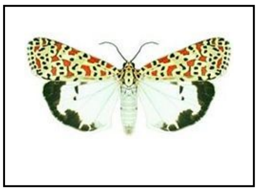
Control

- No cotton or cotton seed or other host plant debris that could serve as breeding material should be left on the ground.
- For small infestations, colonies of cotton stainers on plants can be shaken into a bucket of soapy water. Then the insects can be killed with a spray of soapy or scalding hot water.
- Small heaps of seeds, fruits, or bits of sugarcane can be used as baits to attract cotton stainers.
- The predacious bugs like *Antilochus cocqueberti* F. (Hemiptera; Reduviidae) feed on nymphs and adults.

*** Other control measures same as above cotton pests**

Utethesia pulchella **Linnaeus, 1758 (The Sunnhemp Hairy Caterpillar)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Arctiidae

Genus: *Utethesia*

Species: ***pulchella* Linnaeus, 1758**

Distribution

The Sunnhemp Hairy Caterpillar is found as a common pest of fibre crops in Africa, Southern Europe, Central & Southern Asia, Australia Algeria, Angola, Burundi, Chad, DRCongo, Egypt, Eritrea, Ethiopia, Gambia, Ghana, Kenya, La Reunion, Madagascar, Malawi, Mauritania, Mozambique, Namibia, Nigeria, Rwanda, Senegal, Somalia, Sudan, Tanzania, Uganda, Zambia, Zimbabwe etc. This insect is the most important pest of sunnhemp in Tamil Nadu.

Main Host Plants

The main host plants of *Utethesia pulchella* are *Gossypium, Heliotropium indicum, Lithospermum, Musa paradisiaca, Myosotis, Cystostemon, Trichodesma zeylanicum* and some grass species.

Insect Biology

Life Cycle

The moths lay small whitish eggs on the tender leaves and shoots. On emergence from the eggs, the larvae feed on leaves. As the crops mature and pods appear, the caterpillars feed by thrusting the head in and leaving the rest of the body exposed. The full-grown caterpillar is about 3-8 mm in length and has red, dark and white markings on its body and a brownish head. Pupation takes place either in the leaf folds or in the soil. The adult moth is pale, whitish with red black spots on the upper wings and black marginal blotches on the lower wings. The life-cycle is completed in about 5 weeks and a number of generations are completed in a year.

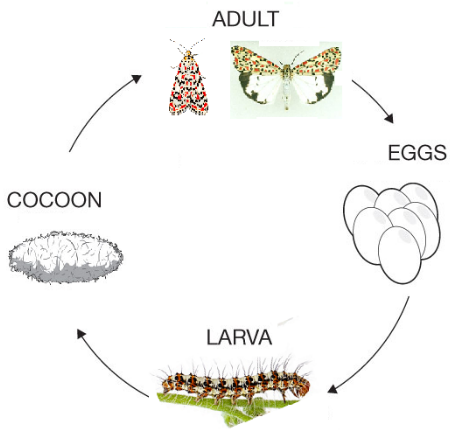


Figure: Life cycle of *Utethesia pulchella*

Nature Of Damage

The caterpillars feed voraciously on host plant leaves and bore into the capsules and severe infestation can also cause the defoliation of the crop. As a result there is a decrease in seed production.

Control

It can be suppressed by hand packing and killing the caterpillars as well as by collecting the moths with nets during the daytime.

*** Other control measures same as above cotton pests**

7.10 Summary

Insect pests can be a serious problem on pulses, oil seeds and cotton crops. The above insect pests can damage different parts of crops by reducing their yield and having a negative impact on their quality. Unaware and illiterate farmers are using synthetic pesticides to combat pests. Besides being hazardous to the farm workers' health and leaving toxic residues on crops.

7.11 Self Assessment Questions

1. Define pest with some examples of insect pests.
2. What are the main host plants of *Helicompera armigera*?
3. What are the control measures for cotton stainer**?**
4. Explain the life cycle of *Lipaphis erysimi* in details.
5. Write an essay on Pests of cotton crops.
6. Give a zoological name of following common insect pests names
   i. The painted Bug
   ii. White Grub
   iii. Castor Semilooper
   iv. Spotted Boll-worms
   v. Pink Boll worm
   vi. Dusky Cotton Bug
   vii. Cotton Stainer
   viii. Sunnhemp Hairy Caterpillar
7. Explain the Biology, nature, extent of damage and control of Agrotis ipsilon?
8. Describe the Biology, nature, extent of damage and control of Dysdercus koenigii.

7.12 References

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Unit - 8

Pests of Agricultural importance – III

Structure of the Unit

8.1 Objectives

After completing the unit, you will be able to understand about-

- Brief idea about paddy crop and its importance
    - Biology, nature of damage and control of Pests of Paddy crop - *Leptocorisa varicornis* Fabricius (Rice Gandhi Bug), *Hispa (Dicladispa) armigera* Olivier [Rice Hispa, Spiny Leaf Beetle], *Spodoptera exempta* Walker, 1857 (African Army Worm, Nutgrass, Armyworm)
- Brief idea about Sugarcane Crop and its importance
    - Biology, nature of damage and control of Pests of Sugarcane crop - *Scirpophaga nivella* Fabricius, 1794 (Sugarcane Top Borer), *Pyrilla perpusilla* Walker (Sugarcane Leafhopper), *Emmalocera depressella* (Swinhoe) *Aleurolobus barodensis*, Maskell, 1896 (Sugarcane whitefly, Mealy wing)
- Brief idea about Sorghum crop and its importance.

- Biology, Life Cycle, Nature of Damage and different types of control measures of Pests of Sorghum crop - *Atherigona varia* Rondani (Sorghum Shoot Fly, Stem Fly), *Calocoris angustatus* (Sorghum ear head bug)

- Brief idea about Wheat crop and its importance.
    - Biology, Life Cycle, Nature of Damage and different types of control measures of Pests of Wheat crop - *Mythimna separate* Walker, 1865(The Northern armyworm, Oriental armyworm), *Macrosiphum miscanthi /Sitobion avenae* (Wheat Aphid, Grain aphid)

- Brief idea about Fruit Crops
    - Biology, Life Cycle, Nature of Damage and different types of control measures of Pests of Fruit crops- *Ophideres fullonia* Clerck, 1764 (Fruit sucking moth), *Papilio demoleus* Linnaeus, 1758 (swallowtail butterfly ,lemon butterfly)

8.2 Paddy crops

India is one of the world's largest producers of white rice and brown rice, accounting for 20% of all world rice production. Rice is India's pre-eminent crop, and is the staple food of the people of the eastern and southern parts of the country. Rice is one of the chief grains of India. Moreover, this country has the largest area under rice cultivation, as it is one of the principal food crops. It is in fact the dominant crop of the country. India is one of the leading producers of this crop. Rice is the basic food crop and being a tropical plant, it flourishes comfortably in hot and humid climate. Rice is mainly grown in rain fed areas that receive heavy annual rainfall. That is why it is fundamentally a kharif crop in India. It demands temperature of around 25 degree Celsius and above and rainfall of more than 100 cm.

The major rice-growing states are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Orissa, Bihar, and Chhattisgarh, which together contribute about 72% of the total rice area and 75% of total rice production in the country. The three largest rice-producing states are West Bengal, Andhra Pradesh, and Uttar Pradesh. These states contributed about 43% of the country’s rice production in 2008-09. Some of the main rice crop pests are Rice hispa, Case worm, Leaf folder, Plant Hoppers, Stem borer, Swarming caterpillar or army worm etc. Farmers lose an estimated average of 37% of their rice crop to pests and diseases every year. In addition to good crop management, timely and accurate diagnosis and pest management can significantly reduce losses.

8.3 Importance of Paddy crops

Rice is the staple food crop for more than 60% of the world people. In other countries attractive ready to eat products, which have, long shelf life inform of popped and puffed rice, instant or rice flakes, canned rice and fermented products are produced. Protein is present in aleuron and endosperm 6 to 9% and average is 7.5%. Rice straw is used as cattle feed, used for thatching roof and in cottage industry for preparation of hats, mats, ropes, sound absorbing straw board and used as litter material. Rice husk is used as animal feed, for paper making, as fuel source. Rice bran is used in cattle and poultry feed, defatted bran,which is rich in protein and can be used in the preparation of biscuits and cattle feed. Rice bran oil is used in soap industry. Refined oil can be used as a cooling medium like cotton seed oil / corn oil. Rice bran wax, a byproduct of rice bran oil is used in industries. Rice is associated with prosperity and with the Hindu goddess of wealth, Lakshmi. Rice is a symbol of life and fertility, which is why rice was traditionally thrown at weddings.

PESTS OF PADDY CROPS

Leptocorisa varicornis **Fabricius (Rice Gandhi Bug)**

SYSTEMATIC POSITION

Phylum: Arthropoda

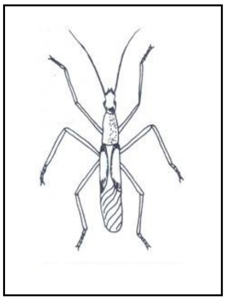
Class: Insecta

Order: Hemiptera

Family: Alydidae

Genus: *Leptocorisa*

Species: *varicornis* Fabricius



Distribution

Rice Gandhi Bug is generally distributed throughout India but is more prevalent in Bengal, Bihar, Uttar Pradesh and southern states. Commonly it is called as “Gundhi Kira”. Rice bugs are found in all rice environments. They are more common in rainfed and upland rice and prefer the flowering to milky stages of the rice crop.

Main Host Plants

The main host plants of *Leptocorisa varicornis* are *Oryza sativa* (rice), *Digitaria ciliaris* (southern crabgrass), *Eleusine indica* (goose grass), *Paspalum conjugatum* (sour paspalum), *Phaseolus* (beans), *Senna tora* (sicklepod), *Vigna* (cowpea).

Insect Biology

Life Cycle

The population of the rice bug increases at the end of the rainy season. Adults are active during the late afternoon and early morning. Under bright sunlight, they hide in grassy areas. They are less active during the dry season. In cooler areas, the adults undergo a prolonged development in grasses. They feed on wild hosts for one to two generations before migrating into the rice fields at the flowering stages.

After copulation female lay eggs symmetrically, into two or three rows. Eggs are dark coloured, oval in outline and flattened at the top. Eggs hatch in about a week. The young nymphs have slender green body and longer legs. These nymphs generally take about twenty days to attain full maturity. The nymphs are found on the rice plant where they blend with the foliage. There, they are often left unnoticed. When disturbed, the nymphs drop to the lower part of the plants and the adults fly within a short distance.

All the stages of developing bug clusters round the ripening ears and suck out the juice. This pest is more common during July to November. During winter their breeding rate is lowered much and the adults manage to tide over the cold on several species of grasses. On paddy it has five broods during the season.

It is grey green adults measure 15 mm in length and can be identified by their smell. Both the adults and the young ones suck the milky grains leaving dull whitish spots on the grains.

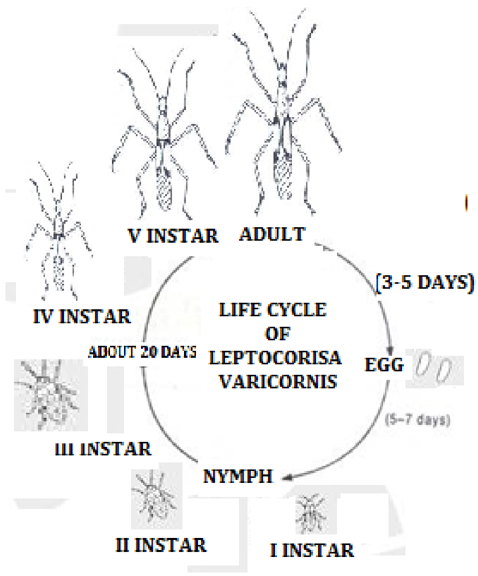


Figure - Life cycle of *Leptocorisa varicornis*

High rice bug populations depends upon factors such as nearby woodlands, extensive weedy areas near rice fields, wild grasses near canals, and staggered rice planting. The insect also becomes active when the monsoonal rains begin. Warm weather, overcast skies, and frequent drizzles favor its population buildup.

Nature of Damage

Rice bugs damage rice by sucking out the contents of developing grains from pre-flowering spikelets to soft dough stage, therefore causing unfilled or empty grains and discoloration. The main symptom associated with damage is the presence of unfilled grains. Rice bug adults and nymphs have piercing-sucking mouthparts. With their sucking mouth parts they suck out the milk from the newly formed grains which soon shrivel. The stalk remains quite sound but without grains and sometimes reduce yield by as much as 30%. Feeding enzymes and micro-organisms enhance feeding damage. Damaged florets may drop. Grain in the milk stage is preferred. Damaged grains are discoloured or 'pecky'. Pecky grains may break during milling. Both the adults and the young pests suck the milky grains leaving dull whitish spots one the grains. The grains remain unfilled. The field bunds should be kept free of weeds. When there are one or more bugs per hill spray neem based insecticide.

Control

Cultural Method:

Removal of host grasses from field on which rice bugs feed and breed, especially during the offseason, and field bundhs help in reducing the pest population. Draining out the water from infested field for three to four days is also helpful. Crop rotation is advisable.

Chemical Method

The choice of insecticide depends on many factors such as the application equipment available, cost of the insecticide, experience of the applicator, or presence of fish. The benefits of using an insecticide must be weighed against the risks to health and the environment.

As soon as the pest is observed in the field dusting with 5% BHC at the rate of 15 kg/ha. Malathion and Methylparathion dust is also effective. Spraying of 0.25% DDT or BHC or 0.04% Endrin atleast two weeks before harvesting.

Mechanical Control:

Collection of the bugs with a hand net and their destruction is a useful mechanical method.

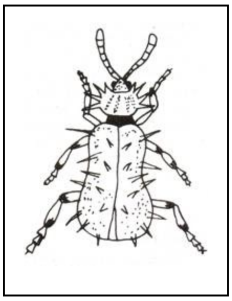
Biological Control:

Cicendala six punctata prey upon the nymph and adults of *Leptocorisa*. A number of natural enemies including parasites and predators are known to attack the rice bug at various stages. The assassin bug *Nabis stenoferus Hsiao* is a common natural enemy of this bug.

Small scelionid wasps *Gryon nixoni* (Masner) parasitize the eggs of *Leptocorisa spp*. Several species of parasitic wasps attack stink bugs. The meadow grasshopper *Conocephalus longipennis* (Haan) preys on rice bug eggs; several species of spiders, e.g., *Neoscona theisi* (Walckenaer), *Argiope catenulate* (Doleschall) and *Tetragnatha javana* (Thorell) prey on nymphs and adults. *Beauveria bassiana* (Balsamo) Vuillemin, a fungus, attacks both nymphs and adults.

***Hispa (Dicladispa) armigera*, Olivier [Rice Hispa, Spiny Leaf Beetle]**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Coeleoptera

Family: Chrysomelidae

Genus: *Hispa (Dicladispa)*

Species: *armigera,* Olivier, 1808

Distribution

Spiny Leaf Beetle is found all over rice tracts of world, in India it is ranked as major pest of paddy. It has been observed in South and North India, that when the paddy is grown as the third crop, it suffers badly. In Bihar it is locally known as "Babhani". Rice hispa scrapes the upper surface of leaf blades leaving only the lower epidermis. It also tunnels through the leaf tissues. When damage is severe, plants become less vigorous.

Main Host Plants

The main host plants of Rice hispa are *Oryza sativa* (rice), *Saccharum officinarum* (sugarcane), *Triticum aestivum* (wheat), *Zea mays* (maize), *Zizania aquatica* (annual wild rice), *Cynodon dactylon* (Bermuda grass), *Cyperus rotundus* (purple nutsedge), *Dactyloctenium aegyptium* (crowfoot grass), *Echinochloa colona* (jungle rice), *Oryza rufipogon* (wild rice), *Panicum repens* (torpedo grass) , *Paspalum distichum* (knot grass),

Insect Biology

The presence of grassy weeds nearby rice fields as alternate hosts and encourage the pest to develop. Heavily fertilized field also encourages the damage. Heavy rains, especially in premonsoon or earliest monsoon periods, followed by abnormally low precipitation, minimum day-night temperature differential for a number of days, and high relative humidity are favorable for the insect's abundance. The rice hispa is common in rainfed and irrigated wetland environments and is more abundant during the rainy season.

Life Cycle

The adult is blue-black and very shiny. Adult is a small bluish-black beetle fringed with numerous short spines over the body. Its wings have many spines. It is 5.5 mm long. Within 3- 4 days, just after emergence the female beetle starts laying eggs and continues to do so for a month. A small dark substance secreted by the female covers each egg. A female lays upto 300 eggs. Fresh egg is white. It is small and oval. It measures 1-1.5 mm long. With age, it turns yellow. Eggs are pushed inside the leaf tissues singly close to the leaf tips. They hatch in about 5-7 days. The grubs start feeding on the mesophyll portion of the leaf and become fully grown in about 15 days. The larva or grub is white to pale yellow. A younger grub measures 2.5 mm long and a mature larva is about 5.5 mm long.

Pupation takes place inside the tunnels formed by larvae which lasts for nearly 5 days. The pupa is brown and round. It is about 4.6 mm long.

The total life cycle is completed in about 20-25 days. The maximum life span for adults is about 80 days. Generally six life cycles are completed by the insect in one year. In the absence of rice the insect keep themselves alive on graminaceous weeds.

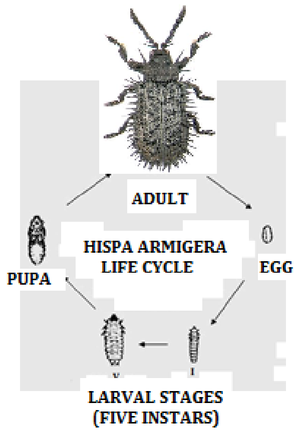


Figure - Life cycle of *Hispa armigera*

Nature of Damage

The adults as well as the grubs feed upon the leaves of paddy and give rise to blisters or blotches. Adult *H. armigera* feed externally on leaf tissue. The larvae mine into the leaf. The adult eats away the green matter resulting in withering and drying of leaves. Rice hispa scrapes the upper surface of leaf blades leaving only the lower epidermis. It also tunnels through the leaf tissues. The presence of characteristic parallel white lines on the leaf surface is an indication of the attack of this beetle. The average loss by this pest to the paddy crop varies between 5-60%.scraping of the upper surface of the leaf blade leaving only the lower epidermis as white streaks parallel to the midrib. Severely infested leaves dry up, and present a white, dried-up appearance in the field. From a distance, severely damaged fields look burnt.

Adult Damage Symptoms

Adult *H. armigera* scrape the chlorophyll from areas between the veins giving the characteristic appearance of white, parallel streaks along the main axis of the leaf. After indiscriminate feeding, where even the veins are affected, white blotches appear on the leaves. Adults are often present on the damaged leaves.

Larval Damage Symptoms

The grubs of *H. armigera* feed on the green tissue between the epidermal membrane of the leaf, tunnelling downwards, and producing irregular white patches. The larva or pupa can be seen by holding the damaged leaf against the light, and can be detected by passing the fingers along the tunnel.

Control

Control of Rice Hispa is necessary during outbreaks or when the beetle is in high abundance in order to prevent high yield losses. The integration of cultural, mechanical and chemical methods is essential to control a high abundance of *H. armigera*; collective and simultaneous action is necessary. Control of the overwintering populations of *H. armigera* in areas of India, where the pest is endemic, effectively reduces migration and pest abundance in the following rice crop.

Mechanical Control

When rice leaves are heavily infested by the eggs and grubs of *H. armigera* at the vegetative stage, the leaf tips can be removed to reduce the abundance of the pest. Leaf clipping controls 75-92% of grubs; the excised leaf tips can be buried, burnt or fed to cattle. During outbreaks or high abundance of *H. armigera*, the collection and destruction of adult beetles by a sweeping net is also effective. Sweeping in the morning, when beetles are less mobile, is more effective than sweeping later in the day. In an outbreak area, sweeping must be practised, collectively and simultaneously, until the adult population is controlled.

Cultural Practices

Damage to rice crops caused by Hispa can be avoided, or limited, by growing the crop earlier in the season. The avoidance of top-dressing the rice crop with high rates of nitrogen fertilizer during high incidence of the pest also reduces damage; this practice makes the rice crop more susceptible to the pest. However, after the pest has been successfully controlled, top-dressing with nitrogenous fertilizer may enhance recovery from damage. Deep and thorough ploughing of the field, Crop rotation, grasses around the paddy field should be destroyed before the paddy transplantation.

Biological Control

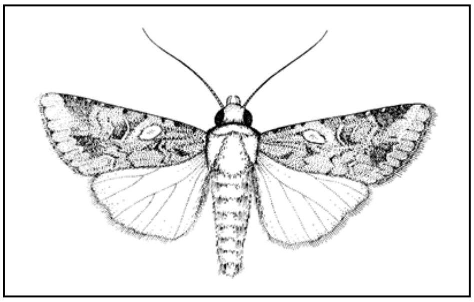
The role of natural enemies in suppressing the population of *H. armigera* has not been fully evaluated. Exotic natural enemies of *H. armigera* have not yet been introduced. The highly active larval parasitoid, *Eulophus femoralis*, has been introduced from Indonesia to Bangladesh and India and may reduce the Hispa problem in these areas. Conservation and the utilization of indigenous natural enemies may also play an important role in the management of this pest.

Chemical Control

- Methyl Parathion 50EC, 0.5ml Fenitrothion 100EC, 0.9ml Diazinon 60EC, Monocrotophos 36SL, Chloropyriphos 20 EC, Fenthoate 50EC, Phasalone 35EC, Endosulfon 35EC,Quinolphos 25EC.
- Transplanted field require 225-230 liter/acre spraying chemical or Carbofuron 3% @7.6kg/acre granules can be used.

***Spodoptera exempta*, Walker, 1857 / *Laphygma exempta,* Walker – (African Army Worm, Nutgrass, Armyworm)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuiidae

Genus: *Spodoptera (Laphygma)*

Species: *exempta* Walker, 1857

Distribution

The main distribution areas of the *Spodoptera* is eastern Africa, (including Kenya, Somalia, Sudan, Tanzania, Uganda) and central and southern Africa (Botswana, Malawi, Mozambique, Swaziland, South Africa, Zambia and Zimbabwe). Populations are also found in West Africa and the Indian Ocean Islands.

The armyworm is a migratory pest, which, in eastern and southern Africa, displays a distinct migratory pattern. The insect apparently starts breeding along the coast of East Africa and Mozambique further south. A progression of outbreaks then follows two directions: one northerly, from Tanzania to Ethiopia and across into Yemen, and the other to the south towards South Africa. However, there are indications that initial breeding might also take place in Angola leading to outbreaks spreading into Zambia and further south into Botswana and Zimbabwe.

Main Host Plants

The African armyworm, *Spodoptera exempta* Walker is a serious and often devastating pest of cereal crops such as maize, sorghum, millet, wheat, barley, rice and forage grasses. Its impact is particularly remarkable in maize, the staple food in most of Africa, including Zambia. The larvae feed on all types of grasses, early stages of cereal crops (e.g., corn, rice, wheat, millet, sorghum), sugar cane, and occasionally on coconut.

Insect Biology

Spodoptera exempta is a very deleterious pest, capable of destroying entire crops in a matter of weeks. The armyworm gets its name from its habit of "marching" in large numbers from grasslands into crops. African army worms tend to occur at very high densities during the rainy season, especially after periods of prolonged drought. During the long dry season. African armyworm population densities are very low. Because outbreaks are never observed during the dry season, it is called as "off-season". *Spodoptera exempta* moths live for about 10 days.

Life Cycle

Eggs

The eggs are laid by female *Spodoptera* in groups of 100-400 in single or multi layers on the leaves.. A female lays several egg masses until a total of up to 1000 eggs. They are covered with black hair scales. When they are laid, the colour of the eggs is yellowish. Just before hatching they turn black. The diameter of the eggs is about 0.5 mm. Hatching takes place after 2-4 days.

Larvae

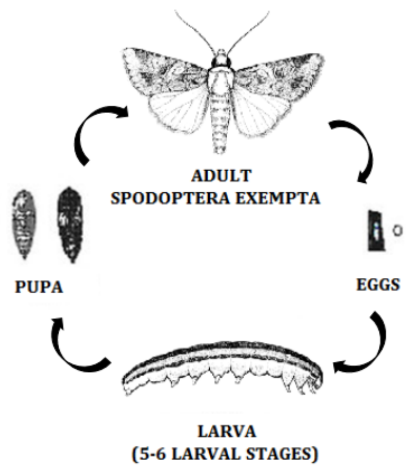
Caterpillars occur in two morphologically distinct forms: a "gregarious" form, which is black with yellow stripes, and a solitary form, which is green or brown. It is the "gregarious" forms of African army worms that cause outbreaks. There are six larval instars. On hatching the larvae are colourless or whitish. They have black heads. As they feed the colour becomes green. During the first three instars the caterpillars remain green. After this they turn black when there are many caterpillars together (gregarious form) or they will remain in various shades of green or brown when there are only few caterpillars together (solitary form). The caterpillars do not have obvious hairs. The head is shiny black and shows a V shaped white mark. The upper side of the first segment behind the head is black and has three narrow white stripes. A full grown caterpillar is 25 - 35 mm long. The larval stage takes 14 - 21 days. Generally, these pests are not noticed by farmers until the caterpillars are 10 days old and change from green to black. The mature caterpillars burrow into the soil. The pupa is brown or black in colour. It is about 17 mm long. In the last instar, larvae burrow 2–3 cm into the ground in chambers to pupate. Adults emerge in 7 to 10 days. The moths migrate over tens, and probably over hundreds, of kilometers between their emergence sites and their oviposition sites.

Pupa

The mature caterpillars burrow into the soil. They pupate in chambers 2 3 cm below the surface. The pupa is brown or black in colour. It is about 17 mm long. The pupal period ranges 7- 12 days.

Adult

The adult is a grey brown night flying moth. The wingspan is 20 - 35 mm for males and 22 - 37 mm for females. The hind wings are pale white with dark veins. The forewings are dull grey brown. They have two spots. The inner (orbicular) spot is elongate and pale. The outer (reniform) spot is kidney shaped and more clearly visible in males than in females. The moths are attracted by lights at night.



Life Cycle of *Spodoptera exempta*

Nature of Damage

Damage caused by African Army Worms to cereal crops is mainly from direct attack on young plants by larvae hatching or dispersing into the crop as first instars, and by invasion of the crop by older larvae from adjacent wild grasses. The caterpillars feed on the leaves eating them down to the midrib. Where these invasions are caused by late-instar larvae moving from heavily infested grasslands, even maturing crops can be totally destroyed. If drought conditions follow an outbreak, plants may not recover from defoliation and replanting may fail to produce a crop. Yield reduction caused by defoliation and is almost directly proportional to the percentage of leaf area available to the larvae at the time of attack. Reported losses range from 9% in plants attacked at the early whorl (four leaves) stage to 100% in those damaged at the pre-tassel stage. Damage is always serious if the apical meristem is affected.

Control

Cultural Practices

- To monitor the presence of armyworm, conduct visual inspection by going around all your fields. Armyworms feed at night and hide under debris during the day. Solitary forms are usually sparsely distributed and difficult to find. However, they can be monitored in late evening or early morning as they may still be actively feeding. Some caterpillars may be seen feeding on overcast days, especially during a severe outbreak. Hand-pick the caterpillars and feed these to chickens and ducks
- Avoid burning and overgrazing of grasslands, which are the natural habitat and food store of the caterpillars. Burning often causes outbreaks because as soon as temperatures rise, eggs are laid in large quantities on the fresh new grass. No oviposition occurs at temperatures less than 20°C. Also if their natural habitat and food is unavailable they will attack other crops.

Mechanical Methods

- Make a deep ditch and fill it with water. This method is helpful, when caterpillars are found to be moving towards your field from the adjacent fields.
- Another method is by making pitfall traps, first dig a deep ditch with vertical sides to trap the caterpillars and prevent them from crawling out.

Dig a hole, a diameter of a fence post, in every 10 meters within the ditch. Caterpillars are lured to congregate in the holes. Collect and properly dispose the trapped caterpillars.

- Use light traps to attract nocturnal pest. They can provide useful information about the population of moths and therefore of caterpillars. Light traps help to predict if there is going to be an outbreak. Use of light traps is primarily a tool in monitoring. In addition, a wooden tripod with a kerosene lantern is a "light trap" locally improvised.
- A tripod made of wooden poles (bamboo) is constructed with a lantern (kerosene) hanging in the middle over a bowl of water.
- Hand picking of caterpillars. This is only practicable in very small plots.

Biological Pest Control

Natural Enemies

- Natural enemies should be encouraged by maintaining natural surroundings with plenty of breeding places for them, including trees and shrubs.
  Many birds, toads, lizards, small mammals, insects and spiders prey on the African armyworm at different stages of its life cycle. Lacewings, predatory wasps, parasitic wasps, flies, and spiders attack armyworm caterpillars, Night birds and bats feed on the African armyworm moths. Birds (storks and crows) may decimate small outbreaks but have little influence on larger ones.

Biopesticides

- Biopesticides (including botanicals/plant extracts and microbials) such as Neem, Pyrethrum and Bt should be applied if larvae are at or above threshold levels and preferably when caterpillars are approximately 12 to 20 mm long, namely before most damage has occurred. Biopesticides should be applied in the evening since armyworms prefer to feed at night. Trials carried out showed that both neem seed and leaf extracts could be used to kill armyworms. Even though neem extracts are as effective as Spex NPV and synthetic pesticides, their use is only practicable in small holdings. The high bulk of neem needed and high transport costs means it is not feasible to use it on a large scale. Pyrethrum powder, Pyrethrum liquid, Bt (*Bacillus thuringiensis*).

8.4 Sugarcane Crop

Sugarcane, *Saccharum officinarum* L., is a perennial grass in the family Poaceae grown for its stem (cane) which is primarily used to produce sucrose. Sugarcane has a thick, tillering stem which is clearly divided into nodes and internodes. The leaves of the plant grow from the nodes of the stem, arranged in two rows on either side of the stem. The leaves are tubular and blade-like, thicker in the centres than at the margins and encircle the stem.

Sugarcane can reach a height of up to 6 m and once harvested, the stalk will re-grow allowing the plant to live for between 8 and 12 years. A sugarcane crop is sensitive to the climate, soil type, irrigation, fertilizers, insects, disease control, varieties, and the harvest period. The average yield of cane stalk is 60–70 tonnes per hectare per year. However, this figure can vary between 30 and 180 tonnes per hectare depending on knowledge and crop management approach used in sugarcane cultivation.

Sugarcane, *Saccharum officinarum* L., an old energy source for human beings and, more recently, a replacement of fossil fuel for motor vehicles, was first grown in South East Asia and Western India. Sugarcane is a renewable, natural agricultural resource because it provides sugar, besides biofuel, fibre and fertilizer. Sugarcane is a cash crop, but it is also used as livestock fodder. Sugarcane is the world's largest crop by production quantity. In 2012, FAO estimates it was cultivated on about 26.0 million hectares, in more than 90 countries, with a worldwide harvest of 1.83 billion tons. Brazil was the largest producer of sugar cane in the world. The next five major producers, in decreasing amounts of production, were India, China, Thailand, Pakistan and Mexico. In India about 527 working sugar factories with total installed annual sugar production capacity of about 242 lakh tonnes are located in the country during 2010-11. Broadly there are two distinct agro-climatic regions of sugarcane cultivation in India, viz., tropical (Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Madhya Pradesh, Goa, Pondicherry and Kerala.) and subtropical (U.P, Bihar, Haryana and Punjab). However, five agro-climatic zones have been identified mainly for the purpose of varietal development. They are (i) North Western Zone (ii) North Central Zone (iii) North Eastern Zone (iv) Peninsular Zone (v) Coastal Zone.

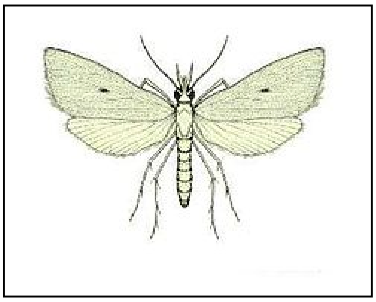
Maharashtra is the largest producer of sugar contribute about 34% of sugar in the country followed by Uttar Pradesh. The world demand for sugar is the primary driver of sugarcane agriculture. Cane accounts for 80% of sugar produced. Other than sugar, products derived from sugarcane include falernum, molasses, rum, *cachaça* (a traditional spirit from Brazil), bagasse and ethanol. In some regions, people use sugarcane reeds to make pens, mats, screens, and thatch.

Sugar cane crop is damaged by a number of pests in different stages of its growth. The main destructive pests of sugarcane are Borers, Leafhoppers, White flies, Termites etc.

Pests Of Sugar Cane

***Scirpophaga nivella,* Fabricius, 1794/ *Trporyza novella* (Sugarcane Top Borer)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Crambidae

Genus: *Scirpophaga*

Species: *novella* Fabricius, 1794

Distribution

Sugarcane Top Borer is a widely distributed species all over the Indian subcontinent and also occurs in China, Taiwan, Indonesia, Japan, Philippines, Nepal, Bangladesh, Sri Lanka, on the Andaman Islands, Myanmar, Thailand, Vietnam, western Malaysia, Singapore, Philippines, Sumatra, Java, Borneo, Timor, Aru, New Guinea, Australia, New Caledonia and Fiji.

Main Host Plants

Scirpophaga nivella is a major pest of sugar cane (*Saccharum* species)but sometimes it can also found as minor pest on *Oryza sativa*, *Scirpus*, *Cyperus*, *Eleocharis* (including *Eleocharis dulcis*) and *Calidum articulatum* and wild grasses etc.

Insect Biology

Life Cycle

- Generally the pest *Scirpophaga nivella* is very active from March to November.
- Moths are silvery white in appearance, male body size is smaller than females.
- Females are about 25-40 mm across the wings when spread & provided with a tuft of yellow, orange or brownish silken hairs over the tip of the anal segment.
- The caterpillar is creamy white in color and rather sluggish.
- Female moth lays approximately 500 elongated & oval eggs in clusters of 30-60 eggs. These eggs are covered with brown tuft of hairs.
- After 5-7 days, eggs hatch into caterpillars which are about 2 mm in length & are black headed.
- They feed voraciously up to 10-15 cm & destroy growing buds which results into dead- hearts. They attain full grown stage through five stages after 30-40 days of larval period.
- The full grown larva is about 30 mm in length, sluggish & creamy white in color.
- Four to five over lapping generations have been recorded in one year.
- It is interesting to notice that the caterpillars of the last generation do not pupate & undergo hibernation inside the tops of cane for the whole winter season in northern India.

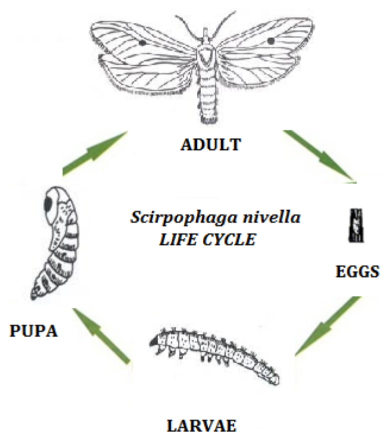


Figure - Life cycle of *Scirpophaga nivella*

Nature of Damage

The attacks of this pest causes reduction in the cane crop & the quality of sugar is also affected. Damage is caused by caterpillar which is generally found in top portion of a cane. Young larvae eat through rolled leaves, then usually penetrate along the midrib of the leaf into the heart of the plant. They then tunnel in the midrib, emerging through the upper epidermis. The first two broods of this pest attack young plants before the formation of canes. These plants are killed and are a total loss. In subsequent broods, the pest attacks the terminal portions of the canes, causing bunchy tops. Damage by the 3rd and 4th broods may result in more than 25% reduction in weight and a decrease in the quality of the juice.

Control

- The infested top shoot of sugarcane should be destroyed.
- Ratoon cropping should be avoided.
- Adult moth can be trapped by using light traps placing far from the field & destroyed.
- Parasite booster (egg parasitoid) with *Trichogramma* sp. or ichneumonid wasp (female)@ 125/ha should be used.
- Spray infested field with Sumithion 50EC or Diazinon 60EC@1lb/acre in 50 gallons of water or Carbofuran 5G@ 40Kg/ha.
- Spraying of 0.02% endrin at the time of egg hatching is quite effective to kill the eggs & young larvae.

***Pyrilla perpusilla* Walker (Sugarcane Leafhopper)**

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Hemiptera

Suborder: Homoptera

Family: Fulgoridae

Genus: *Pyrilla*

Species: *perpusilla*

Distribution

The pest is found throughout the Indian subcontinent from Afghanistan to Burma and Thailand. It is distributed all over India but is more prevalent in U.P. and Bihar. Usually great loss is recorded from Uttar Pradesh, Madhya Pradesh & Maharashtra.

Main Host Plants

Although *Pyrilla perpusilla* is a major pest of sugar cane yet it can also sometimes attacks on Maize, Wheat, Baru, Kahi, Jowar, oats, sorghum, bajra and wild grasses etc.

Insect Biology

Adult sugarcane leaf hoppers are straw coloured to brownish insect pests with a pointed snout having piercing and sucking types of mouthparts. They are found gregariously and jump off readily when disturbed. The Adult leafhoppers are active fliers, migrating from one crop to another and breed throughout the year. The increase in population of leafhoppers is favoured by high humidity and luxuriant plant growth as in heavily manured and irrigated field or in rainy season. The pest prefers soft varieties of canes having broad succulent & drooping leaves with loose leaf sheaths.

Life Cycle

Egg

Eggs are light yellowish in colour, oval, one mm long and laid on the underside of leaves & inside leaf sheaths in groups of about 20 eggs. A single female lays about 150 eggs. Eggs are laid by the female in large clusters, covered with large fluffy filaments. The incubation period is about 7 days depending on temperature.

Nymph

The freshly hatched nymphs are cream coloured, with growing age they turn into pale brown & are wingless and with a pair of anal filaments covered with whitish fluffy waxy material with a pair of characteristics anal filaments. They starts sucking the sap of the canes & change into adults after 5-6 instars of variable duration. There is great mortality during the hot weather. The nymphs which survive develop into adult by the first week of July. The total life history during the hot weather takes about 60 days & much longer during winter which is mostly passed in the nymphal stage.

Adult

The adults is an active straw colored bug, have a body length of about 8-10 mm. The head of pest is prolonged anteriorly and modified into a snout like structure & has prominent red eyes. They have 2 pairs of wings folded roof shaped on the back & the head extended like a pointed beak. The rostrum encloses the stylets. Tarsi are two jointed and there is a pair of elongated, twisted anal process. The two pairs of wings generally remains folded over the back. The females can be distinguished from the males by the presence of a pair of pads on the posterior end of the body. Prominent bundles of white waxy threads develop over these pads during the egg-laying period.

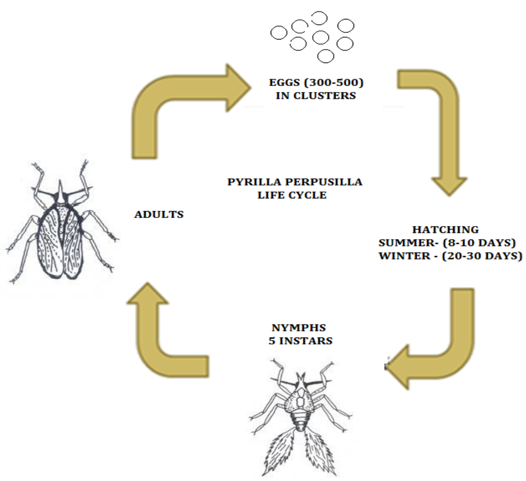


Figure - Life cycle of *Pyrilla perpusilla*

Nature Of Damage

The sugarcane leafhopper is found gregariously on the under surface of the leaves where they suck up plant sap that causes yellowing and eventually drying of leaves. Both nymphs & adults suck the cell sap of leaves of sugar cane by their rostrum. In case of low infestation yellow patches appear on the leaves, photosynthetic rate is affected. Resulting in the reduction of sucrose content of the juice by up to 30%. Hoppers secrete a sweet substance called honey dew that coats the leaves and attracts a blackish fungus, which also reduces photosynthesis resulting in the poor quality & quantity of sugar and yield loss. In case of severe infestation the sugar recovery may fall to as low as 75% than the normal.

Control

Mechanical Method:

- After harvesting, all thrash of sugarcane crop should be burnt, in an infected field.
- Removal of the leaves bearing egg-clusters in October planted crop during March-April.
- Uprooting and destruction of seriously infected plants.

Chemical Method:

- Dusting the infected crop with 10% BHC, 10% Toxaphane and 10% Carbaryl or 5% Malathione @ 20-40 kg/ha.
- Spraying with Endrin, Endosulfan Trithione, Phosphamedon, Malathione or Formothione @ 0.5 – 1.0 kg/ha.
- The pest can be controlled by spraying 0.05% of parathion, thiodon, fenitrothion or rogor.
- Dusting the plants with 10% Aldrin or dieldrin also helps.

Biological Method:

- Introduction of hyper parasites like *Tetrastychus pyrillae* & *Ooencyrtus spp* parasitize the eggs of this pest whereas nymphs are parasitized by *Dryinus pyrillae, Pseudogonatopus pyrillae* etc. Caterpillars of *Epipyrops melanoleuca* are predacious on nymphs and adults of leaf borer.

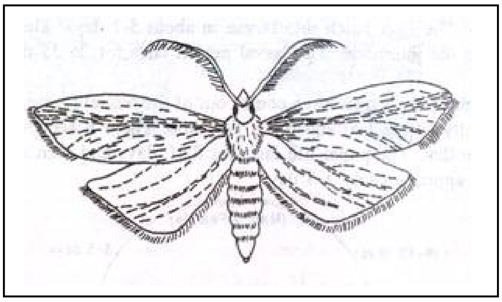
- Conservation of the following natural enemies helps in containing the pest:
    - Egg parasitoids: *Tetrastichus pyrillae, Cheiloneurus pyrillae, Ooencyrtus pyrillae, O. pipilionus, Agoniaspis pyrillae.*
    - Nymphal parasitoid: *Lestodryinus pyrillae, Pyrilloxenos ompactus, Chlorodryinus pallidus.*
    - Predators: *Coccinella septempunctata, C. undecimpunctata, Chilomenes sexmaculata, Brumus suturalis.*
    - Egg-predators: *Nimboa basipunctata, Goniopteryx pusana.*

Chemical Control

- Spraying -0.25% endosulfan / 0.025% fenitrothion.
- Spraying -0.01% endrin emulsion at a rate of 500 liter per acre.

***Emmalocera depressella* (Swinhoe)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Pyralidae

Genus: *Emmalocera*

Species: *depressella*

Distribution

Although pest *Emmalocera depressella* is distributed throughout India, Pakistan, Bangladesh, they are more common in northern regions. This species was first recorded in 1885 in sugarcane in India, however, it received attention as a key pest only recently. *E. depressella* is currently considered a major pest of sugarcane in some parts of India and Pakistan. A recent outbreak of *E. depressella* was recorded during 2005-2006 in the West Nimar Valley of Madhya Pradesh in Central India.

Main Host Plants

Sugarcane is the main host of *Emmalocera depressella* but also recorded as feeding on *Sorghum bicolor, Sorghum halepense, Erianthus munja*, *Sclerostachya fusca* and *Pennisetum purpureum* etc.

Insect Biology

Life Cycle

The adult moth, *Emmalocera depressella* measures about 25 mm in wing span. Fully grown caterpillars are white in colour, relatively active and measures 2-5 cms in length. The moths are pale yellow-brown and have white hindwings. Hind wings are larger in width than forewings. It has a dark lengthwise strip on each wing. Abdomen of male tapering but cylindrical in female.

The female moth has a pre oviposition period of about five days. Females lays eggs singly on the leaves or on the stem or in the soil. The number of eggs laid by a female varies between 180-280. In the climatic conditions of Punjab it completes five broods during active period (April-November).

The larva of the fifth brood hibernates in the stubble of the sugar cane plants. The larval period lasts for 4-7 days but during the crop season it may extend upto 28-32 days. A hibernating larva may survive for 200 or more days. The larva enters the plant at the base of the cane and grows in size feeding on the plant's internal tissues. Pupation occurs inside the stem, at or below the soil surface, generally in the early stages of plant growth. Before pupation the pupating larva makes an exit hole in the stem. Larva constructs a tube of silk leading to soil surface and pupates 4 cms below the ground level. High temperature and low humidity accelerates the multiplication rate of the pest. The life span of male moth is 3-10 days and that of female is 10-15 days.

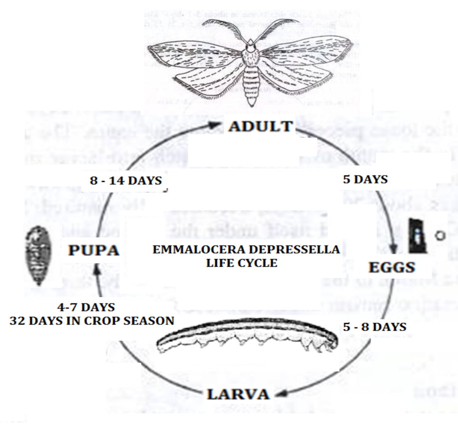


Figure - Life cycle of *Emmalocera depressella*

Nature of Damage

The damage caused to cane crop is mainly done by the immature caterpillar stages of this pest. Caterpillars after hatching, crawl down the plant and enter the soil to bore into the plant tissue below the soil surface. Drying up of inner whorl of leaves and formation of dead hearts are the common symptoms of the attack of this pest. On an average 5-15% of the cane crop is attacked by this pest. It causes reduction in weight by 10%. The sucrose content is also lowered by only about 0.5%. They are called as root borers, but they rarely bore into the root, only that part of the stem which is below the ground level is attacked by this pest. Studies from India report on varying levels of productivity loss ranging between 1.3-10% due to E. depressella infestation. A reduction of up to 66.2% and 73.0% of cane length and weight, respectively, has been recorded.

Control

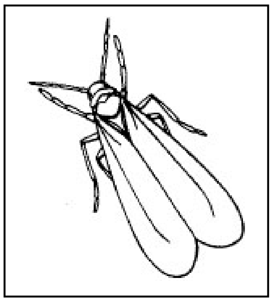
- Destruction of weeds in and around cane field as weeds are the host of the pest
- Removal of dry leaves from the canes.
- Deep ploughing of field before plantation.
- Removal and destruction of late shoots at the time of harvesting.
- Infested free setts should be planted and infested plant should be uprooted and destroyed.
- Ratoon cropping should be avoided.
- Crop rotation should be followed.
- Collecting egg masses and destroy them properly.
- Adult moth can be trapped by using light placing far from the field.
- After harvesting field should be burnt.
- Destruction of weeds in and around cane field as weeds harbour the pest.
- Removal of dry leaves from the canes.
- Deep ploughing of field before plantation.
- Removal and destruction of late shoots at the time of harvesting.
- Spray infested field with Endosulfan@ 30Kg/ha or Carbofuran 5G@ 40Kg/ha in the soil between two rows of canes or spraying of Endrin

fortnightly during July to September is quite effective in controlling this pest.

- Spraying of Endrin fortnightly during July to September is quite effective in controlling this pest.
- Spraying of crop with Monocrotophus.

***Aleurolobus barodensis*, Maskell, 1896 (Sugarcane whitefly, Cane White-fly Mealy wing)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Hemiptera

Suborder: Sternorrhyncha

Superfamily: Aleyrodoidea

Family: Aleyrodidae

Genus: *Aleurolobus*

Species: *barodensis* Maskell, 1896

Distribution

The sugarcane whitefly, *Aleurolobus barodensis* is noticed in serious proportions on sugarcane in growing areas all over the India, Indonesia (Jawa), Malaya, Philippines, Pakistan, Taiwan,etc. In India it is one of the serious sucking pests on sugarcane in Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu and Uttar Pradesh.

Main Host Plants

Saccharum officinarum L. (Poales, Poaceae), other related species like *Erianthus aurundanaceum* (Poales, Poaceae), *Miscanthus sp.* (Poales, Poaceae), etc.

Insect Biology

Life Cycle

The pale yellow or whitish adult female of *A. barodensis* lays about 80 eggs in straight rows, usually on the underside of leaves. Fresh unopened leaves in the central whorl are preferred for egg laying. The average number of eggs laid varies with the season. The eggs are fixed firmly on the leaf tissue by a stalk or pedicel at one end and the incubation period varies from 8 - 31 days. The eggs are generally pyriform or ovoid. The pedicel is a peglike extension of the chorion, and it has been suggested that, in addition to providing a means of attachment, it serves as a guide for spermatozoa during fertilization.

The freshly hatched nymphs are creamy pale and slowly change colour to a shiny black hue. They develop fringes of wax and a waxy deposit on the body and the three nymphal instars last for respectively 4 - 7, 3 - 7 and 3 - 8 days. After each moult, the nymphs change colour from pale to blackish. Most 2nd and 3rd instar nymphs have an oval or elongate-oval body, and have shallow breathing folds in the ventral body wall, two thoracic and one caudal. These form a passage to the spiracles and may assist in the conduction of air.

The first instar larvae (crawlers) are mobile and can crawl short distances to reach suitable feeding sites. After the first moult, the remaining three larval instars are sessile. The fourth instar is often referred to as a pupa. However, it is not a true pupa as feeding occurs during the first stage and transformation into an adult takes place in the last stage without any pupal moult. The legs and antennae of the 2nd, 3rd and 4th nymphal instars are atrophied, making these instars sessile.

The adults copulate immediately after emergence. The life-cycle is completed in 32 - 44 days. Adults of *Aleurolobus barodensis* are small, fly-like and often dull white in colour. There is a presence of powdery wax on their membranous wings which give the alternative name 'mealy wing'. Adult body length is 1 - 3 mm approximately.

The conditions favouring *A. barodensis* populations are drought, nitrogen deficiency, waterlogging (high humidity and temperatures conducive to multiplication of this pest), heavy rains, rationing of canes and soil alkalinity.

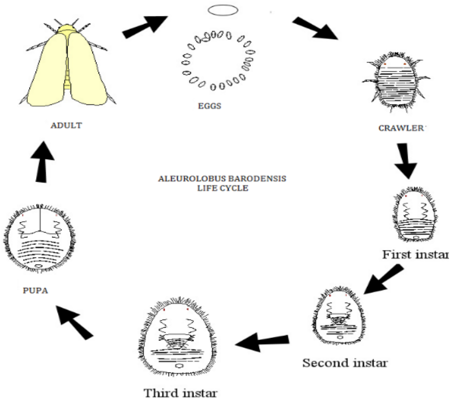


Figure - Life cycle of *Aleurolobus barodensis*

Nature of Damage

The Sugarcane whitefly, *Aleurolobus barodensis* is an important pest of sugarcane in regions where this insect occurs. Sugarcane whiteflies suck sap from the leaves and the affected crop appears pale and sickly. Attack in the early stages of crop development results in a serious setback to the crop and at the later stages causes deterioration in juice quality.

The nymphs are responsible for most of the damage to plants. The nymphs of white flies suck the sap from the under surface of leaves which turn yellow and pinkish in severe cases and gradually dry up. They feed via stylet mouthparts with which they pierce plant tissues and suck phloem sap. Heavy infested leaves are covered by the sooty mould caused by the fungus, which adversely affects photosynthesis.

The sap drainage by nymphs result in the leaf gradually turning yellow and pinkish and ultimately the leaf dries up. These insects often produce large amounts of sugar-rich excreta, whilst extracting sufficient protein-building amino acids from the sap to facilitate body growth. The excreta, termed 'honeydew' may support the growth of sooty mould on affected plants, which interferes with the photosynthetic activities of the leaves. Whitefly has been reported to breed well on neglected ratoons, especially in waterlogged areas, which are generally poor in nitrogen content.

The nymphs excrete large quantities of honey dew which accumulates on the affected leaves and the leaves appear black due to development of sooty mould, *Capnodium* spp. interfering with photosynthesis. High infestation causes stunted crop growth and reduces juice quality. Severe whitefly infestation may result in reduction in cane yield up to 65%. As the nymphs grow, they become covered with a white waxy meal which helps protect them from the action of insecticides. Whiteflies are distinctive in that all life stages, except the egg, can produce extracuticular waxes that cover the body, which protects them from insecticide applications.

Control

Whitefly control is difficult and complex, as whiteflies rapidly gain resistance to chemical pesticides. We should try for an integrated program that focuses on prevention and relies on cultural and biological control methods when possible. While an initial pesticide application may be necessary to control heavy infestations, repeated applications may lead to strains of whiteflies that are resistant to pesticides, so only use of selective insecticides is advised. Care should be taken to ensure that the insecticide used will not kill the natural predators of whiteflies. For effective use of biological method after application of pesticide, plant washing is advised prior to release of predators or parasitoids.

Chemical Control

Pesticides used for whitefly control usually contain neonicotinoid compounds as active ingredients: clothianidin, dinotefuran, imidacloprid and thiamethoxam, Neonicotinoids can be harmful if ingested. Rotation of insecticides from different families may be effective at preventing the building of tolerance to the product. Clothianidin and dinotefuran are of the same family. Spraying the leaves using insecticidal soap is another, environmentally friendly, method for its control.

Non Chemical Control

Biological methods have also been proposed to control whitefly infestation, and may be paired with chemical methods. Washing the plant, especially the undersides of leaves, may help reduce the number of the pests on the plants and make their management by other methods more effective. Whiteflies are also attracted by the color yellow, so yellow sticky paper can serve as traps to monitor infestations. Dead leaves or leaves that have been mostly eaten by whiteflies can be removed and burned or carefully placed in closed bins to avoid reinfestation and spreading of the disease.

Several predators and parasitoids may be effective in controlling whitefly infestations, including green lacewings, ladybirds, minute pirate bugs, big-eyed bugs, damsel bugs, and phytoseiid mites. Integrated management of whiteflies can as well be done using biopesticides based on microbials such as *Beauveria bassiana* (effective on nymphs and adults) or *Isaria fumosorosea*, *Ablerus aligarhensis*, *Ablerus delhiensis*, *Encarsia isaaci* , *Encarsia macroptera*, *Encarsia muliyali*, *Encarsia udaipuriensis*, *Euderomphale secunda* , *Amitus aleurolobi etc.*

8.5 Sorghum Crop

SORGHUM (*Sorghum bicolor*) CROP

Sorghum (*Sorghum bicolor* [L.] Moench) is the world's fifth major cereal in terms of production and acreage. It is a staple food crop for millions of the poorest and most food-insecure people in the semi-arid tropics of Africa, Asia and Central America. The crop is well adapted to hot and dry agro-ecologies where it is difficult to grow other food grains. In 2010, the USA was the world's largest producer of sorghum (8.8 million metric tons annually), followed by India (7.0), Mexico (6.9), Nigeria (4.8) and Argentina (3.6).

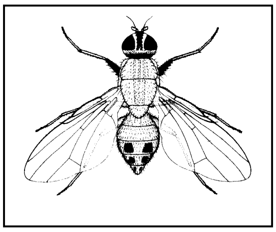
Sorghum is a multipurpose crop that gives food, feed, fodder and fuel without significant trade-offs in grain production. Currently research work is going on the use of sweet sorghum for ethanol production technology. Sorghum has the potential for high levels of iron and zinc in the grain. Therefore sorghum biofortification (genetic enhancement) of grain iron (Fe) and zinc (Zn) contents is targeted to complement other methods to reduce micronutrient malnutrition globally.

Pests Of Sorghum

***Atherigona varia* Rondani (Sorghum Shoot Fly, Stem Fly)**

Systematic Position

Phylum:	Arthropoda
Class:	Insecta
Order:	Diptera
Family:	Anthomyiidae
Genus:	*Atherigona*
Species:	*varia*



Distribution

Sorghum Shoot Fly is distributed world widely in Southern Europe, North and East Africa, India and the Middle East. In India it is more serious pest in southern parts.

Main Host Plants

The main host of Sorghum Shoot Fly is Sorghum. It also infests maize, wheat, broom corn, small millets, grasses and various Gramineae (Poaceae).

Insect Biology

Life Cycle

The female shoot fly is about 3-3.5 mm in length. The body is grey-brown in colour, abdomen and legs yellow, the abdomen with dark spots. Larva size is about 6.5 mm long and with 2 posterior black spiracular lobs. Generally the female fly lays its eggs singly on the lower surface of leaf blades. Each female deposited close to 240 eggs and lived for about 30 days. The eggs are elongate, flattened and somewhat boat shaped and are provided with 2 wing like lateral projections. The eggs hatch in 1-2 days and tiny maggots creep out and reach in the between the sheath and axis and bore into the stem. The maggots feed on the plant's growing point. They feed inside the main shoot for 6-10 days and when fully grown, they may pupate either inside the stem or come out and pupate in the soil. The pupal period in the summer last about a week. A life-cycle may be completed in 3-6 weeks, and annually the pest can complete up to 10 generations.

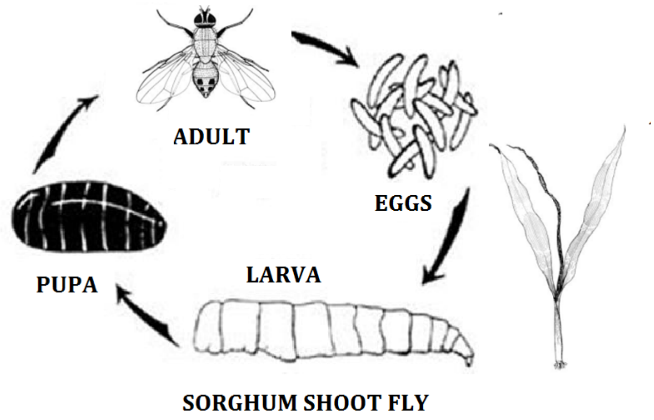


Figure - Life cycle of *Atherigona varia*

Nature of Damage

This pest is considered to be one of the most important and destructive sorghum pest, whenever plants are attacked at the seedling stage, especially in the semi-arid tropics. The maggots starts feeding on the plant's growing point which may kill the central stem, causing "deadheart" disease. This symptom of infestation is evident within 2-3 days after attack. It causes damage to seedling as well as to the early stages of the crop. The young plants show typical dead heart symptoms when the attacked plants are somewhat older, tillers are produced which mature latter than the main crop. The total loss in the yield is more than 60%

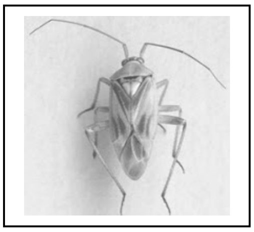
Control

- Yellow sticky traps are used for monitoring the pest.
- One another method is counting the number of infested "hearts" in young sorghum plants.
- Such sorghum varieties are used which are strongly resistant to the pest.

- Seeds coating with a neonicotinoid moderately reduce the pest damage.
- Several Eulophidae, namely *Tetrastichus nyemitawus* Rohwer and *Tetrastichus* spp. attack the pest in India. The parasitism of *Neotrichoporoides nyemitawus* Rohwer in India was greater (up to 30%) in a sorghum-cowpea intercrop than where sorghum was the sole crop. The eggs of *A. soccata* are parasitized by species of *Trichogramma* and killed by spiders. All of them are biological controlling agents.

***Calocoris angustatus* (Sorghum ear head bug)**

Systematic Position



Phylum:	Arthropoda
Class:	Insecta
Order:	Hemiptera
Family:	Miridae
Genus:	*Calocoris*
Species:	*angustatus*

Distribution

It is most destructive pests of sorghum widely distributed in southern India, China, the Middle East and Europe. Both nymphs and adults stages feed on the green ear heads.

Main Host Plants

Insect Biology

The adult is small, slender, greenish, yellow bug, measuring 5-8mm in length and 1mm in width. It mostly feeds on number of cereals, millets and grasses. Its breeding is mainly restricted to sorghum on which it assumes the status of a pest.

Life Cycle

The adult appears on sorghum crop as soon as the ears emerge from the leaf sheaths. The female bugs lays eggs under the glumes or in between anthers of florets by inserting its ovipositor. The female lays 150-200 eggs, which are cigar shaped and measure about 1.5mm. The eggs hatch in 5-7 days and the nymphs starts feeding on developing grains in the milk stage. The nymphs pass through five instars and develop into adult in about 3 weeks. The adults of the second generation are again ready to oviposit in the ears having developing grains which might be available on the same crop. As soon as the grains are ripe, the bugs stop multiplying on that crop. The insect completes its life cycle in about one month and produces a number of generations in a year.

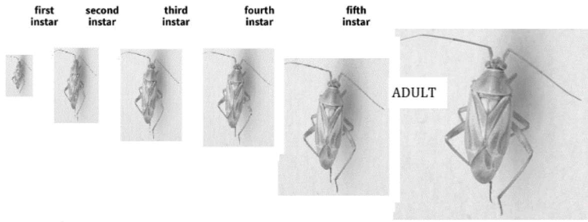


Figure – Developmental stages of *Calocoris angustatus*

Nature of Damage

Head bug, *Calocoris angustatus* nymphs and adults suck sap from the developing grains. Large number of nymphs and adults are seen on the ear head. The damage starts as soon as the panicle emerges from the boot leaf. Bug damaged grain shows distinct red-brown feeding punctures. High levels of bug damage lead to tanning and shrivelling of the grain. Head bug damage reduces grain yield, quality, and renders the food unfit for human consumption. Such grains also show poor seed germination. As a result of feeding by the bugs the grains remain chaffy or shrivelled. When a large army of tiny nymphs feeds, the whole ear becomes blackened at first and may eventually dry up, producing no grains. Nymphs and adult suck the juice from within the grains when they are in the milky stage.

Control

Insect pests can be a major limiting factor in grain sorghum production in India. Growers must be prepared to scout and prevent injury from insects. However, a proper insect pest management program will minimize losses to insects and ensure appropriate insecticide use.

- Crop Rotation will help to minimize the growth of sorghum pests in the same field.
- Selection of such plant varieties which are well-adapted, vigorous, high-yielding hybrids with good disease resistance and standability.
- Periodically soil tests and fertilizer and lime application to maintain the proper soil fertility.
- Early plantation often escapes major insect damage. Sorghum head bug pest, do not usually reach damaging population levels until after early plantings are mature.

- In conventional-tillage, bury previous-crop residue and keep free of weeds for at least 2 weeks before planting. This practice helps reduce the incidence of damage from insects which may establish infestations on weeds, volunteer grasses or grass sod.
- Timely harvesting also helps to prevent seed damage by pests and birds.
- Apply any one of the following chemicals on 3rd and 18th day after panicle emergence :
  - Carbaryl 10 D 25 kg/ha
  - Malathion 5 D 25 kg/ha
  - Neem seed kernel extract 5%
  - Spray twice with Malathion 50 EC 500 ml/ha. in 500 lit of water at
    10% heading and 9 days after.

8.6 Wheat crop

Wheat is the most important food-grain of India next to Rice and is the staple food of millions of Indians, particularly in the northern and north-western parts of the country.

It is rich in proteins, vitamins and carbohydrates and provides balanced food. India is the fourth largest producer of wheat in the world after Russia, the USA and China and accounts for 8.7 per cent of the world's total production of wheat.

Conditions of Growth

Conditions of growth for wheat are more flexible than that of rice. In contrast to rice, wheat is a rabi crop which is sown in the beginning of winter and is harvested in the beginning of summer. The time of sowing and harvesting differs in different regions due to climatic variation.

The sowing of wheat crop normally begins in the September-October in Karnataka, Maharashtra, Andhra Pradesh, Madhya Pradesh and West Bengal; October-November in Bihar, Uttar Pradesh, Punjab, Haryana and Rajasthan and Nov.-Dec. In Himachal Pradesh and Jammu & Kashmir. The harvesting is done in Jan.- Feb. in Karnataka, Andhra Pradesh, M.P., and in West Bengal; March-

April in Punjab, Haryana, U.P. and Rajasthan and in April-May in Himachal Pradesh and J&K. The growing period is variable from one agro climatic zone to an other that effects the vegetative and reproductive period leading to differences in potential yield. The important factors affecting the productivity are seeding time and methodology, crop establishment and climatic conditions during the growing season.

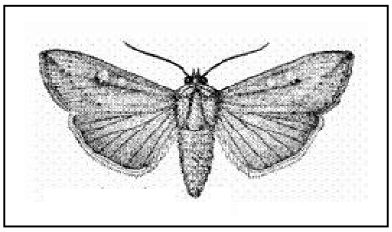
Wheat is primarily a crop of mid-latitude grasslands and requires a cool climate with moderate rainfall. The ideal wheat climate has winter temperature 10° to 15°C and summer temperature varying from 21°C to 26°C. The temperature should be low at the time of sowing but as the harvesting time approaches higher temperatures are required for proper ripening of the crop. But sudden rise in temperature at the time of maturity is harmful.

WHEAT (*Triticum aestivum*) CROP

Wheat is the world's most favored staple food. Wheat is the staple food of most Indian population. Wheat grains are grounded into flour (atta) and soft wheat is used for making chapatee, bread, cake, biscuits, pastry and other bakery products. Hard wheat is used for manufacturing rawa, suji and sewaya. In areas where rice is a staple food grain, wheat is eaten in the form of puri and uppuma. It is also used for making flakes and sweet meats like kheer, shira, etc. Wheat grain is used for preparing starch. Wheat straw is used as fodder, padding material and mulching material.

***Mythimna separata* Walker,1865 /*Leucania consimilis* (The Northern armyworm, Oriental armyworm or Rice ear-cutting caterpillar)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: ` Lepidoptera

Family: Noctuidae

Genus: *Mythimna (Pseudaletia)*

Species: *separata* (Walker, 1865)

Distribution

The term “Armyworm” is used for *Mythimna separata* because of their habit to spread out in a line across a lawn or pasture, and slowly “marching” forward, meanwhile consuming the foliage they encounter. It is distributed in India, China, Korea, Japan, Southeast Asia, Australia, Oceania, in the south of Uzbekistan, New Zealand, and some Pacific Islands. In India these are prevalent in U.P, Bihar, Rajasthan, and Punjab as pests of wheat, especially in the seedling stage.

Main Host Plants

Mythimna separata is polyphagous in nature, its main host plants are *Triticum aestivum* (wheat), *Avena sativa* (oats), *Beta vulgaris var. saccharifera* (sugarbeet), *Brassica rapa* subsp. *chinensis* (Chinese cabbage), *Brassica rapa* subsp. *rapa* (turnip), *Cajanus cajan* (pigeon pea), *Cannabis sativa* (hemp), *Eleusine coracana* (finger millet), *Eleusine indica* (goose grass),*Glycine max* (soyabean),*Hordeum vulgare* (barley),*Nicotiana tabacum* (tobacco), *Oryza sativa* (rice), *Pennisetum glaucum* (pearl millet), *Phaseolus* (beans), *Pisum sativum* (pea), *Saccharum officinarum* (sugarcane), *Secale cereale* (rye), *Sorghum bicolor* (sorghum), *Urochloa mutica* (para grass), *Zea mays* (maize)

Insect Biology

Life Cycle

Size and coloration of *Mythimna separata* varies insignificantly. Sexual dimorphism is not clearly observed. Adult body size with wing span is 38-48 mm. Forewings are grayish-yellow, with dark-gray or reddish-yellow tint. Round and reniform spots are light or yellowish with indistinct edges; reniform spot with white point at lower margin. External wing margin blackened obliquely from top backward, with dark stroke and with a row of dark points. Hindwings are grey in colour having dark external margin. Antennae are thread-like.

Female fertility varies from 300 to 1600 eggs. Moth life span is about 2-3 weeks. Usually eggs are laid in cluster, consisting of approximately 500 eggs. Eggs have spherical form (0.5-0.6 mm in diameter), milky-white; their surface is thinly reticulate. The young caterpillars hatch from the eggs in 4-5 days. After hatching the caterpillars starts feeding on the leaves of the seedlings. Generally the caterpillars move in swarm from one field to the other. The caterpillars are fully grown in about 15 days and measures 3-5 cm in length. After attainment of full size the larva pupates inside the soil and remains in this condition for about 15 days. Thus, the life cycle is completed in about 30-35 days which is repeated several times each year.

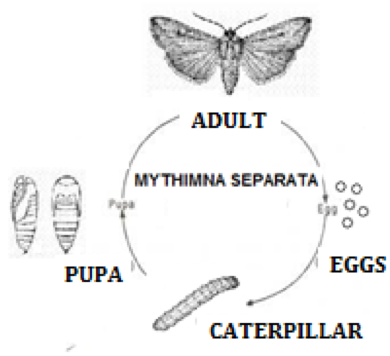


Figure - Life cycle of *Mythimna separata*

Nature of Damage

The major damage to the seedlings is caused by caterpillars which move in swarm. After destroying crop of one field, they move to the other crop. The caterpillars feed upon the leaves of the seedlings and devour the ear heads as a result further growth of the plant ceases. Economic threshold of harmfulness on agricultural lands as a whole is 10 larvae /sq.m. for the 1st noctuid generation, and 20 larvae /sq. m. for the 2nd generation. Control measures include weeding, interrow cultivations, removal of crop residues from fields after harvesting, deep autumn plowing, optimal dates of early sowing, cultivation of resistant varieties, insecticide treatments of crops, release of such entomophages as *Trichogramma* spp. Monitoring is possible with use of sex pheromone traps.

During the vegetative stage of rice, *M. separata* damage is evident as massive leaf removal, often including leaf veins. They may also eat the lemma and palea of the developing grains as well as the anthers of flowers. Large angular notches can be cut away from young seedlings in a seedbed, giving an irregular appearance. Damage is often localized to one part of a field. During outbreaks many fields can be affected at the same time. A characteristic peculiar to *M. separata* occurs during the grain filling stage when the mature larva cuts off panicles at their base causing some to bend while others are completely severed and fall to the ground.

Control

Cultural Control

A number of cultural control measures are available. When armyworms attack a seedbed the water level can be raised to drown the larvae. In endemic areas, farmers should avoid rotating host crops such as wheat or maize after rice. The rice-wheat cropping pattern is popular in temperate regions of China, Pakistan, India, Nepal, and Bangladesh but encourages build up of *M. separate*. Farmers should keep weeds (particularly Gramineae) in check as they are also alternative hosts. Nitrogen fertilizer should be used with care as the improved nutrition causes greater armyworm fecundity and more larval feeding and survival. The water level can be raised when the population is in the pupal stage to drown them. Flooding also limits plant to plant dispersal of *M. separata* larvae.

Mechanical and Physical Control

Different types of barriers can be constructed to divert migrating *M. separata* larvae. Water moats can protect a seedbed or kerosene can be poured in *M. separata's* path. Egg masses or larvae can be hand-picked from seedbeds .

Biocontrol

Ducks are often raised in rice areas and can be herded into damaged fields to feed on *M. separata* larvae. Ducks can locate *M. separata* larvae hiding in the soil or at the base of plants. Perching in the fields can increase predation by insect-predatory birds.Parasitism of *M. separata* greatly increased (from 50-55% to over 80%) and the numbers of larvae in the crops have significantly declined. Of even greater importance is that parasitized larvae have weaker appetites. A high rate of control has been evident despite high rates of hyperparasitism by the pteromalid *Eupteromalus parnarae* [*Trichomalopsis apanteloctena*] which normally ranges from 41-97%. The hyperparasite became abundant after the armyworm was under control.

Chemical Control

Greater care should be taken in opting for selective insecticides during the early crop-growth stages when natural enemy populations are increasing. Less care would be needed during the panicle stage as the crop is about to be harvested. Selective materials include poisoned bait made from rice- or wheat-bran that can be placed along field borders or in the field if it is dry for control of larvae. Microbial insecticides with nuclear polyhedrosis virus are highly selective but should be applied sooner than conventional chemicals as they are slower acting. Farmers themselves can re-use the virus by collecting infected larvae from the field, macerating them, and straining the body mass directly into sprayers.

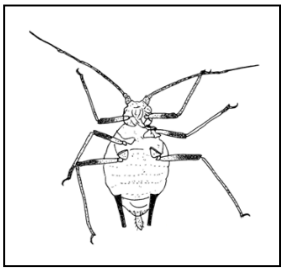
Integrated Pest Management

The management strategy for *M. separata* is based on early detection. High-risk areas can be identified based on the history of past outbreaks and vigilance can be intensified during seasons of expected occurrence. Early-warning systems have been developed in Japan and China to detect immigrating moths.

Preventative measures can be taken such as planting a high-tillering cultivar and carrying out good crop management. The rice crop is then monitored for larval build-up on a weekly basis. Scouting should be done throughout the entire field area as populations are often highly aggregated. Control decisions should be made before the population attains the last larval stage which not only causes more damage, but is more difficult to control due to its large body-size. Larvae can be collected from the field and reared to determine the incidence of parasitoids. If parasitoid activity is low, corrective actions such as the use of ducks and perches in the field can be practiced before larval population reach the economic threshold, while or a microbial pesticide can be taken when the larval population reach the economic threshold.

***Macrosiphum miscanthi / Sitobion avenae* (Wheat Aphid, Grain aphid, Bird cherry aphid, Rose grain aphid)**

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Hemiptera

Family: Aphididae

Subfamily: Aphidinae

Tribe: Macrosiphini

Genus: *Macrosiphum (Sitobion)*

Species: *miscanthi (avenae)*

Distribution

Macrosiphum miscanthi is a monoecious aphid with a complex lifecycle found widespread throughout cold, temperate, and warm climates across Europe, Asia, Africa and the American continents. Wheat Aphid is widespread throughout the world, with a preference for temperate climates.

Main Host Plants

Macrosiphum miscanthi occurs on all cereal species including rice and maize and can develop on most cultivated or wild Poaceae, as well as on some Juncaeae and Cyperaceae. Wheat Aphid show differences in host range and preferences, some of the host plants are as follows- *Triticum aestivum* (wheat), *Agropyron* (wheatgrass), *Avena sativa* (oats), *Cynodon dactylon* (Bermuda grass), *Eleusine coracana* (finger millet), *Hordeum vulgare* (barley), *Oryza sativa* (rice), *Pennisetum glaucum* (pearl millet), *Poaceae* (grasses), *Saccharum officinarum* (sugarcane), *Secale cereale* (rye), *Sorghum bicolor* (sorghum), *Zea mays* (maize) etc.

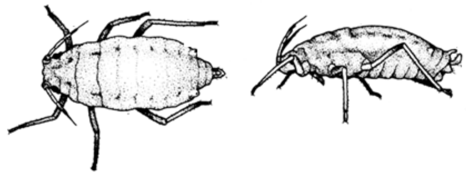


Figure: External morphology of *Macrosiphum miscanthi*

Insect Biology

Life Cycle

Eggs

*Macrosiphum miscanthi e*ggs are small, ovoid, and either green or black. Eggs are overwintering, being laid in autumn and hatching the following spring, generally diapausing for 2-3 months during a cold winter. A high humidity is required for egg survival, especially prior to hatching, which can usually be found in the cold, wet climatic conditions found where its sexual reproduction occurs.

Nymphs

Wheat aphid passes through 4 nymphal instars, which have roughly the same colouration as adults but do not show the developed morphological features required for their precise identification. First and second instar nymphs can be acknowledged by their 5-segmented antennae, while the third and fourth instar nymph's antennae are 6-segmented. Male nymphs can sometimes be recognised by their bright red- brown or orange colouration which is carried on into adult form.

Adult

The adult wingless form is 1.3 - 3.3mm long, and broadly spindle-shaped. It ranges from yellowish green to a dirty reddish brown. It has black antennae and two black tubes called as siphunculi at the rear end, which are a little longer than the pale rather pointed tail called as cauda or cornicles or horney tubes . The winged form is 1.6 - 2.9 mm long and similarly coloured, with distinct dark intersegmental markings on the upper surface of the abdomen.

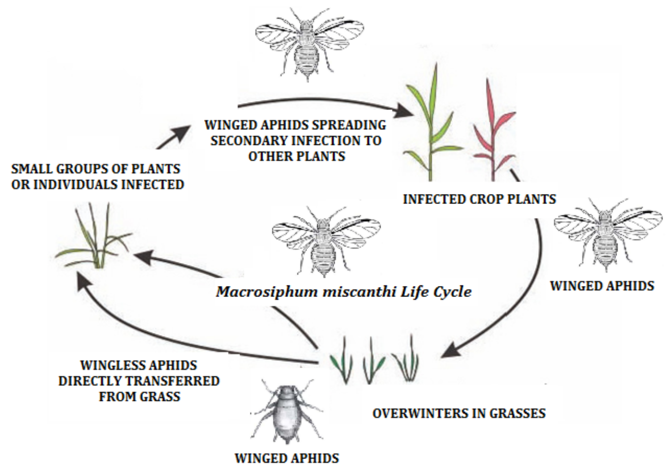


Figure - Life cycle of *Macrosiphum miscanthi*

Nature Of Damage

The species can cause economic damage to plant crops as a result of its direct feeding activity. In high enough densities it can remove plant nutrients which can potentially cause a reduction in the number of heads, the number of grains per head, and a reduced seed weight. It may cause yellowing to upper leaves and ears, symptoms which are common to many aphid species and plant pathogens. Indirect damage can be caused by excretion of honeydew, and as a vector for viruses, most notably two strains of the Luteovirus Barley Yellow Dwarf Viruses. *Sitobion avenae* causes direct damage by feeding on leaves, stalks and ears, and indirect damage by excreting honeydew and the transmission of viruses. The main impacts are reduced yields caused by the removal of plant nutrients and reduced photosynthesis as caused by honeydew accumulations. Other damage to wheat aphids can also cause reduced number of heads, reduced number of grains per head, and reduced grain or seed weight. Wheat yields can be reduced by around 20-30% during outbreaks. Wheat aphids causes maximum yield loss on wheat between ear emergence and flowering.

During direct feeding, nutrients, amino acids and carbohydrates are extracted from leaves and earheads, while some plant physiological processes may be disrupted. Honeydew and sooty moulds interfere with light capturing by green tissues and reduce photosynthetic efficiency.

Damage is dependent on the number of tillers infested, the number of aphids per tiller and the duration of infestation. The resulting yield loss can be quantified in terms of a reduced number of earheads, reduced number of grains per head or reduced seed weight. Maximum yield losses in cereals are most likely to occur because of attack between ear emergence and flowering. *S. miscanthi* feeds on leaves, moving to the earheads as they develop.

Control

Natural enemies:

Ladybirds are the best known predators of aphids. Among other enemies are flower flies, ground beetles, green lacewings, bugs, parasitic wasps and parasitic fungi. The natural enemies can reduce the aphid population significantly but often do not appear in high numbers until late in the growing season. Late cultivars are more exposed to attack than early cultivars. High levels of nitrogen promote aphid development. Fungus control is favourable to the aphid as this keeps the plant material fresh and green for a longer period.

Chemical control:

The specific insecticides should be used against aphids because they destroys the beneficial animals also. Very severe attacks can be difficult to control through pyrethroids. In case of treatment with pyrethroids application must take place outside the spray from 9 p.m. to 3 a.m. In wheat the aphids are easy to control as they sit in the ears.

Host-plant Resistance

The use of resistant varieties of wheat and other cereals can reduce aphid infestations and yield loss. Most of the work on host-plant resistance in cereals has concentrated on other aphid species, such as *Schizaphis graminum* and *Sitobion avenae*, rather than *S. miscanthi*. However, resistant varieties are often effective against cereal aphid species complexes .

Biological Control

Native parasitoids and predators may play an important role in controlling outbreaks of *S. miscanthi* in cereals. The parasitoid *Aphidius uzbekistanicus* has potential as a biological control agent.

Pests of Fruits

India is the second largest producer of Fruits after China, with a production of 44.04 million tonnes of fruits from an area of 3.72 million hectares. A large variety of fruits are grown in India , of which mango, banana, citrus, guava, grape, pineapple and apple are the major ones. Apart from these, fruits like papaya, sapota, annona, phalsa, jackfruit, ber, pomegranate in tropical and sub-tropical group and peach, pear, almond, walnut, apricot and strawberry in the temperate group are also grown in a sizeable area. Although fruit is grown throughout the country, the major fruit growing states are Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Bihar, Uttar Pradesh,Uttrakhand ,Punjab ,J&K and Gujarat. Fruit have a great demand in the international market. Therefore, they are one of the potential earners of foreign exchange.

Pests in fruits can have a negative economic impact on individual commercial producers and on the entire fruit industry. In addition to indigenous species and strains, there is a threat from the spread of foreign pests and diseases that could impact on the Indian fruit production industry. Many insect attacks on fruit crops or trees in India. Although some affect production in nearly all locations, many others are of only local significance. Relatively few species cause significant crop loss in their own right, and are only a problem when the population exceeds damaging thresholds. The less important species may at times require special attention, especially if their natural enemies have been disrupted by chemical sprays.There are a few pests affecting leaves, flowers and fruit, and some others causing fruit crops deaths or decline. Some of the main pests of fruits are Fruit borers like *Conopomorpha sinensis* Bradley, Fruit-piercing moths such as *Eudocima (Othreis) fullonia* (Clerck), *Eudocima salaminia* (Cramer) and *Eudocima jordani* (Holland), Leaf-feeding caterpillars like *Oxyodes scrobiculata* F. and *Oxyodes tricolor* Guen., Leafrollers like *Olethreutes perdulata* Meyr., *Platypeplus aprobola* (Meyrick), *Adoxophyes cyrtosema* Meyr., *Homona coffearia* Nietne, Beetle borers such as The longicorn beetle, *Aristobia testudo* (Voet), *Uracanthus cryptophagus,* Scarab beetles like The elephant beetle, *Xylotrupes gideon* (Linnaeus), Soft scales like *Pulvinaria* (*Chlorpulvinaria*) *psidii* (Maskell), Fruit flies, Gall flies. It is very important that we can recognise early signs of pests and diseases in our crops in order to deal with the problem.

***Ophideres fullonia/ Eudocima fullonia,* (Clerck, 1764) / *Othreis fullonia* / Fruit sucking moth**

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Ophideres (Eudocima)*

Species: *fullonia* Clerck, 1764

Distribution

This Fruit sucking moth is native to the Indo-Malaysian region, and found in large parts of the tropics. It is widespread throughout the Pacific basin, Asia, and Africa. It is not recorded in the Americas. Some countries where it is found include Australia, China, India, Japan, Korea, the Philippines, Papua New Guinea and Thailand. It was also reported in Kauai, Hawaii, Maui, Molokai, New Zealand and the Society Islands.

Main Host Plants

The *Ophideres fullonia* attacks many fruit and vegetable crops. Fruit crops infested by this moth includes *Actinidia chinensis* (Chinese gooseberry), *Anacardium occidentale* (cashew nut), *Ananas comosus* (pineapple), *Annona squamosa* (sugar apple), *Artocarpus altilis* (breadfruit), *Artocarpus heterophyllus* (jackfruit), *Averrhoa carambola* (carambola), *Capsicum annuum* (bell pepper), *Carica papaya* (pawpaw), *Casimiroa edulis* (white sapote), *Chrysophyllum cainito* (caimito), *Citrus limon* (lemon), *Citrus reticulata* (mandarin), *Citrus sinensis* (navel orange), *Citrus x paradisi* (grapefruit), *Coffea arabica* (arabica coffee), *Cucumis melo* (melon), *Dimocarpus longan* (longan tree), *Erythrina variegata* (Indian coral tree), *Ficus carica* (fig)fruits, *Litchi chinensis* (lichi), *Malus sylvestris* (crab-apple tree), *Mangifera indica* (mango), *Musa* (banana), *Opuntia* (Pricklypear), *Prunus americana* (American plum), *Prunus domestica* (plum), *Prunus persica* (peach), *Prunus salicina* (Japanese plum), *Psidium cattleianum* (strawberry guava), *Psidium guajava* (guava), *Punica granatum* (pomegranate), *Solanum lycopersicum* (tomato), *Vitis vinifera* (grapevine), apricots, bananas, kiwifruit and star fruit. Vegetable crops attacked include tomatoes and melons. The fruit sucking moth larvae develop on plants belonging to the Menispermaceae family, especially the creepers belonging to the *Tinospora, Tiliacora, Triclisia*, and the *Stephania* genuses.

Insect Biology

Life Cycle

Eudocima phalonia is a fruit piercing moth. The adult is considered an agricultural pest, causing damage to many fruit crops by piercing it with its strong proboscis in order to suck the juice. The duration of the life cycle from egg to egg-laying adult female was 35 to 49 days in colder conditions and 30 to 33 days in the warmer conditions. Their generations are continuous throughout the year.

Eggs

The moth have small hemispherical eggs are about 1/25 inch (1 mm) in diameter and are colored yellowish green. When moth populations are low, a single female moth lays her eggs in batches of up to 100. When moth populations are high, eggs are laid in batches of several hundred eggs by individual females. Eggs are generally laid on the underside of leaves but may be found on the bark or on other plants nearby. Eggs hatch in 3 to 4 days.

Larvae

This moth has 5 larval instars, separated by 4 molts. After each molt, the discarded skins are eaten by the newly emerged caterpillars. Caterpillars are cylindrical in shape and are 1/5 to 1/3 inch long during the first larval stage. They reach up to two inches in length when fully grown. Like other caterpillars belonging to the Noctuidae family, they have eight pairs of legs - three pairs under the thorax, four pairs in the middle portion of the abdomen. The first pair of leg is rudimentary), and the last pair at the end of the abdomen. The last segment (the 11th) is considerably humped, a feature that develops during the second instar. They are either dark green to black or pale green to yellow. The dark coloration occurs when larval densities are high, and the light colored larvae are found with isolated larvae. On the second and third abdominal segments, there are paired, lateral markings resembling eyes. On the upper surface of the body, they have numerous small creamy-white spots and bars edged with black that tend to coalesce in some places.

Pupae

Matured larvae of fruit sucking moth pupates within a cocoon spun between leaves and woven together with silk. The leaves containing the cocoon may remain on the host plant or dry and fall to the ground. Pupae are very dark brown with a purplish cast and about 1-1/8 inch (28 mm) long. Pupation lasts for 14 to 21 days. If pupation occurs under very dry conditions the adult may not be able to emerge successfully.

Adults

The adult moth is large and robust. It has a wingspan of almost 4 inches (10 cm) and a stout body, about 2 inches (5 cm) long that does not extend, or slightly extend beyond the hindwings. The eyes are large. The area behind the head of the moth, the thorax, is pale to purple-brown and the abdomen is pale brown at the base brightening to yellow-orange at the tip. The forewings resemble a leaf by being olive to purple-brown and may have white and green colored flecks. Usually the colored flecks are more common on females. This leaf-like appearance of the forewings makes this moth protective and it is difficult to see when it is at rest, especially, because the bright hindwings are not visible. The outer edges of the female's forewings are scalloped or toothed where those of the male's are evenly curved. The hind wings are bright orange, have a black comma-shaped mark and are fringed by a black border with white dots. After emerging from the pupa, females have a preoviposition period of 4 to 8 days before she begins to lay her eggs. Each female may lay up to 750 eggs during her lifetime. Females live for 27 to 30 days and males 26 to 28 days.

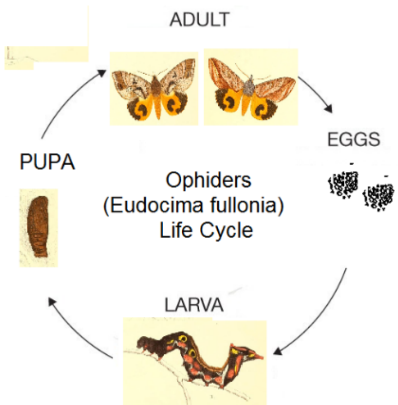


Figure: Life cycle of *Ophiders fullonia*

Nature of Damage

In case of most moth and butterfly pests, the damaging stage is usually caterpillar stage but the *Ophiders fullonia* differs in this aspect because it is the adult moth that is the damaging stage, and the larvae are essentially not harmful. The mouth parts of the moth are about an inch long and strong enough to penetrate through tough-skinned fruit. Once the moth has punctured the skin of the fruit, a process that usually takes a few seconds, it feeds upon the juices of the fruit. Feeding occurs at night and the fruit does not have to be ripe to be fed upon by this moth. Fruit flesh damaged by this moth becomes soft and mushy differing from fruit damaged by fruit flies which is more liquid.

Fruits are damaged not only a result of the direct feeding of this moth but also by the secondary infection which is fungal and bacterial infections that develop at the wound site. This moth is a known vector of *Oospora citri*, a fungus that rots the fruit and has a penetrating odor that attracts this moth. Other microorganisms that gain entrance into the fruit and cause rotting include *Fusarium* sp., *Colletotrichum* sp., and several types of bacteria. When moths are abundant green fruit is attacked, causing premature ripening and dropping of fruits. On oranges, a green fruit turns yellow at the site of the piercing and fungi soon develop within the wound. On tomatoes, the puncture of the tomato skin causes the fruit to turn white and quickly rot.

Incidence of damage by this moth is normally low, however when outbreaks occur, most of the crop is affected. Caterpillars mostly feed between 5:00 PM and 10:00 AM, but may feed at any time. They are usually located beneath or on the edges of leaves. Young larvae drop to the ground at any sign of danger, while the older larvae take an aggressive attitude by hanging on to the food plant with their hind legs and swaying the rest of their body from side to side.

Although their flight is slow and heavy adult moths are very strong fliers and can travel great distances from their breeding grounds in search of food. Adults fly mainly between the hours of dusk and 11:00 PM. They are not usually attracted to light. When disturbed, the moth flares its forewings, exposing its conspicuous hindwings.

Control

Cultural and mechanical Control

- Once the moth has begun to feed, it is not easily disturbed so it can be captured easily by fruit netting and killing of moths is possible. This is best accomplished an hour after sunset when there is sufficient darkness with the aid of torches or a strong flashlight. This method is most feasible when fruit are easily accessible and populations of this moth are small. This method is not very effective once a large population of this moth exists.

- This fruit sucking moth is negative towards light and it usually avoids light, therefore the illumination of orchards was tested as a possible means of preventing fruit-piercing moth attack.
- By mechanical protection of fruit against moth attack was achieved by covering the fruit with brown paper or transparent oil paper bags. Brown paper bags last for about a month in the field and the transparent oil paper bags may be used for up to two seasons if the weather is not very wet. This method is most practical when each individual fruit is of significant value or when fruits are easily accessible and are of large size or relatively compact bunches. Although this method is labor intensive, it is especially good if regular attention cannot be given to the crop or it is desired to have the fruits fully ripen on the trees.
- By smoking of the Orchard the moth can be confused from of the the odor of the smoke with the odor of mature and ripening fruit that attracts the moth. Containers full of inflammable material, oil, tar and some green plant trimmings to enhance the smoke were placed within the orchard at a rate of 2 to 4 per acre. The smoking process was started a half an hour before dusk and continued for 2 to 3 hours after nightfall. This period represents the time in which the moths are seeking their night time feeding grounds.
- Orchard Sanitation method can be applied, this involves the regular collection and proper disposal of all attacked and spoiled fruits. Both fallen fruit and attacked fruit on the tree should be collected, buried deeply or boiled in water for 10 minutes then broken up for compost. These procedures dissipate the odor emanating from the spoiled fruit so they cannot serve as an attractant for the moths.
- When severe infestations are predicted, infestation may be avoided by forced harvesting the entire crop as soon as signs of fruit ripening is observed. This should be done only when revenue loss from premature harvesting is less than that from possible damage.

Chemical Control

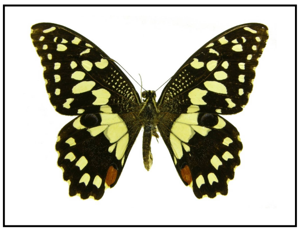
- The chemical baits are effective in control of fruit sucking moths. Repellents like taste repellents or odor repellents are also effective. Odour is the initial attractant for getting the moths to the host sight, control methods using repellent sprays focus on odour repellents. Citronella oil sometimes is also effective against these moths.

Biological Control

- The low incidence of damage by this pest is attributed to the effectiveness of its natural enemies throughout most of the world. The common parasites of the *Ophiders fullonia* are *Trichogramma chilonis* (Trichogrammatidae) and *Euplectrus plathypenae* (Eulophidae).

Papilio demoleus, Linnaeus, 1758 (swallowtail butterfly , lemon butterfly, citrus swallowtail)

Systematic Position



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Papilionidae

Genus: *Papilio*

Species: *demoleus* Linnaeus, 1758

Papilio demoleus is a common pest and invasive species from the Old World. It is commonly known as the lime butterfly, lemon butterfly, lime swallowtail, small citrus butterfly, chequered swallowtail, dingy swallowtail and citrus swallowtail. These common names refer to their usual host citrus plants. Unlike most swallowtail butterflies, it does not have a prominent tail.

Distribution

The lime swallowtail, *Papilio demoleus* Linnaeus, is widely distributed and is an extremely successful invader. This species is found throughout tropical and subtropical regions of southern Asia, ranging from Saudi Arabia, Iran and the Middle East to India, Nepal, southern China, Taiwan, and Japan. It is also found in Malaysia, Indonesia, New Guinea, and Australia. In recent years, *Papilio demoleus* has been recorded in the Dominican Republic, Puerto Rico, and Jamaica also.

Main Host Plants

Papilio demoleus feeds on plants of the Rutaceae family. It is known to feed on virtually all species and varieties of citrus plants like *Citrus limon*, *Glycosmis pentaphylla* (Jamaica mandarin orange), *Ruta graveolens* (common rue), *Aegle marmelos* (golden apple), *Murraya koenigii* (curry-leaf tree), and *Chloroxylon swietenia* (East Indian satinwood). *Papilio demoleus* has been observed ovipositing on *Citrus aurantium* (bitter orange) and *Citrus aurantifola*

The Australian and New Guinean populations feed on Fabaceae. They have been observed on species of *Cullen australasicum* (tall verbine), *Cullen badocanum*, *Cullen balsamicum*, *Cullen cinereum*, *Cullen patens* (spreading scurf-pea), *Cullen pustulatum*, *Cullen tenax* (tough scurf-pea), and *Cullen leucanthum*. They are also found on *Soralea pinnata* (fountain bush), and *Microcitrus australis* (Australian lime). They are known to oviposit on Rutaceae: *Citrus aurantium* (bitter orange) and *Citrus aurantifola* (Key lime).

Insect Biology

Life Cycle

Papilio demoleus is capable of producing multiple generations per year depending on temperature constraints. Nine generations may be seen near equatorial region. The average length of a generation varies from 26 to 59 days. In colder climates, pupae may overwinter.

Eggs: Usually females lay eggs singly near the edges of the host citrus plant leaves. The eggs are pale yellow in colour of nearly spherical shape, about 1.5 mm, basally flattened, and smooth.

Larvae: In *Papilio* five instars are observed during its life cycle. First instar stage is black with a black head, with two sub-dorsal rows of short fleshy spines. Second, third, and fourth instars stages have a dark brown, glossy head capsule. The anterior, middle, and posterior parts have broad transverse off-white bands, giving larvae a bird dropping like camouflage pattern. There is an additional row of paired fleshy spines on the thorax. The head is brown, smooth and glossy, with short hairs. In fifth instar stage there is a cylindrically shaped and tapered anteriorly. Two pairs of fleshy spines are located posteriorly and again immediately behind the head. These spines are very short, and gradually change from yellowish-orange to green. They have rows of orange or pink spots edged with black laterally and subdorsally with black transverse markings located anteriorly, with more scattered black markings laterally and at the rear end. There is a white sub-lateral line along the abdominal area just above the legs. The fleshy spines are orange. The head is large and brown with a dull orange inverted V mark. The osmeterium is yellow at the base to orange at the tips. This fleshy, forked structure is located on the head of the larvae of swallowtail butterflies. It is normally hidden but can be everted when the caterpillar feels threatened. It emits smelly compounds that prevent some predators.

Pupae: The pupae are stout, wrinkled and about 30 mm long. They are attached to the thicker stems of the host plant, or to adjacent sticks and rocks. The colour is dimorphic, typical for many swallowtails, being either pale green or pink-brown with other variable cryptic markings. The green form is usually marked dorsally with yellow. The colour pattern imitates the dominant surrounding color to which the pupa is attached. The pupal duration for development is variable, it is about 30 days in spring, while 18 days in summer, but often those pupae formed in captivity in lab conditions during autumn will not produce adults until the following spring, or even longer.

Adults: The adults butterfly size ranges in wingspan from 80-100 mm. The hindwing is devoid of tail. The upper portion of the forewing is largely black and the outer wing margin has a series of irregular yellow spots. Two yellow spots are present at the upper end of the discal cell with several scattered yellow spots in the apical region. The upper hindwing has a red tornal spot and the discal black band is dusted with yellow scales. The underside is paler yellow with the black areas more heavily dusted with yellow. The adults fly in every month but are more abundant after monsoons.

This butterfly is an avid mud-puddler and visitor of flowers. It basks with its wings held wide open on tufts of grass, herbs and generally keeps within a metre above the ground, even on cloudy days. It relies on its quick flight for escape. It is an interesting butterfly in that it has a number of modes of flight. In the cool of the morning, the flight is slow considering that it is an edible and unprotected swallowtail. As the day progresses, it flies fast, straight and low. In the hotter part of the day, it may be found settling on damp patches where it will remain motionless, except for an occasional flutter of wings, if not disturbed. It is also a frequent visitor of flowers in gardens, where it shows a preference for flowers of smaller herbs rather than larger plants such as the ubiquitous *Lantana* with its plentiful blooms. It was found that emerged imagines of *Papilio demoleus* shows preference while feeding for blue and purple colours while the yellow, yellowish-green, green and blue-green colours are completely neglected.

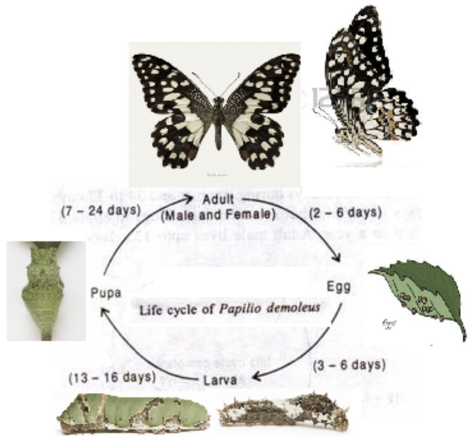


Figure - Life cycle of *Papilo demoleus*

Nature of Damage

The New World arrival of this easily movable lepidopteran pest is a potential threat to the citrus industries in the India. The larvae are a serious pest of citrus nursery stock trees and other young citrus trees in Asia and the Middle East, where they are capable of defoliating entire nursery groves. Larvae may utilize young leaf flush on more mature trees. Larvae are voracious feeders of tender leaves and defoliate the trees. They eat leaves from margin inwards, leaving the larger veins intact. *Papilio* infestation can cause defoliation and death of younger plants.

Control

Mechanical control-

The Papilio larvae is prominently visible on the leaves so it is easily hand picked and destroyed but this practice requires intensive labor if butterfly infestation is high.

Chemical control-

Dusting the trees with sodium fluosilicate or BHC 5% or spraying malathion, endosulfan, parathion, fentrothion 0.02% or lead arsenate 0.25% effectively controls the pests orchards. Severe infestations are generally controlled by applying chemical pesticides or plant extracts to the foliage, e.g. carbaryl, phosalone, acephate, pirimiphos-methyl, fenitrothion, permethrin, etc.

Biological control-

The different concentrations of the biopesticides like spores of *Bacillus thuringiensis* and *Beauveria bassiana*, as well as of neem seed kernel extract, neem oil and azadirachtin can be used against *P. demoleus*. Spraying of *B. thuringiensis* can control the 100 % pest population after 5 days of application.

The egg-parasites, *Trichogramma evanescens, Petromalus luzonensis* and *Telenomus* sp. destroy large number of eggs. The larval parasites, *Erycia nymphalidaephaga, Charops* sp. and *Brachymeria* sp. have also been recorded on this pest. The other parasitoids known for parasitizing *Papilio demoleus* larvae in India are *Apanteles* (=*Ooencyrtus*) *papilionis*, *Apanteles* sp., *Bracon hebetor* (Hymenoptera: Braconidae). Egg parasites like *Ooencyrtus malayensis* Ferriere (Hymenoptera: Encyrtidae) and *Tetrastichus* sp. (Hymenoptera: Eulophidae), larval parasites, *Erycia nymphalidophaga* Baronoff (Diptera: Tachinidae), pupal parasites - *Brachymeria* sp. (Hymenoptera: Chalcididae) and *Pteromalus puparum* Linnaeus (Hymenoptera: Pteromalidae). Other natural enemies of larvae are predatory pentatomid bug, *Cantheconidea furcellata* (Wolff), reduviid bugs, spiders, sphecids, chameleons, and birds.

8.7 Summary

Insect pests can be a serious problem on paddy, sugarcane, sorghum, wheat and fruits crops. These insect pests can damage different parts of crops by reducing their yield and having a negative impact on their quality. Unaware and illiterate farmers are using synthetic pesticides to combat pests. Besides being hazardous to the farm workers' health and leaving toxic residues on crops.

8.8 Self-Assessment Questions

1. Define pest.
2. What are the main host plants of *Papilio demoleus*?
3. What are the control measures for *Macrosiphum miscanthi*?
4. Explain the life cycle of *Sciropophaga nivella* in details.
5. Write an essay on Pests of sugarcane crops.
6. Give a zoological name of following common insect pests names

a) Rice Gandhi Bug
b) White Sugarcane fly
c) African Army Worm
d) Sugarcane Top Borer
e) Spiny Leaf Beetle
f) Sorghum Shoot Fly
g) Oriental armyworm
h) Wheat Aphid

8 Explain the Biology, nature, extent of damage and control of *Ophideres fullonia*?

9 Describe the Biology, nature, extent of damage and control of *Pyrilla perpusilla*.

8.9 Reference Books

- Agricultural Pests of India and South-East Asia - A. S. Atwal, Publisher- Kalyani Publishers, 1986, ISBN-817096475X, 978817096475
- Forest Entomology - William Ciesla, Publisher- John Wiley & Sons, 2011, ISBN- 1444397877, 9781444397871
- Destruction and Useful Insect, Their Habits and Control, C. L. Metcalf, W. P. Flint and R. L. Metcalf, Mc Grow Hill Co. New York.
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- Hemsingh Pruthi : A Text Book of Agricultural Entomology
- Elements of Entomology- Rajendra Singh- Rastogi Publications.

Unit- 9

Storage products Pests and Pests of medical and veterinary importance

Structure of the Unit

9.1 Objectives

By the end of the chapter, the student would acquaint himself with- Storage Products Loss, Primary and secondary grain pests, Stored Products Pests - Systematic Position, Distribution, Food, Description, Life Cycle, Nature of Damage of *Sitophilus oryzae* Linnaeus, 1763 (The Rice Weevil), *Rhyzopertha dominica*, Fabricius, 1792 (Lesser Grain Borer, Grain weevil), *Trogoderma granarium,* Everts, 1898 (The Khapra Beetle), *Sitotroga cerealella,* Olivier, 1789 (The Angoumois Grain Moth), *Callosobruchus chinensis,* Linnaeus, 1758 (Pulse beetle), Stored Products Pest Management (Control)

The various Pests of Medical & Veterinary Importance - Systematic Position, Distribution, Hosts, Description, Life Cycle, Nature of Damage, Medical Importance (Diseases), Control of Mosquito (*Anopheles, Culex, / Aedes*), *Musca domestica* Linnaeus, 1758 (House Fly),*Tabanus atratus* (Horse Fly),*Stomoxys calcitrans,* Linnaeus, 1758 (Stable Fly, biting flies),*Xenopsylla cheopis,* Rothschild, 1903 (The Oriental Rat-Flea / Black Death), *Hypoderma lineatum* Devillers (The Bot / Warble Flies / Heel Flies, Gadflies), *Pediculus sps.* (Human Louse and Head Louse)

9.2 Introduction

Storage Products Loss

According to report by UN March, 2013 present world population is expected to reach 10.5 billion by 2050, further adding to global food security concerns. This increase translates into 33% more human mouths to feed, with the greatest demand growth in the poor communities of the world. In order to fulfil food demand in2050, food supplies would need to increase by 60%. This will be only possible by increasing production, improving distribution, and reducing the losses. Thus, reduction of post-harvest food losses is a critical component of ensuring future global food security.

Every year approximately one quarter and one third of the world grain crop is lost during storage by insect pests. The main reason behind this is improper storage management, in India, unscientific storing, rodents, insects and microorganisms accounts for nearly 10% wastage of food grains, a quantity good enough to feed at least fifty million people. Food storage continues to be an important problem from the time man learned to grow crops. Millions of tons of food-grains are either damaged or lost for want of adequate scientific knowledge and methods of storage. The loss is not merely in terms of quantity but also in quality of the food-grains. The qualitative loss is attributed to change in the various essential chemical constituents who retard the nutritive significance of the grains. Grain quality is severely reduced by insect damage. Many grain pests preferentially eat out grain embryos, thereby reducing the protein content of feed grain and lowering the percentage of seeds which germinate. Many stored grain pests include the lesser grain borer, rice weevil and rust red flour beetle causes both quantitative and qualitative losses. Stored-grain pests attack, consume, contaminate and make the grains unfit, either as food or as seed.

Insect pests also increase costs to grain growers both directly through the expense of control on the farm, and indirectly through the costs incurred by grain handling authorities in controlling weevils in bulk storages.

Grain insect pests may be divided into primary and secondary pests. Primary grain insects have the ability to attack whole, unbroken grains, while secondary pests attack only damaged grain, dust and milled products.

Primary grain pests

Insects considered as primary pests of stored products cause damage to stored grains by directly feeding on the grain at some point in their lifecycle. Primary pests will attack grains that are intact and stable. Whole sound grain is stable when its temperature and moisture content are below the levels needed for germination. Primary pest species often develop and reproduce very quickly when the conditions are optimal. This allows for large populations and, therefore, considerable damage to ensue within a matter of a few months.

Some examples of primary grain pests are

- ***Lesser grain borer (*****Rhyzopertha dominica*****)***
- ***Granary weevil (*****Sitophilus granarius*****)***
- ***Rice weevil (*****Sitophilus oryzae*****)***
- ***Angoumois grain moth (*****Sitotroga cerealella*****)***

Secondary grain pests

Secondary pests generally feed on grain that is damaged or is going out of condition. Damaged grain kernels have exposed endosperm that is accessible food for insects and fungi. The presence of secondary insect pests often indicates that the grain is not at optimal condition and that measures should be implemented to protect the grain from a further decline in quality.

Some examples of secondary grain pests are

- ***Rust-red flour beetle (*****Tribolium castaneum*****)***
- ***Confused flour beetle (*****Tribolium confusum*****)***
- ***Saw-toothed grain beetle (*****Oryzaephilus surinamensis*****)***
- ***Flat grain beetle (*****Cryptolestes** ***spp.)***
- ***Warehouse moth (*****Ephestia** ***spp.)***
- ***Indian meal moth (*****Plodia interpunctella*****)***
- ***Warehouse beetle (*****Trogoderma variable*****)***

On the basis of feeding behaviour stored grain pests are categorised as follows:

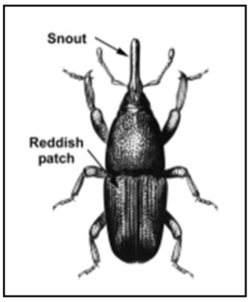
Paddy:	Rice weevil (*Sitophilus oryzae* (Linnaeus))
	Angoumois grain moth (*Sitotroga cerealella* (OIivier))
	Lesser grain borer (*Rhyzopertha dominica* (Fabricius))
	Siamese grain beetle (*Lophocateres pusillus* (Klug))
	Flat grain beetle (*Cryptolestes pusillus* (Schonherr))
Rice:	Maize weevil (*Sitophilus zeamais* Motschulsky)
	Rice weevil (*S. oryzae* (Linnaeus))
	Red flour beetle (*Tribolium castaneum* (Herbst))
	Rice moth (*Corcyra cephalonica* Stainton)
	Saw-toothed grain beetle (*Oryzaephilus surinamensis* (Linnaeus))
	Flat grain beetle (*Cryptolestes pusillus* (Schonherr))
Maize & sorghum:	Maize weevil (*Sitophilus zeamais* Motschulsky)
	Red flour beetle (*Tribolium castaneum* (Herbst))

	Corn-sap beetle (*Carpophilus dimidiatus* (Fabricius))
	Rice moth (*Corcyra cephalonica* Stainton)
	Tropical warehouse moth (*Ephestia cautella* (Walker))
Pulses:	Cowpea beetle (*Callosobruchus maculatus* (Fabricius))
	Southern cowpea beetle (*C. chinensis* (Linnaeus))
	Tropical warehouse moth (*Ephestia cautella* (Walker))
Cassava:	Coffee bean weevil (*Araecurus fasciculatus* (Degeer))
	Lesser grain borer (*Rhyzopertha dominica* (Fabricius))
	Cigarette beetle (*Lasioderrna serricorne* (Fabricius))

9.3 Pests of Stored Grains

Sitophilus oryzae **Linnaeus, 1763 (The Rice Weevil)**

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Curculionidae

Genus: *Sitophilus*

Species: *oryzae,* Linnaeus, 1763

DISTRIBUTION

The Rice Weevil is found quite abundantly throughout the warmer parts of the world, extending up to Baluchistan in Europe and Japan in the east. It is the commonest and, perhaps, the most destructive pest of stored grain throughout the world. The pest is found throughout India. These pests are carried all over the world in grain shipments and can establish themselves wherever there is food and where grain moisture and temperature are favourable.

FOOD

Rice weevils are usually found in grain storage facilities or processing plants, infesting wide variety of grains with preference for wheat, other food of rice weevil are oats, rye, barley, nuts, rice, and corn. They are sometimes found infesting beans, birdseed, sunflower seeds, dried corn, and flour products. It is also observed on processed cereal products such as pasta, macaroni and spaghetti etc. Rice weevils do not bite, nor do they damage wood or furniture.

DESCRIPTION

Adult weevils are about 3/32 to 1/8 inch long. The adult rice weevil is a dull reddish-brown to black with round or irregularly shaped pits (round depressions) on the thorax and four light reddish or yellowish spots on the elytra. The adult is with a cylindrical body and a long, slender, curved rostrum. It can fly and is attracted to lights.

In Palaearctic region the species is replaced by *Sitophilus granarium.* It is distinct from another allied species, the grain weevil, *Sitophilus granarium,* which is wingless with punctuate prothorax and elytra but without four yellow spots on elytra. Both the species are similar in size and appearance and are found together feeding upon rice, wheat, maize and other grains. The rice weevil may, however, be found in the paddy fields as well.

LIFE CYCLE

The rice weevil breeds from April to October and hibernates in winter as an adult inside cracks and crevices or under wheat bags in the godowns. During the active season, the females lay eggs on the grain by making a depression with the help of their mandibles. After an egg has been laid, the hole is sealed with a gelatinous secretion. The adult female rice weevil lays an average of 4 eggs per day and may live for four to five months. Female produces 250-400 eggs. A single generation can be completed in around 28 days. The eggs hatch in 6-7 days and the young larvae bore directly into grain, where they feed and grow to maturity. Then, they pupate inside the grain. The pupa, at first, is dirty white, but later on becomes dark brown. The full-grown larva is 5 mm in length, and is plump, fleshy legless creature, having a white body and a yellow-brown head and is humpbacked. The larvae feed inside the grain kernel for an average of 18 days. The pupal stage lasts an average of 5-16 days range. The new adult will remain in the seed for 3 to 4 days while it’s cuticle hardens and matures. On emergence, the adult weevil cuts its way out of the grain and lives for about 4-5 months. At least 3-4 generations are completed in a year.

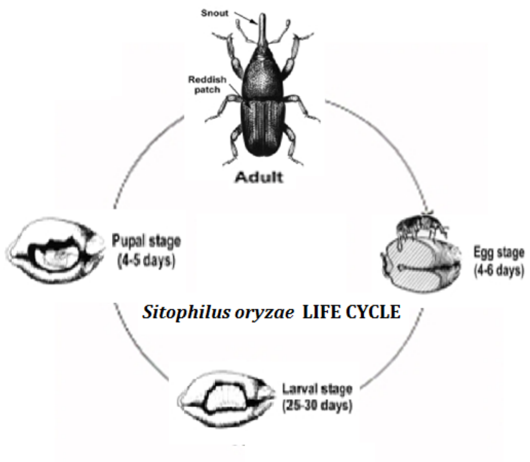


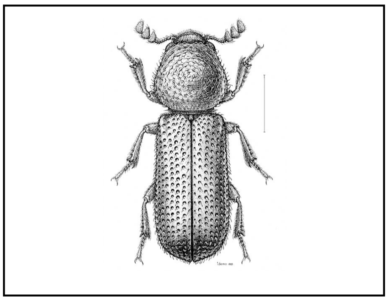
Figure: Life cycle of *Sitophilus oryzae*

NATURE OF DAMAGE

The rice weevils destroy more than what they eat. Heavy damage is caused by this pest to wheat, rice, maize and sorghum grains, particularly in the monsoon. It has also been reported feeding on oats, barley, cotton-seed, linseed and cocoa. Both (grubs) larva as well as the adult cause damage to grains. Larvae feed inside the seed and make in hollow and exit by making a circular hole on the surface. Adults can damage several seeds by cutting an irregularly lined circular hole, through which they feed on the kernel.

***Rhyzopertha dominica*, Fabricius, 1792 (Lesser Grain Borer, Grain weevil)**

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Bostrichidae

Genus: *Rhyzopertha*

Species: *dominica,* Fabricius, 1792

DISTRIBUTION

The lesser grain borer is thought to be originate from the Indian subcontinent but it now has a cosmopolitan distribution. The lesser grain borer is found throughout the tropical and also in temperate countries. It is a serious pest of dried stored products and most likely spread as a result of the international trade in food products combined with its strong flying ability.

FOOD

The lesser grain borer feeds mainly on maize, oats, barley, rice, millet, sorghum, wheat, durum wheat, chilli, coriander, turmeric, cassava, beans, ginger, wheat flour, and a variety of dried stored products. The lesser grain borer can be found mainly in cereal stores, buildings, shipping containers and food and animal feed processing industries.

DESCRIPTION

The adult *R. dominica* is 2-3mm long, reddish-brown in colour with a slim cylindrical shape. The elytra, which cover membranous hind wings, have regular rows of coarse punctures, finer at sides covered with curved setae. The front edge of the pronotum (plate-like covering of front segment of the thorax) has a saw-toothed appearance. The head is not visible when viewed from above and its antennae end in a distinctive 3-segmented club-shape.

LIFE CYCLE

R. dominica females lay between 200 and 500 eggs in their lifetime. The eggs are laid outside grains either singly or in clusters of up to about 20. The eggs are ovoid in shape, 0.6 mm in length, 0.2 mm in diameter, laid loosely in grains. They are white when first laid, and turn rose to brown before hatching. The larvae are white to cream coloured, with biting mouthparts and three pairs of legs. There are usually four larval instars. The larvae are scarabaeiform, the first two instars are not recurved, the third and fourth instars have the head and thorax recurved towards the abdomen. The widths of the head from the first to the fourth instar are 0.13, 0.17, 0.26 and 0.41 mm, and the lengths of the larvae are 0.78, 1.08, 2.04 and 3.07 mm, respectively. The young larvae are mobile in grain bulks but become immobile and gradually more C-shaped as they complete their development concealed within grain or flour. The pupae are 3.91 mm in length, with 0.7 mm between the eyes. At the end of the abdomen, the male pupae have a pair of 2-segmented papillae fused to the abdomen for their entire length, whereas female papillae are 3-segmented and project from the abdomen. Adults are emerged out by chewing through the outer grain layers. Adults are 2-3 mm in length, reddish-brown and cylindrical. The elytra are parallel-sided, the head is not visible from above, and the pronotum has rasp-like teeth at the front. They can live up to 240 days.

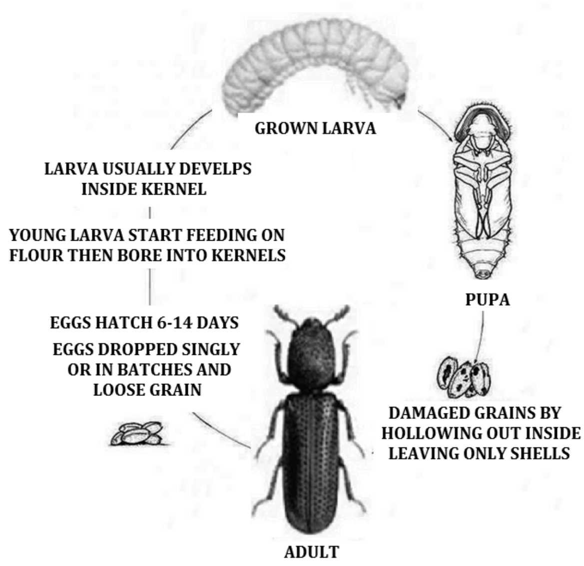


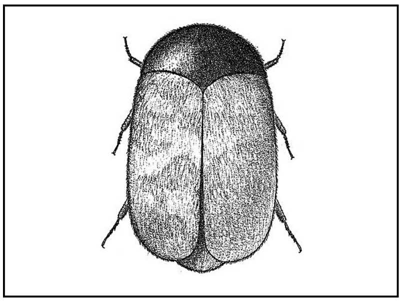
Figure: Life cycle of *Rhyzopertha dominica*

NATURE OF DAMAGE

The lesser grain borer is a serious pest of stored grain and cereal products. Both adult and larva damage the grain by boring or feeding the grains internally. The pest hollows previously undamaged grains, eating the starch. The holes are characteristic with an even edge. They feed on the entire grain apart from the bran leaving behind empty husks and flour.

***Trogoderma granarium,* Everts, 1898 (The Khapra Beetle)**

SYSTEMATIC POSITION



Phylum:	Arthropoda
Class:	Insecta
Order:	Coleoptera
Family:	Dermestidae
Genus:	*Trogoderma*
Species:	*granarium*, Everts, 1898

DISTRIBUTION

The khapra beetle is now found in almost all continents where grain and grain products are stored. Although a native of India, khapra beetle has gone abroad and has been reported from England, Germany, Israel and the USA. In the Indian Subcontinent, it is a very destructive pest of wheat and other grains, particularly in the north-western dry regions of Pakistan, Rajasthan, Haryana and Punjab. It has been described as one of the 100 worst invasive species worldwide.

FOOD

It is considered an important pest of *Arachis hypogaea* (groundnut), *Cicer arietinum* (chickpea), *Gossypium* (cotton), *Helianthus annuus* (sunflower), *Hordeum vulgare* (barley), *Oryza sativa* (rice), *Panicum miliaceum* (millet), *Pennisetum glaucum* (pearl millet), *Sesamum indicum* (sesame), *Sorghum bicolor* (sorghum), *Triticum aestivum* (wheat), *Vicia faba* (faba bean), *Vigna unguiculata* (cowpea), *Zea mays* (maize). Apart from above, the insect has also been recorded on poppy (Papaver somniferum), pulses, pistachio, walnut and other dried stored products.

DESCRIPTION

The adults are oblong-oval beetles, approximately 1.6 to 3.0 mm long and 0.9 to 1.7 mm wide. Males are brown to black with indistinct reddish brown markings on their elytra. The head is small, retractile and deflexed with short 11-segmented clubbed antennae. The antennae have a club of three to five segments, which fit into a groove in the side of the pronotum. The adults are covered with hairs. The males are distinguished from females by being smaller usually half the size of the females and darker, with more elongated terminal points of the antennae.

LIFE CYCLE

Adult khapra beetles have wings, but apparently do not fly and feed very little. Mated females live from four to seven days, unmated females from 20 to 30 days, and males from seven to 12 days. The insect breeds from April to October and hibernates in the larval stage from November to March in cracks and crevices of walls and floors or in other sheltered places. Copulation takes place 2-3 days after emergence, a male being capable of fertilizing more than one female. One to three days after copulation, the female begins to lay, on the grains, white translucent eggs, singly or sometimes in clusters of 2-5. The eggs are rather cylindrical, rounded at one end and narrow at the other. A female may lay 13-35 eggs in 1-7 days at the rate of 1-26 eggs per day, the largest number being laid on the first day. The incubation period varies from 3-5 days in June to 6-10 days in October. The viability of the eggs varies from 86 per cent in September to 58 per cent in October. A newly emerged yellowish-white larva is about 1.5mm long and has a brownish head. When full-grown, it is about 4mm in length and is brownish, with yellow-brown transverse bands across the body which has long hairy bristles. The integument between the segments and the ventral surface of the body is plate yellow. The male larva is full-fed in 20-30 days and the female larva in 24-40 days. Pupation takes place in the last larval skin among the grains. This stage lasts 4-6 days. The adults are incapable of flying. There are 4-5 generations in year.

NATURE OF DAMAGE

The adult beetle does not bore into host material but only young larvae feed on damaged seed and older larvae on whole grains. The greatest damage is done in summer from July to October. Only the larvae cause damage. The grubs eat the grain near the embryo or at any other weak point and from there proceed inwards. They usually confine themselves to the upper 50 cm layer of grains in a heap or to the periphery in a sack of grains. Since the larvae are positively thigmotactic, they can be collected by merely placing gunny bags on a heap of grain. Damage can be severe with weight losses of between 5-30% and in extreme cases 70%.

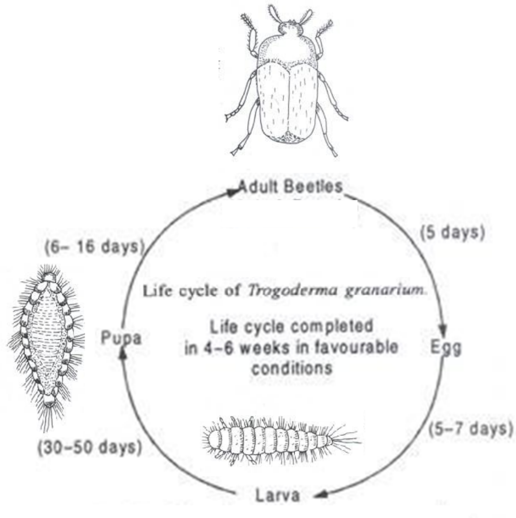
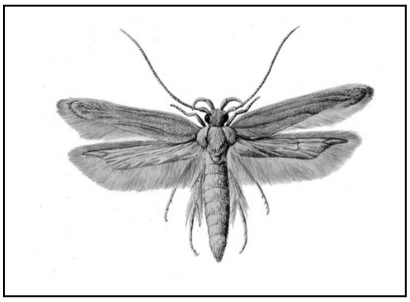


Figure: Life cycle of *Trogoderma granarium*

***Sitotroga cerealella*, Olivier, 1789 (The Angoumois Grain Moth)**

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Gelechiidae

Genus: *Sitotroga*

Species: *cerealella,* Olivier, 1789

DISTRIBUTION

It is commonly called as "Angoumois grain moth" because it was first described in 1736 from Angoumois province of France. This pest is found in almost all parts of the world and is one of the most destructive to the unmilled grains. In America it is commonly called "Fly Weevil". In Bengal it is known as 'Survi'. In the Indian Subcontinent, the pest is more abundant in the mountainous areas or where the climate is rather mild.

FOOD

It is considered an important pest of stored grain, such as *Triticum aestivum* (wheat), *Vigna unguiculata* (cowpea), *Zea mays* (maize), *Sorghum bicolor* (sorghum), *Arachis hypogaea* (groundnut), *Cicer arietinum* (chickpea), *Gossypium* (cotton), *Helianthus annuus* (sunflower), *Hordeum vulgare* (barley), *Oryza sativa* (rice), *Panicum miliaceum* (millet), *Pennisetum glaucum* (pearl millet), *Sesamum indicum* (sesame), etc.

DESCRIPTION

The adult is a buff, grey-yellow, brown or straw-coloured moth, measuring about 10-12mm in wing-expanse. The head, thorax and filiform antennae are pale brown; labial palpi are long, slender, sharply pointed and upcurved, pale brown with dark tips, terminal segment longer than second, second segment rough-scaled beneath. The forewing is elongate, pale brown or ochreous-brown, with a few black scales at the base of the dorsum and a concentration of black scales towards the apex. The hind wing is greyish-brown, apex greatly produced and abdomen is brownish in appearance. It can be distinguished from other common moths by the presence the narrow pointed wings fringed with long hair, most prominent along the posterior margin.

LIFE CYCLE

Generally breeding in the Angoumois Grain Moth takes place from April to October. After emergence, moths mate within 24 hours and the females start laying eggs singly or in batches on or near the grain. The eggs are small and white, when freshly laid, turning reddish later on. The egg is oval with the anterior (micropylar) end truncate and bearing longitudinal ridges and weaker transverse ridges. A single female lays on an average 150 eggs, usually within a week after mating. The eggs are laid singly or in clumps of variable numbers.

The newly emerged larvae bore into the grain where they will complete their development. The larva is rarely seen, because it completes its development within a single grain. The tiny caterpillar crawls about and penetrates the grain, effecting entrance generally through a crack or abrasion in the pericarp. The head is small and yellowish-brown and retracted into the thorax. The body of the larva is stout and yellowish-white, the peritreme of spiracles is brown. The prothoracic and anal plates are weakly developed and concolorous with the integument. The abdominal prolegs are weakly developed, each with no more than three crotchets. The anal comb is absent. It feeds on the kernel and remains there for the rest of its life. The full grown caterpillar is about 5.0 mm long. The rate of development is dependent on temperature, humidity and the host. The incubation period is about 4-8 days in summer. A silken cocoon is spun, inside which reddish-brown pupa is formed. The larval stage lasts for 2-3 weeks.

The final-instar larva spins a silken cocoon and changes to a reddish-brown pupa. The abdominal spiracles are slightly raised and the pupal cremaster has one dorsal and two lateral, short, stout spines. Later, the adult emerges, by pushing aside the seed-coat that covers the exit. After one week of the pupation period, the young moth emerges through the thin seed-coat left by the caterpillar.

The newly emerged adult comes out through the window of the seed coat, leaving a small, but characteristic, round hole, usually in the crown end of the grain. Adults are strong fliers and can disperse easily. However, they are not strong and are can only infest the outermost layers of stored grain if it is closely packed. Several generations are completed in a year.

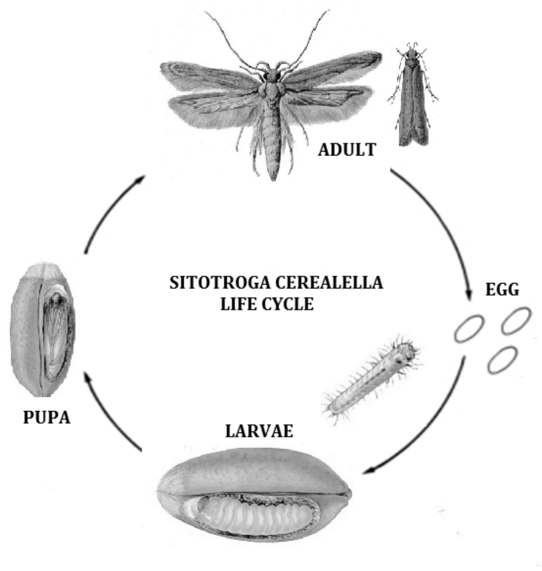


Figure: Life cycle of *Sitotroga cerealella*

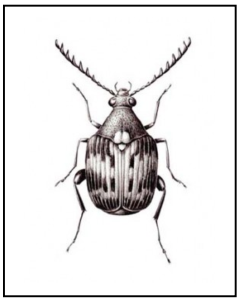
NATURE OF DAMAGE

Only whole cereals are attacked, greatest damage occurs in the upper layer grains in bags, bins etc. The damage is maximum during the monsoon. Infestation starts in the field itself as damp grain is preferred for oviposition. The initial infestation takes place when the young grain is in or passing through the 'milk stage' in the field and usually a small percentage of grain kernels are infested in the beginning. Larvae is the main damage causing stage. The larva bores its way into the grain. Due to the small size of larva the hole made in grain is difficult to detect. It is often noticed that after the larva enters into the grain, it turns about and spins a silken web over the opening through which it has entered, thus making it even more difficult to locate the entrance hole once it is inside the grain, the larva eats out the kernel. The infected grains are hollowed out by the larvae and replaced by their excrement and webbing.

The larva bores into the grain and feeds on its contents. As it grows, it extends the hole which partly gets filled with pellets of excreta. Usually, about 30-50 per cent of the contents are consumed, but some-times the larva finishes off the entire grain. With infestation the grains give out an unpleasant smell and present an unhealthy appearance, each grain being covered with scales shed from the moths. In a heap of grain, it is the upper layers that are most severely affected.

***Callosobruchus chinensis*, Linnaeus, 1758 (Pulse beetle)**

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Chrysomelidae (Bruchidae)

Genus: *Callosobruchus*

Species: *chinensis,* Linnaeus, 1758

DISTRIBUTION

C. chinensis displays a cosmopolitan distribution pattern and has been spotted in most countries due to the commercial export of beans. The pulse beetle is distributed in the tropics and subtropics of Asia, and their population has grown extensively since the cultivation and distribution of legumes. Their distribution is heavily influenced by human production and they only live by legumes that are suitable for them to mate on and their larvae to feed on. Both the larvae and the adults feed on the legume.

FOOD

C. chinensis is a major pest of chickpeas, lentils, green gram, broad beans, soybean, adzuki bean and cowpeas in various tropical regions. It also attacks other pulses on occasions, but appears to be incapable of developing on common beans (*Phaseolus vulgaris*). It prefers cowpea (*Vigna catjang*) but it also infest the seeds of different pulses such as red gram, arhar, lentil, pea, small pea, mung, urid, moth, soyabean, khesari etc. It also causes damage to seeds in pods of red gram in the field.

DESCRIPTION

C. chinensis adults are 2.0-3.5 mm long. The antennae are pectinate in the male, and serrate in the female. The elytra are pale brown, with small median dark marks and larger posterior dark patches, which may merge to make the entire posterior part of the elytra dark in colour. The side margins of the abdomen have distinct patches of coarse white setae. In common with other species of *Callosobruchus*, *C. chinensis* has a pair of distinct ridges (inner and outer) on the ventral side of each hind femur, and each ridge has a tooth near the apical end. The inner tooth is slender, rather parallel-sided, and equal to (or slightly longer than) the outer tooth.

LIFE CYCLE

The life cycle of the most economically important species of bruchid is relatively short. Under optimal conditions complete development takes place in as little as 22-25 days. The optimum temperature for oviposition is 23°C. As the eggs are laid, they are firmly glued to the surface of the host seed, smooth-seeded varieties being more suitable for oviposition than rough-seeded varieties. The eggs are domed structures with oval, flat bases. When newly laid they are small, translucent grey and inconspicuous. Eggs hatch within 5-6 days of oviposition. Upon hatching, the larva bites through the base of the egg, through the testa of the seed and into the cotyledons. Detritus produced during this period is packed into the empty egg as the insect hatches, turning the egg white and making it clearly visible to the naked eye.

The developing larva feeds entirely within a single seed, excavating a chamber as it grows. The larvae chew tunnels through the bean until it is ready to pupate. Mature adults emerge from the bean, biting a neat circular exit from the pod as soon as 25 days after hatching. The adult beetles live up to two weeks after emerging from the pupa. The optimum development conditions for *C. chinensis* are around 32°C and 90% RH. The minimum development period is 22-23 days for *C. chinensis*, pupation taking place within the seed 26 days after oviposition.

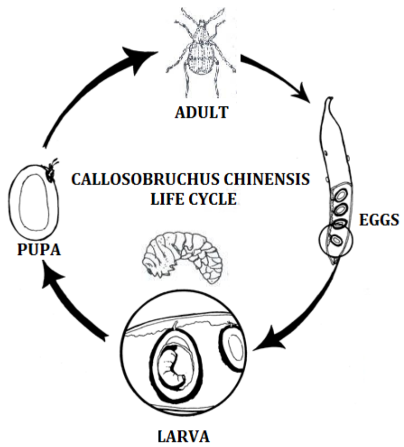


Figure: Life cycle of *Callosobruchus chinensis*

NATURE OF DAMAGE

Callosobruchus chinensis is a very serious primary stored pest, causing enormous damage to almost all kind of pulse grains. Infestation may start in the pods before harvest and carry over into storage where substantial losses may occur. Levels of infestation may be high. Damage to the pulse grain is mainly caused by the developing larvae. Just after hatching young larvae bores into the grain, feed upon the contents of the grain making them almost hollow and empty.

STORED PRODUCTS PEST MANAGEMENT (CONTROL)

Physical control

Physical control of stored grain pests involves the manipulation of the temperature, relative humidity, atmospheric composition (air gases composition), sanitation, ionizing radiation and the removal of adult insects from the grain either by sieving or air. All these practices may be helpful in eliminating or reducing insect pest infestations to a tolerable level.

Sieves

- Damaged grain can be differentiated from normal grains. The infested grain usually give off a sweet smell. Sieving a sample of grain is the simplest detection method but it will only detect adults and larvae that are outside the grain. It will be difficult to detect or isolate eggs or early larval pest instars.
- In Indian Families use of hand sieves is a very ancient and traditional method to isolate pests from stored grains or products. Hand sieves are commonly used for assessing the foreign matter content of small samples of grain. Round-framed sieves or square-framed sieves with a diameter of 300 to 310 mm are used. Each set of sieves should be provided with a bottom receiver, for the collection of filtered material passing through the screens, and a lid to prevent spillage during the sieving.
- Sack sieves are used for assessing foreign matter content of grain more accurately by screening the contents of whole sacks.
- A sack sieve should possess two essential features a hopper for feeding grain gradually on to the screen and a screen and a

screen that moves during the sieving operation. The slope of a moving screen should ensure that the grain is kept in motion towards the discharge end. Lateral movement of the screen, as in a rotary type of sieve, is more efficient in separating out foreign matter than the end-to-end movement of other kinds of mechanical sieve.

Sanitation and hermetic sealing

Cleaning during grading operations, drying, cool storage and hermetically sealed packaging can all play an effective role in conserving the seed viability with residue free pest control.

Grain packaging in airtight structures is one of the most important physical methods controlling pests. The structures should be pressure-tested to confirm airtightness. Portable hermetic storage bags are also available.

Removing insects by sieving is not equally effective for all species as several insect species, spend most time of their life cycle remaining inside the grain or kernel. Impacting the grain, either by moving the grain using a pneumatic conveyer or dropping the grain onto a spinning, studded disc, can reduce pest's populations by over 90%. Good sanitation, particularly the removal of spilt grain around storage facilities, is a preliminary step in reducing insect populations that can infest grain in storage.

Aeration and drying

One of the more effective non-chemical control methods is to cool the grain with aeration fans, which gradually suppresses insect population growth in the storage period. Aeration starting from harvesting, using automatic fan controllers, allowed safe storage of grain for several months.

A moisture content of 25% is not uncommon in newly harvested grain in humid regions, but grains with 14% mc can be safely stored for 2-3 months. For longer storage periods, from 4-12 months, the moisture content must be reduced further. Reducing grain moisture content reduces the number of eggs produced and the survival of offspring and adults. There are 3 types of drying: ambient air drying, sun drying and mechanical drying. In ambient air drying system, air is heated and passed through grain to produce a relatively high vapour pressure gradient between the moisture in the grain and the moisture in the drying air. This gradient causes moisture to move from the grain into the air, where it is then exhausted from the grain bulk to the outside atmosphere. In many countries in Asia, Africa, and Latin America grain drying is achieved by spreading a thin layer of grain in the sun, on the threshing floor or on rooftops. A mechanical way to remove the water from wet grains is by blowing (heating) air through the grain. Mechanical drying of wheat grain is not practiced in many the developing countries, which largely rely on sun drying.

Radiation

Radio-frequency heat treatment is increasingly used as a new thermal method for the disinfection of post-harvest insect populations in agricultural commodities. The application of this method leaves no chemical residue and provides acceptable product quality with minimal environmental impacts. More recently, a flameless catalytic infrared emitter was used to disinfest hard red winter wheat containing different life stages (eggs, larvae, pupae and 2-week-old adults) of *R. dominica*.

Airtight storages

When grains are stored in an airtight container, the oxygen content in this container will decrease slowly due to the metabolism of the grains, insects and microorganisms until there will not be enough oxygen for any insect development. Airtight storage is an attractive way to protect produce against insects without pesticides, but often the costs of constructing suitable silos prevent their general use. For airtight storage on a small scale, oildrums or plastic bags may be used.

Temperature Control

Since most stored product insects cannot tolerate extreme temperature, heating and cooling are logical approaches to insect control. To some extent it has been a common practice to superheat some commodities for insect control. The temperatures of 55-60°C maintained for 10 to 12 hours are effective. Actually, these temperatures kill most insects very quickly but when the grain and materials are involved, the certain temperature must be kept for several hours to ensure complete penetration.

Low temperature is probably the most important single factor in making long term storage possible and economical. The insects become inactive and eventually die at a temperature below 12°C. Freezing quickly kills many insects. Low temperature is also important in maintaining seed viability.

Moisture Control

Most of the stored grain insects are unable to survive and reproduce in grain whose moisture content is below 9 per cent. Most favorable grain moistures for insect development ranges from 12 to 15 per cent. If, by various means, it is possible to reduce and maintain the moisture below than favorable for reproduction and development, then we have in effect, controlled the insects.

All agricultural products should be well dried before storage especially for storing in silos. A high moisture content tends to increase insect and mould development; to bacterial deterioration, and chemical changes in the produce. When the crop is ripe it still has a high moisture content. Under dry weather conditions the crop is usually left in the field to dry, but in the humid tropics artificial drying is often necessary.

Produce should not be stored at moisture contents higher than indicated below.

Paddy	15%
Rice, Maize, Wheat, Sorghum	13%
Millet	16%
Cowpeas, Beans	15%
Groundnuts, Cocoa Beans	7%

The manipulation of gases (nitrogen (N_2), oxygen (O_2) and carbon dioxide (CO_2) within storage structures has been widely studied for the control of insect infestations. The two main approaches involve increasing CO_2 concentration and reducing oxygen in the storage vicinity. To control the insect infestations, oxygen levels must be maintained below 1% for 20 days, or carbon dioxide levels maintained at 80% for 9 days, 60% for 11 days or 40% for 17 days. The storage structures should be sealed properly before the addition of gases.

Biological control

- There are a few parasites and predators that attack the stored grain pests but their effectiveness in the field is uncertain. The fungus *Beauveria bassiana* can be used as a biological insecticide.
- Use of different types of predators like *Teretriosoma nigrescens*, a histerid beetle that is found in Central America, where it primarily feeds on *Prostephanus truncates*, a species closely related to *R. dominica*. It is able to feed on *R. dominica*. However, the ability of *T. nigrescens* to significantly reduce *R. dominica* populations has yet to be determined.
- *Xylocoris flavipes* (Hemiptera: Anthocoridae) is a predator of many stored product insect pest. The cadelle *Tenebroides mauritanicus* also feeds on grain, mites and stored-product insect eggs, including *Rhyzopertha*. The predatory mites *Cheyletus eruditus* and *Pyemotes ventricosus* feed on a wide variety of stored product insect eggs, but their effect on populations in the field has not been determined. Among the four *Cheyletus* species found in storage structures of Central Europe, only *C. eruditus* is employed for the biocontrol of stored grain insect pests.
- Most of the parasitoids that attack the primary beetle pests are in the families Pteromalidae and Bethylidae. These hymenopteran parasitoids are very small, do not feed on the grain and can easily be removed from the grains by using normal cleaning processes. *Choetospila elegans* is a small pteromalid wasp that attacks *R. dominica* and certain other coleopteran and lepidopeteran insect pests. The wasp normally parasitizes larvae that are feeding inside the grain. The hymenopteran parasitoid *Anisopteromalus calandrae* suppressed *R. dominica* populations in all types of storage bag except those made of polythene. The highest percentage (81%) suppression occurred in calico bags and the lowest suppression (57%) occurred in polypropylene bags. The egg parasitic mite *Acarophenax lacunatus* significantly reduces the population of *R. dominica*.
- The use of entomopathogenic fungi has been evaluated extensively in laboratory and field studies against different stored grain pests. The pathogenicity of entomophaghous fungi depends upon various physical (temperature, relative humidity, application time of fungal insecticide,

dark and light period etc.) and biological factors (the specific host species, host pathogen interaction etc.). Unlike other microbial control agents, fungi possess the ability to infect the insects through cuticle. *Beauveria bassiana* (Ascomycota: Hyphomycetes) and *Metarhizium anisopliae* (Ascomycota: Sordario) are the most extensively studies fungal species in this regard.

- By application of different botanical insecticides there can be effective control of various stored grain pests. Over the last 15 years, due to environmental concerns and insect pest resistance to conventional chemicals, interest in botanical insecticides has increased. Botanical insecticides are naturally occurring insecticides which are derived from plants. Compared to synthetic compounds they are less harmful to the environment, generally less expensive, and easily processed and used by farmers and small industries. Botanical insecticides are used in several forms, such as powders, solvent extracts, essential oils and whole plants, these preparations have been investigated for their insecticidal activity including their action as repellents, anti-feedants and insect growth regulators.
- Natural feeding inhibitors found in either wild or cultivated plants are usually alkaloids and glycosides. The mode of action of these compounds is complex and poorly understood, although it is found that insects exposed to such substances usually stop feeding, resulting in a decreased body weight or even death if the insects fail to feed for a long period of time.
- Plant essential oils and solvent extracts are the most studied botanical methods of controlling stored grain insect infestations. The essential oils obtained from different plant species repel several insect pests and possess ovicidal and larvicidal properties. Although they are considered by some as environmentally compatible pesticides, some botanicals, especially essential oils, are toxic to a broad range of animals, including mammals

Chemical Control

For the protection of stored produce against the insects the following groups of pesticides are used:

1. Insecticides

2. Fumigants

For the protection of store products, only pesticides with low mammalian toxicity should be used. Insecticides which are accumulated in the human body e.g. DDT are of course completely unsuitable for use on stored produce.

Insecticides may be used for spraying wall, floors and ceilings of warehouses or storerooms in order to kill a residual infestation. The insecticides can also be sprayed directly on bagged produce. This may prevent or delay reinfestation of insect-free produce. Insecticides may be mixed with the produce. This can give complete protection for a long period and may also kill pests which have already infested the produce. The best way however to disinfect produce, warehouses or storerooms, is by means of fumigation. The fumigants used penetrate into the grain or compressed products like tobacco and kill all insects. Some fumigants kill also micro-organisms. After fumigation, reinfestation must be prevented by insecticides or by storing the produce in an insect proof silo or container.

1) Insecticides

During the past years a number of other insecticides have become available, the use of few is permitted in several countries. The most important and commonly used insecticides are the following:

- Malathion - This is a safe insecticide which can be admixed to or sprayed on shelled (threshed) or unshelled (unthreshed) grains. On stored produce only premium grade malathion must be used. The product must be dry, (moisture content not higher than 13.5%) otherwise the malathion breaks down very fast.
- Pyrethrins - are mostly admixed with a synergist to increase their effectiveness and stability and to reduce costs. The shelf life of dust formulations is rather short.
- Bioresmethrin
- Bromephos
- Chlorpyrifos-Methyl
- Fenitrothion
- Pirimiphos-Methyl

- Tetrachlorvinphos

2) Fumigants

A fumigant is a chemical which at the required temperature and pressure can exist in the gaseous state in sufficient concentration to be lethal to a given pest organism. Many fumigants are available and several are commonly used throughout the world. Any confined space which can be made airtight, may be used for fumigations, e.g. silos, railway, trucks, ship holds, plastic bags, etc. Bagged produce is mostly fumigated under gasproof sheets.

The following are commonly used fumigants-

- Methylbromide. It penetrates easily in large stacks of bagged produce but, without a special circulation system its use in large silos is limited because of unsatisfactory distribution of the gas in the grain bulk. Methylbromide is highly toxic and rather sophisticated equipment such as gas cylinders piping systems, gas masks and gas detectors are necessary. The fumigation has to be carried out by trained personnel.

- Phosphine. This fumigant is available in the form of tablets (pellets or sachets). Moisture absorption liberates phosphine which is very toxic to insects. The tablets must be evenly distributed through the grain by adding them to the grain flow when a bin is filled. The tablets can also be inserted in or between bags which then must be covered by air-tight sheets. Since the development of phosphine starts some hours after application, the use of phosphine is easy, but gas masks are necessary when aerating large stacks.

- Liquid fumigants like carbon tetrachloride or mixtures of carbon disulphide, ethylene dibromide or ethylene dichloride and carbon tetrachloride are easier to handle as they are less toxic to man. The liquid is poured on the produce or left in trays to evaporate. Such a fumigation takes several days depending on the temperature and quantity of fumigant used.

MEDICAL AND VETERINARY ENTOMOLOGY

Medical entomology, or public health entomology, is focused upon insects and arthropods that impact human health. Medical entomology includes scientific research on the behavior, ecology, and epidemiology of arthropod disease vectors, and involves a tremendous outreach to the public, including local and state officials and other stake holders in the interest of public safety, efficient disease control, newly budding zoonotic diseases.

Veterinary entomology deals with arthropod pests and vectors of disease agents to livestock, poultry, pets, and wildlife. It is allied with the fields of medical entomology, parasitology, animal sciences, veterinary medicine, and epidemiology. The main pests of veterinary concern are sucking and biting lice, biting flies, nonbiting muscoid flies, bot flies, fleas, and Acari (mites and ticks).

9.4 Pests of Medical and Veterinary Importance

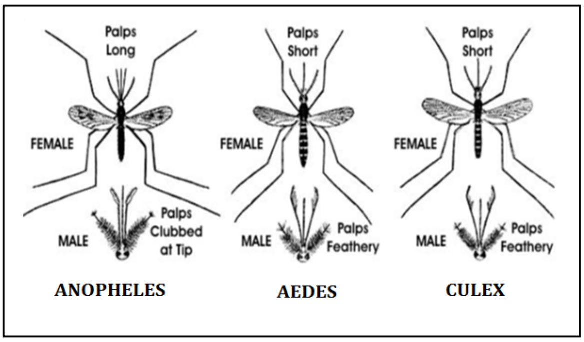
Insects and other arthropods have a great impact on human health and welfare directly and indirectly. These organisms have the capacity to inflict injury, disease, discomfort, or distress. They can be a direct cause of illness, pain, and suffering through bites and stings, infested wounds, or allergic reactions. They feed on blood or body tissues and they may transmit deadly pathogens or parasites. Economic losses associated with these pests are borne not only by the affected individuals and their families, but also by human society in general. Losses include not only the direct costs of medicine and health care, but also indirect costs resulting from stress, absenteeism, and reduced productivity. All of the arthropods that can pierce human skin have mouthparts that are especially adapted for piercing, cutting, or burrowing, causing or spreading various diseases. Some of the examples are:

1. Diptera (mosquitoes, black flies, horse flies, deer flies, stable flies, sand flies, and various biting midges)
2. Hemiptera, (bed bugs, assassin bugs, water bugs)
3. Thysanoptera (thrips)
4. Phthiraptera (sucking lice)
5. Siphonaptera (fleas)
6. Class Arachnida (spiders, mites, and ticks).

In this unit we are going to discuss some pests of medical and veterinary importance which are related directly or indirectly to our life.

Mosquito (*Anopheles* Meigen 1818 / *Culex,* Linnaeus, 1758 / *Aedes,* Meigen, 1818)

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Diptera

Family: Culicidae

Genus: *Anopheles* / *Culex* / *Aedes*

Mosquitoes belong to the sub-order Nematocera of the order Diptera and, all the 3,500 species described in the world so far, belong to the family Culicidae. The mosquitoes are a family of small, midge-like flies- the Culicidae. Although a few species are harmless or even useful to humanity, most are considered a nuisance because they consume blood from living vertebrates, including humans. The females of many species of mosquitoes are blood-eating pests. In feeding on blood, some of them transmit extremely harmful human and livestock diseases, such as malaria, yellow fever and filariasis. There are over 3,500 species of mosquitoes in the world, and most dangerous and common are *Culex*, *Anopheles*, and *Aedes* genera.

DISTRIBUTION

Mosquitoes inhabit almost all parts of the world except the polar regions. They inhabit up to 14,000 feet altitudes in Kashmir and 3,760 feet below the sea level in gold mines of South India. Their egg, larval and pupal stages are spent in water and therefore, the presence of water in the environment is essential for their breeding and existence. They commonly breed in marshy lands, near filthy stagnant ponds, cesspools, dump cellars, and standing rain or canal waters. The mosquitoes are among the most unwelcome biting pests because they cause irritation and itching. In India, about 350 species of Culicinae mosquitoes are in prevalence. Of these nearly 20 species are active in the transmission of human diseases.

HOSTS

The feeding habits of mosquitoes are quite unique in that it is only the adult females that bite man and other animals. The male mosquitoes feed only on plant juices. Some female mosquitoes prefer to feed on only one type of animal or they can feed on a variety of animals. Female mosquitoes feed on man, domesticated animals, such as cattle, horses, goats, etc; all types of birds including chickens; all types of wild animals including deer, rabbits; and they also feed on snakes, lizards, frogs, and toads. Most female mosquitoes have to feed on an animal and get a sufficient blood meal before she can develop eggs. If they do not get this blood meal, then they will die without laying viable eggs. However, some species of mosquitoes have developed the means to lay viable eggs without getting a blood meal.

DESCRIPTION

Mosquitoes are small (3-6 mm), two-winged insects belonging to the family Culicidae of the order Diptera (two-winged flies). They are easily distinguished from most other flies by a combination of the following characters: a long proboscis projecting forwards from the head; the presence of scales on the wing veins; a fringe of scales along the posterior margin of the wing; and a characteristic wing venation, the second, fourth and fifth longitudinal veins being branched. Males and females can be differentiated by the form of the antennae. In males they are very plumose, while in females they only have a few short hairs. In most others than *Anopheles* species the maxillary palps in the female are very short in contrast to the male where they are longer than the proboscis. (In both sexes of *Anopheles* the maxillary palps are long, but clubbed in the male.)

They are Holometabola with the first stage differing completely from the last one in form, structure and habits. Most of the common and important mosquitoes as transmitter of pathogens for animal and man belong to following genera: *Anopheles, Culex* and *Aedes*.

***Anopheles* mosquitoes**

They're the easiest genus to recognize because they rest with their body slanted, unlike other genera who keep their body level. Mosquito species in this group also breed during the warmer months. Females also deposit their eggs on the surface of water in groups of 50 to 200. The eggs hatch and go through the same developmental process as *Culex* mosquitoes. However, unlike other mosquito larvae, *Anopheles* larvae do not have breathing tubes, so they must lie parallel to the surface and breath through holes in their sides called spiracles. While *Culex* mosquitoes can breed and thrive in stagnant or polluted water, the *Anopheles* mosquitoes prefer clean water habitats in marshes, swamps, and rice fields, among others. The adult females usually live about two weeks and feed at dusk and dawn. They tend to feed on people and cattle, rather than other warm-blooded creatures. *Anopheles* mosquitoes are the carriers of the parasite that causes malaria and transmit the bugs through their saliva when they bite. More than one million deaths each year are attributed to malaria passed on by *Anopheles* mosquitoes.

***Culex* mosquitoes**

These mosquitoes tend to hibernate over the winter and breed during the warmer months, laying rafts of eggs at night on the surface of standing water anywhere it can be found. Over a period of about two weeks, the eggs hatch, larvae emerge, develop into pupae, and then into adult mosquitoes. They normally don't travel more than a few hundred yards from where they hatched. Adults feed primarily from dusk until a few hours after dark and are considered aggressive and persistent biters, although they prefer birds to people. Females need the protein in blood to develop eggs, which they lay about every third night. They can live up to a month. The most prevalent is the *Culex pipiens*, known as the northern house mosquito. It is the main carrier of West Nile virus.

***Aedes* mosquitoes**

The mosquitoes in this genera are floodwater mosquitoes, meaning they lay their eggs on moist soil or in containers that periodically catch rainfall. They prefer to breed in tree holes, overflow ditches, and old tires. The eggs can survive drying and hatch once flooded by water. They develop in a four-stage process like other mosquitoes. As a predominantly tropical and subtropical group, *Aedes* mosquitoes tend to breed in warm weather, although some species can survive in colder environments. The adults feed day and night, and several of the species are considered particularly troublesome. *Aedes vexans*, the inland floodwater mosquito, is known as a fierce and painful biter. Two *Aedes* mosquitoes are also carriers of dangerous disease. *Aedes albopictus*, the Asian tiger mosquito, transmits dengue fever and eastern equine encephalitis, while *Aedes aegypti*, the yellow fever mosquito, transmits dengue and yellow fever.

LIFE CYCLE

All mosquitoes must have water in which to complete their life cycle. This water can range in quality from melted snow water to sewage effluent and it can be in any container imaginable. The type of water in which the mosquito larvae is found can be an aid to the identification of which species it may be. Also, the adult mosquitoes show a very distinct preference for the types of sources in which to lay their eggs.

They lay their eggs in such places such as tree holes that periodically hold water, tide water pools in salt marshes, sewage effluent ponds, irrigated pastures, rain water ponds, etc. Each species therefore has unique environmental requirements for the maintenance of its life cycle.

The length of life of the adult mosquito usually depends on several factors: temperature, humidity, sex of the mosquito and time of year. Most males live a very short time, about a week; and females live about a month depending on the above factors.

The mosquito goes through four separate and distinct stages of its life cycle and they are as follows: Egg, Larva, pupa, and adult. Each of these stages can be easily recognized by their special appearance. There are three common groups of mosquitoes. They are *Aedes, Anopheles, Culex.*

Egg

- Eggs are laid one at a time and they float on the surface of the water.
- *Culex* mosquitoes usually lay their eggs at night. A mosquito may lay a raft of eggs every third night during its life span.
- *Culex* mosquitoes lay their eggs one at a time, sticking them together to form a raft of from 200- 300 eggs. A raft of eggs looks like a speck of soot floating on the water and is about 1/4 inch long and 1/8 inch wide.
- *Anopheles* and *Aedes* species do not make egg rafts but lay their eggs separately.
- *Culex* and *Anopheles* lay their eggs on water while *Aedes* lay their eggs on damp soil that will be flooded by water.
- Most eggs hatch into larvae within 48 hours.
- *Culex* mosquitoes lay their eggs on the surface of fresh or stagnant water. The water may be in tin cans, barrels, horse troughs, ornamental ponds, swimming pools, puddles, creeks, ditches, or marshy areas. Mosquitoes prefer water sheltered from the wind by grass and weeds.
- *Anopheles* mosquitoes lay their eggs singly on the water, not in rafts.
- *Aedes* mosquitoes lay their eggs singly on damp soil.
- *Aedes* eggs hatch only when flooded with water (salt water high tides, irrigated pastures, treeholes, flooded stream bottoms, etc.).

Mosquito Larva

- Mosquito larvae, commonly called "wigglers" or "wrigglers", must live in water from 7 to 14 days depending on water temperature.
- Tiny mosquito larvae emerge from the eggs within 24 hours.
- Larvae must come to the surface at frequent intervals to obtain oxygen through a breathing tube called a siphon.
- The larva eats algae and small organisms which live in the water.
- *Anopheles* are unlike *Culex* and *Aedes* larvae since they do not have a breathing tube, they must lie parallel to the water surface in order to get a supply of oxygen through a breathing opening.
- The larva live in the water and come to the surface to breathe.
- Most larvae have siphon tubes for breathing and hang from the water surface.
- *Anopheles* larvae do not have a siphon and they lay parallel to the water surface.
- The larva feed on micro-organisms and organic matter in the water.
- During growth, the larva molts (sheds its skin) four times.
- The stages between molts are called instars. At the 4th instar, the larva reaches a length of almost 1/2 inch.
- When the 4th instar larva molts it becomes a pupa.

Mosquito Pupa

- Mosquito pupae, commonly called "tumblers", must live in water from 1 to 4 days, depending upon species and temperature.
- The pupa is lighter than water and therefore floats at the surface.
- It takes oxygen through two breathing tubes called "trumpets".
- When it is disturbed it dives in a jerking, tumbling motion and then floats back to the surface.

- The pupa does not eat.
- The metamorphosis of the mosquito into an adult is completed within the pupal case.
- The adult mosquito splits the pupal case and emerges to the surface of the water where it rests until its body can dry and harden.
- The pupal stage is a resting, non-feeding stage.
- This is the time the mosquito turns into an adult.
- It takes about two days before the adult is fully developed.
- When development is complete, the pupal skin splits and the mosquito emerges as an adult.

Mosquito Adult

- Only female mosquitoes bite animals and drink blood. Male mosquitoes do not bite, but feed on the nectar of flowers.
- *Aedes* mosquitoes are painful and persistent biters, attacking during daylight hours (not at night). They do not enter dwellings, and they prefer to bite mammals like humans. *Aedes* mosquitoes are strong fliers and are known to fly many miles from their breeding sources.
- *Culex* mosquitoes are painful and persistent biters also, but prefer to attack at dusk and after dark, and readily enter dwellings for blood meals. Domestic and wild birds are preferred over man, cows, and horses. *Culex tarsalis* is known to transmit encephalitis (sleeping sickness) to man and horses. *Culex* are generally weak fliers and do not move far from home, although they have been known to fly up to two miles. *Culex* usually live only a few weeks during the warm summer months. Those females which emerge in late summer search for sheltered areas where they "hibernate" until spring. Warm weather brings her out in search of water on which to lay her eggs.
- *Anopheles* mosquitoes are the only mosquito which transmits malaria to man.
- The newly emerged adult rests on the surface of the water for a short time to allow itself to dry and all its parts to harden.

- Also, the wings have to spread out and dry properly before it can fly.
- The egg, larvae and pupae stages depend on temperature and species characteristics as to how long it takes for development.
- The following account show a comparative account of mosquito egg raft, larva, pupa, and adult.

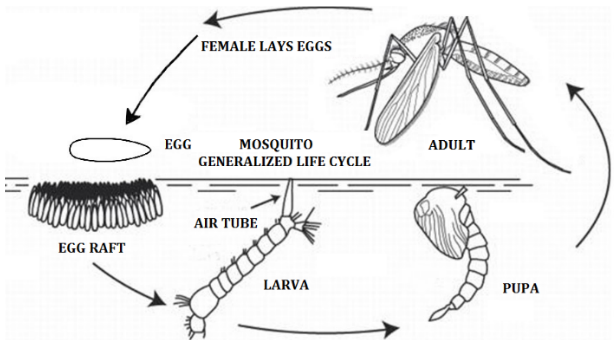


Figure – Generalized life cycle of mosquito

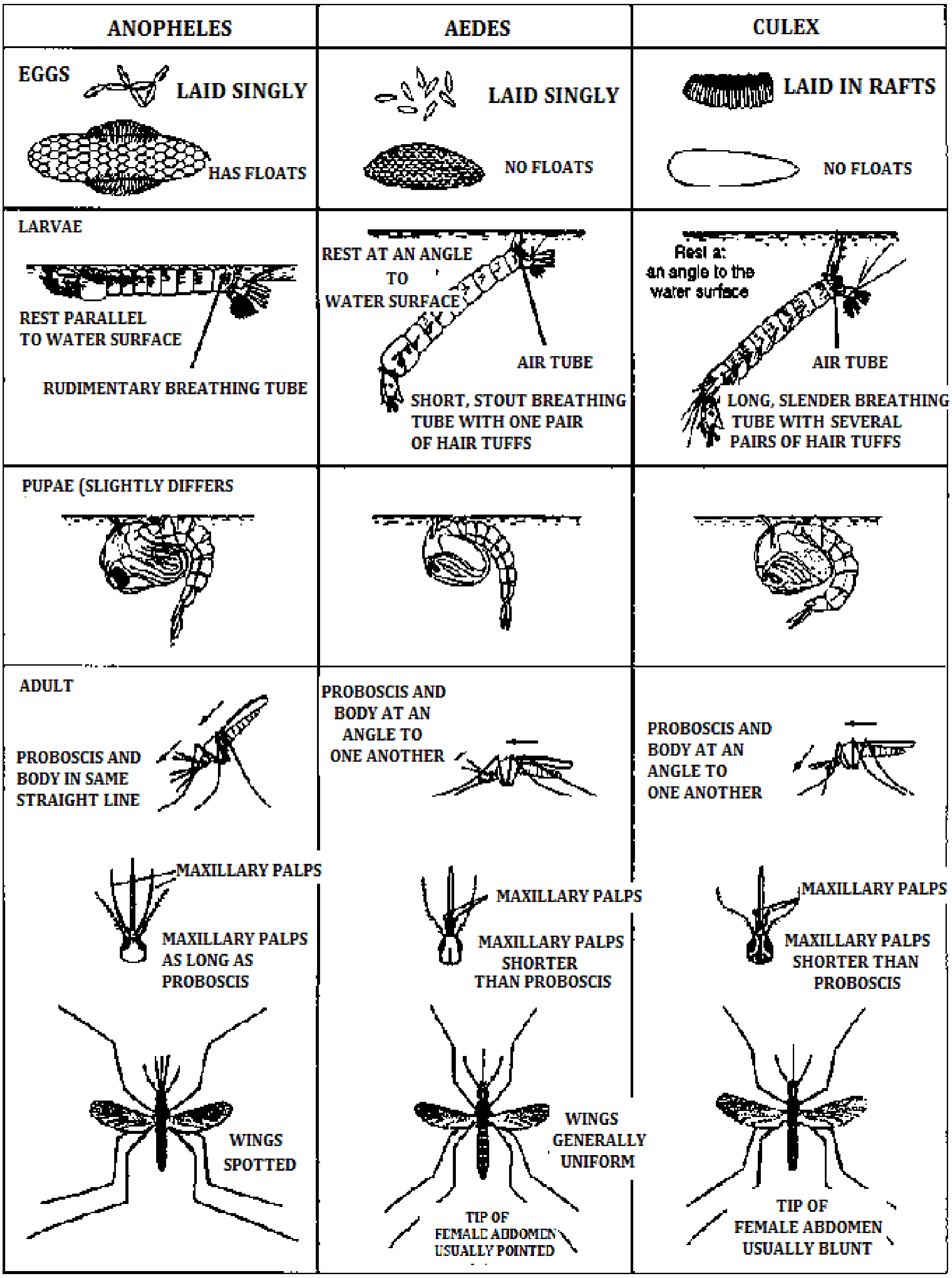


Figure- Comparison of *Anopheles, Culex & Aedes*

MEDICAL IMPORTANCE (DISEASES)

Mosquitoes can act as vectors for many disease-causing viruses and parasites. Infected mosquitoes carry these organisms from person to person without exhibiting symptoms themselves.

Mosquito-borne diseases include:

- Viral diseases, such as yellow fever, dengue fever and chikangunya, transmitted mostly by *Aedes aegypti*. Dengue fever is the most common cause of fever in travellers returning from the Caribbean, Central America, and South Central Asia.
- The parasitic diseases collectively called malaria, caused by various species of *Plasmodium*, carried by mosquitoes of the genus *Anopheles*
- Lymphatic filariasis (the main cause of elephantiasis) which can be spread by a wide variety of mosquito species.
- West Nile virus is a concern in the United States, but there are no reliable statistics on worldwide cases.
- Eastern equine encephalitis virus is a concern in the eastern United States.
- Tularemia, a bacterial disease caused by *Francisella tularensis*, is variously transmitted, including by biting flies.
- *Culex* and *Culiseta*are vectors of tularemia, as well as arbovirus infections such as West Nile virus.
- Mosquitoes as a group, transmit, in human being malaria (protozoan pathogen), Bancroftian and Malayan filariasis (nematode infection), and the arboviruses namely, the yellow fever virus, the breakbone or dengue haemorrhagic fever (DHF) and the dengue shock syndrome (DSS) viruses, the Chikun-gunya virus, Japanese encephalitis virus, the West Nile Fever virus, etc.
- *Culex pipiens fatigans* is the principal intermediate host of *Wuchereria bancrofti* and spreads filarial in urban areas, while the *Mansonia* spp. are the intermediate hosts of *Brugia malayi* and spread filaria in rural areas. *Aedes aegypti* and *Aedes albopictus.*

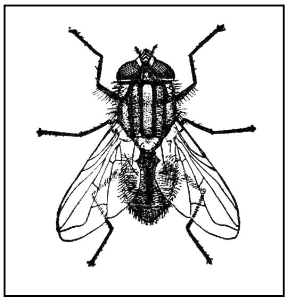
CONTROL

- The most efficient method of controlling mosquitoes is by reducing the availability of water suitable for breeding and larval and pupal growth.

- Large lakes, ponds, and streams that have waves, contain mosquito-eating fish, and lack aquatic vegetation around their edges do not contain mosquitoes; mosquitoes thrive in smaller bodies of water in protected places.
- Dispose of unwanted tin cans and tires. Clean clogged roof gutters and drain flat roofs. Change water in birdbaths, fountains, and troughs twice a week.
- Clean and chlorinated swimming pools and when they are not regularly used, they should be emptied.
- Several commercially available insecticides can be effective in controlling larval and adult mosquitoes. These chemicals are considered sufficiently safe for use by the public. Select a product whose label states that the material is effective against mosquito larvae or adults. For safe and effective use, follow the instructions for applying the material.
- For use against adult mosquitoes, some liquid insecticides can be mixed according to direction and sprayed lightly on building foundations, hedges, low shrubbery, ground covers, and grasses.
- Some insecticides are available as premixed products or aerosol cans. These devices spray the insecticide as very small aerosol droplets that remain floating in the air and hit the flying mosquitoes.
- Various commercially available repellents can be purchased as creams, lotions, or in pressurized cans and applied to the skin and clothing.
- Some manufacturers also offer clothing impregnated with repellents; coarse, repellent-bearing particles to be scattered on the ground; and candles whose wicks can be lit to release a repellent chemical.
- The effectiveness of all repellents varies from location to location, from person to person, and from mosquito to mosquito.

9.5 *Musca domestica* Linnaeus, 1758 (House Fly)

SYSTEMATIC POSITION



Phylum:	Arthropoda
Class:	Insecta
Order:	Diptera
Family:	Muscidae
Genus:	*Musca*
Species:	*domestica*

DISTRIBUTION

The house fly, *Musca domestica* Linnaeus, is a cosmopolitan insect pest of both outdoor and indoor area. This species is always seen in association with humans or the activities of humans. This is believed that the common housefly was originated on the steppes of central Asia, but now occurs on all inhabited continents, in all climates from tropical to temperate, and in a variety of environments ranging from rural to urban. The housefly is distributed all the world over and it assumes alarming proportions in hot and humid climates. In India, the common housefly belongs to main species, *Musca vicina* and *M. nebulo,* the latter being commoner. *M. domestica* Linnaeus occurs only in the temperate climate obtained in the Himalayas and other places.

HOST

Musca domestica is the most common species found in association with humans, on hog and poultry farms, horse stables and ranches. House flies causes a nuisance and can also transport numerous disease-causing organisms. Excessive fly populations are not only an irritant to farm workers but, when there are nearby human habitations, a public health problem could occur. It is commonly associated with dead and decay matter, animal feces, but has adapted well to feeding on garbage, so it is abundant almost anywhere people live.

DESCRIPTION

Adult houseflies have short antennae, a grey thorax with four darker longitudinal stripes, and a grey or yellow abdomen with a darker median line and irregular pale yellowish spot at the anterior lateral margins. The abdomen consists of 8 segments in males and 9 segments in females. In females, the first 5 segments are visible externally. The last 4 segments are normally retracted but they extend to make the ovipositor when the female lays her eggs. This allows females to bury the eggs several mm below the surface. Females are slightly larger than males. Like all flies (Diptera), houseflies have only one pair of wings. The second pair is reduced to halteres, which are used for balance. Their wings are translucent and fold back straight at rest. Houseflies are 4 to 8 mm long, and 6.35 mm long on average.

Like many other dipteran flies, mouthparts of adults are sponge-like. Mouthparts are comprised of two fleshy, grooved lobes called the labella, which are attached to the lower lip, known as the labium. The lower surface of these lobes contains numerous transverse grooves that serve as liquid food channels. Houseflies can only intake food in liquid form. The mouthparts are suspended from the rostrum, which is a membranous projection of the lower part of the head. The larvae have mouth hooks used to filter-feed on masses of bacteria

The stable fly, *Stomoxys calcitrans* (Linnaeus), superficially resembles the house fly, but bears stiff, elongated mouthparts modified for biting animals and people and feeding on blood. They are very persistent and usually bite around the ankles. Their life cycle and food sources are similar to house flies, although development is slower (20 to 25 days from egg to adult).

LIFE CYCLE

The breeding site suitable for house fly may be consists of dead and decay matter, horse manure, human excrement, cow manure, fermenting vegetable, and kitchen waste. It may be at place of swine, horse, sheep, cattle, and poultry. Fruit and vegetable cull piles, partially incinerated garbage, and incompletely composted manure also are highly favoured breeding sites.

The house fly shows a complete metamorphosis with distinct egg, larval or maggot, pupal and adult stages. The house fly overwinters in either the larval or pupal stage under manure piles or in other protected locations. Warm summer conditions are generally optimum for the development of the house fly, and it can complete its life cycle in as little as seven to ten days. However, under suboptimal conditions the life cycle may require up to two months. As many as 10 to 12 generations may occur annually in temperate regions, while more than 20 generations may occur in subtropical and tropical regions. Copulation takes place 24 hours after emergence and the females lay 15 to 150 small, white, elongate eggs in batches in heaps of manure faeces or any other type of filth.

Eggs

Each female fly can lay up to 500 eggs in several batches of 75 to 150 eggs over a three to four day period. The number of eggs produced is a function of female size which, itself, is principally a result of larval nutrition. Maximum egg production occurs at intermediate temperatures, 25 to 30°C. The white egg, about 1.2 mm in length, is laid singly but eggs are piled in small groups. Eggs must remain moist or they will not hatch. Female flies lay numbers of eggs in suitable larval food sources such as decomposing food in garbage, animal excrement or other decomposing organic materials.

Maggot

The incubation period varies from 12 hours to 12 days, depending upon the season. Eggs hatch within a day into small maggots. Early instar larvae are 3 to 9 mm long, typical creamy whitish in color, cylindrical but tapering toward the head. The head contains one pair of dark hooks. The posterior spiracles are slightly raised and the spiracular openings are sinuous slits which are completely surrounded by an oval black border. The legless maggot emerges from the egg in warm weather within eight to 20 hours. Maggots immediately begin feeding on and developing in the material in which the egg was laid.

The larva goes through three instars and a full-grown maggot, 7 to 12 mm long, has a greasy, cream-colored appearance. High-moisture manure favours the survival of the house fly larva. The optimal temperature for larval development is 35 to 38°C, though larval survival is greatest at 17 to 32°C. Larvae complete their development in four to 13 days at optimal temperatures, but require 14 to 30 days at temperatures of 12 to 17°C.

Pupa

When the maggot is full-grown, it can crawl up to 50 feet to a dry, cool place near breeding material and transform to the pupal stage. The pupal stage, about 8 mm long, is passed in a pupal case formed from the last larval skin which varies in color from yellow, red, brown, to black as the pupa ages. The shape of the pupa is quite different from the larva, being bluntly rounded at both ends. Pupae complete their development in two to six days at 32 to 37°C, but require 17 to 27 days at about 14°C). The emerging fly escapes from the pupal case through the use of an alternately swelling and shrinking sac, called the ptilinum, on the front of its head which it uses like a pneumatic hammer to break through the case.

Adult

The house fly is 6 to 7 mm long, with the female usually larger than the male. The female and can be distinguished from the male by the relatively wide space between the eyes (in males, the eyes are much closed). The head of the adult fly has reddish-eyes and sponging mouthparts. The thorax bears four narrow black stripes and there is a sharp upward bend in the fourth longitudinal wing vein. The abdomen is grey or yellowish with dark midline and irregular dark markings on the sides. The underside of the male is yellowish.

Adults usually live 15 to 25 days, but may be live up for two months. Without food, they survive only about two to three days. Longevity is enhanced by availability of suitable food, especially sugar. Access to animal manure does not lengthen adult life and they live longer at cooler temperatures. They require food before they will copulate, and copulation is completed in as few as two minutes or as long as 15 minutes. Oviposition commences four to 20 days after copulation. Female flies need access to suitable food (protein) to allow them to produce eggs, and manure alone is not adequate. The potential reproductive capacity of flies is tremendous, but fortunately can never be realized. They require food before they will copulate, and copulation is completed in as few as two minutes or as long as 15 minutes. Oviposition commences 4-20 days after copulation. Female flies need access to suitable food (protein) to allow them to produce eggs, and manure alone is not adequate.

The flies are usually inactive at night, with ceilings, beams and overhead wires within buildings, trees, and shrubs, various kinds of outdoor wires, and grasses reported as overnight resting sites.

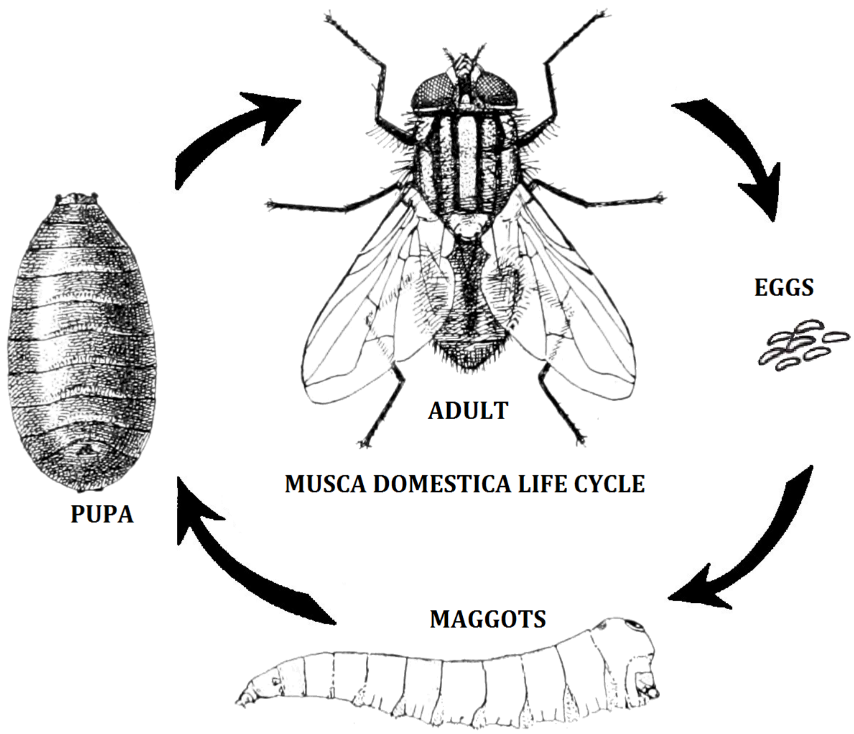


Figure – Life cycle of *Musca domestica*

MEDICAL IMPORTANCE (DISEASES)

Although *Musca domestica* does not bite, but its control is vital to human health and comfort in many areas of the world. The most important damage related with this insect is the annoyance and the indirect damage produced by the potential transmission of pathogens (viruses, bacteria, fungi, protozoa, and nematodes) associated with this fly. Pathogenic organisms are picked up by flies from garbage, sewage and other sources of filth, and then transferred on their mouthparts, through their vomitus, feces and contaminated external body parts to human and animal food. They are capable of carrying over 100 pathogens, such as those causing food poisoning, typhoid, cholera, salmonellosis, bacillary dysentery, tuberculosis, anthrax, ophthalmia, diarrhea, shigellosis and parasitic worms. Among the pathogens commonly transmitted by house flies are *Salmonella, Shigella, Campylobacter, Escherichia, Enterococcus, Chlamydia*, and many other species that cause illness.

The greatest damage done by flies is the contamination of food, resulting in the transmission of important infectious diseases to human beings and in the transmission of parasitic diseases to certain mammals and birds of agricultural importance. House flies feed on liquid or semiliquid substances beside solid material which has been softened by saliva or vomit. Because of their large intake of food, they deposit feces constantly, one of the factors that makes the insect a dangerous carrier of pathogens.

It is one of the four F’s in the epidemiology of these infectious diseases : faeces, fingers, flies and food. It also serves as an intermediate host for Helminthes, of which 3 species of tape worms are parasitic on poultry and 3 species of nematodes are parasitic on horses, mules and donkeys.

CONTROL

The more commonly used control measures for house flies are sanitation, use of traps, and insecticides, but in some instances integrated fly control has been implemented. The use of biological control in fly management is still at a relatively early stage.

Cultural control

- Cleanliness is the most important measure for housefly management. All the breeding suitable materials on which the flies can lay eggs must be removed, destroyed. Since the house fly can complete its life cycle in as little as seven days, removal of wet manure at least twice a week is necessary to break the breeding cycle. Wet straw should not be allowed to collect inside or near the buildings.
- Killing adult flies may reduce the infestation, but elimination of breeding areas is necessary for good management. Garbage cans and dumpsters should have tight-fitting lids and be cleaned regularly. Dry garbage and trash should be placed in plastic garbage bags and sealed up. All garbage receptacles should be located as far from building entrances as possible.
- Around homes and businesses, screening or covering of windows, doors or air doors, and trash containers proves useful in denying access of flies to breeding sites. Packaging household trash in plastic bags, and burying trash under at least 15 cm of soil and in sanitary landfills also helps to eliminate breeding. Trash cans and dumpsters should have tight-fitting lids; failing this, slow release fumigant insecticide dispensers are sometimes installed on the inside of the lids to reduce fly survival.
- In agricultural areas, manure can be scattered over fields so that it quickly dries and becomes unsuitable for egg and larval survival. Composting of manure can be effective if the compost is properly

maintained, including regular turning. Manure can also be liquefied and stored in lagoons anaerobically, though at some point the solids need to be separated.

Traps

- Fly traps may be useful in both indoors and outdoors for fly control. House flies are attracted to white surfaces and to baits that give off odors. Indoors, ultraviolet light traps collect the flies inside an inverted cone or kill them with an electrocuting grid. Recommended placement areas outdoors include near building entrances, in alleyways, beneath trees, and around animal sleeping areas and manure piles. Openings to buildings should be tightly screened with standard window screen, thereby denying entrance to flies.
- Traps can be baited with molasses, sugar, fruit or meat, and often are used in combination with a device that captures the attracted flies. The sex pheromone (Z)-9-tricosene also functions as an aggregation pheromone, and is called muscalure. Muscalure is formulated with sugar as a commercially-available fly bait for local population suppression, as well as an enhancement for population monitoring.
- Ultraviolet light traps can also be used to reduce housefly population levels.

Biological control

- Alternative house fly control strategies must be focussed with the increasing insecticide resistant house fly populations, rising costs of insecticides.
- Natural biological control of the house fly can be done primarily from the actions of certain chalcidoid wasps (Hymenoptera: Pteromalidae), *Muscidifurax* and *Sphalangia* spp. Ichneumonids and other parasitoids, as well as some predatory insects (especially histerids [Coleoptera: Histeridae] and staphylinids [Coleoptera: Staphylinidae]), etc.
- Periodic release of parasitoids during winter and spring, and following manure removal using insectary-reared parasitoids has been quite successful in some dairies, feedlots and poultry house situations. The species most often released for biological suppression are *M. raptor*, *M. raptorellus*, *S. endius*, and *S. nigroaenea*.

- The larva of the black dump fly, *Hydrotaea* (=*Ophyra*) *aenescens*, is also popular as a biological control agent for controlling house flies on poultry farms without the use of pesticides. The adult black dump fly is similiar in appearance to the adult house fly.

Integrated fly control

Integrated fly control programs for caged-poultry houses are based on the following strategy:

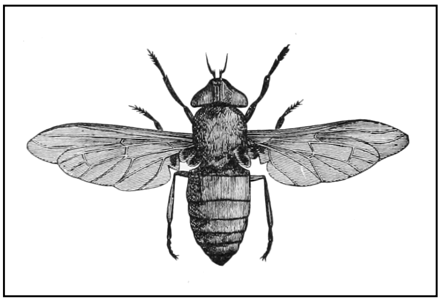
- Selective applications of insecticides against the adult,
- Start insecticide control measures early in the spring before flies appear and repeat as frequently as needed through the warm months.
- The manure is left undisturbed throughout the warm months when fly breeding may occur. The manure should be removed once very early in the spring before any flies appear.

Chemical control

- When the house fly is a major pest, the control of this insect is done by the application of adulticides, or larvicides to directly or indirectly suppress adult densities. Residual wall sprays can be applied where the flies congregate. Resistance to permethrin develops more rapidly in fly populations from farms on a continuous permethrin regime than in farms in which permethrin and diclorvos have been alternated.
- Outdoors, the control of flies includes the use of boric acid in the bottom of dumpsters, treatment of vertical walls adjacent to dumpsters and other breeding sites with microencapsulated or wettable powder formulation, and the use of fly baits near adult feeding sources.
- Indoors, the control of flies includes automatic misters, fly paper, electrocuting and baited traps that can be used in milk rooms and other areas of low fly numbers.
- Inside the houses, spraying the flies with DDT-5 per cent, malathion/diazinon 2 per cent, lindane/chlordane 1 per cent, or trichlorphon 0.5 per cent is effective in killing them.

9.6 *Tabanus atratus* (Horse Fly)

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Diptera

Family: Tabanidae

Genus: *Tabanus*

Species: *atratus*

DISTRIBUTION

Horse-flies are found all over the world except for some islands and the Polar Regions. These flies are found in most areas of India. There are more than 2,000 species of blood sucking flies in the family Tabanidae, of which about 150 occur in India. These true flies are often large and agile in flight, and the females bite animals, including humans, to obtain blood. They prefer to fly in sunlight, avoiding dark and shady areas, and are inactive at night.

HOSTS

The female fly bites and sucks blood from its shoots, which include horse, cattle, camel, elephant and sometimes man also. The females of *T. atratus* feed on mammalian blood, while males, which lack mandibles, feed on nectar and plant juices. A blood meal is necessary in order for females to nourish their developing eggs. Horseflies are diurnal, usually feed during the day. The mouthparts are made of six piercing organs: two mandibles, two maxillae, hypopharynx, and a labrum-epipharynx. The mandibles and the maxillae have sharp serrated teeth on them, which are used for puncturing the skin and rupturing blood vessels. The labrum then functions to lap up the pool of blood that is formed from the bite, otherwise known as telmophagy. When searching for a host, females are attracted to large, dark, moving objects and to CO_2. Larvae feed voraciously on other insect larvae, other invertebrates and small vertebrates. The horse flies are commonly seen more from June to August feeding on the blood of cattle, ponies, etc. other mammals.

DESCRIPTION

Horsefly is approximately 20-25 mm in length. These are entirely black, including the wings, or dark brown to blackish purple. *Tabanus atratus* have large compound eyes, which are dichoptic (separated) in females, and holoptic (continuous) in males. They have prominent mouthparts, which are easily distinguishable- The fascicle is made of six piercing organs. Starting from the outside, there are 2 flattened, bladelike mandibles with tooth like serrations used for cutting. Two narrow maxillae also serrated used to pierce the tissue and blood vessels of the host, a median hypopharynx and a median labrum-epipharynx. The hypopharynx and labrum-epipharynx make up the food canal, while the labrum is a large sponge like organ used to lap up blood. Short stout hairs cover the body, and wing venation is pronounced.

LIFE CYCLE

The *Tabanus* flies are densely populated in those areas where temperatures are moderately high, water is easily available and vegetation is present. They are particularly common during the monsoon when they are seen sitting on walls or on window panes. They like the sunshine and are active during the day-time only. Females generally attack the animals in the sun and a blood meal is essential for the maturation of eggs which are deposited in masses on aquatic and subaquatic vegetation as well as logs of wood near water.

Eggs are laid on stones or vegetation usually close to water. The egg masses are attached together with a thin layer of transparent material which is waterproof. The eggs are torpedo-shaped, 1-2 mm long and are white when freshly laid but become darker later on. In one cluster, there may be 300-600 eggs which hatch in 4-7 days.

On hatching, the larvae fall into water or moist earth, feeding voraciously on invertebrates, such as snails, earthworms and other insects. It is aquatic and feeds on small crustaceans or on the maggots of flies. Larvae can be white to brownish in colour, having a slender, cylindrical body, measures about 3.5 mm which tapers at the head. The larva of the black horsefly has twelve segments and a retractable tracheal siphon used for respiration. The retractable head of the larva has two sharp mandibles that can cause a painful bite. They pass through 7-8 instars and may complete their development in 9 days to almost 7 months, depending upon the species, season and food supply.

On completing their development, the larvae move to drier soil on the banks of streams to the edge of ponds or to similar aquatic habitats. The pupa is generally yellowish brown, finely wrinkled and has a lateral tuft of hairs on each abdominal segment. The pupae have a series of spines sticking out from the abdominal segments, and usually exhibit little movement. The pupal stage lasts from 3 to 21 days and the adult flies, on emergence, have iridescent eyes. The life-cycle is completed within 4-5 months and there are usually two generations in a year.

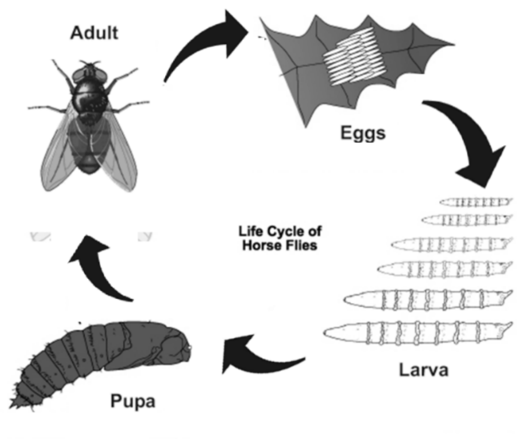


Figure- Life cycle of *Tabanus atratus*

MEDICAL IMPORTANCE (DISEASES)

- Usually *Tabanus atratus* do not bite humans, but when it bites seldom it is painful. This fly can also transmit bacterial, viral, and other diseases such as surra and anthrax, to both humans and other animals through its bite. These flies are well known vectors for some blood-borne bacterial, viral, protozoan and worm diseases of mammals, such as the equine infectious anaemia virus and various species of *Trypanosoma* which cause diseases in animals and humans. Tabanids are also known to transmit anthrax among cattle and sheep, and tularemia between rabbits and humans.
- The effect of *T. atratus* on livestock can be a serious problem. Blood loss and irritation from the flies can severely affect meat and milk production, as well as grazing. Livestock usually have no way of avoiding the painful bites, and millions of dollars have been spent trying to control these pests.

- Adult flies may pass a number of disease agents, nematode parasites to animals. Equine infectious anemia (EIA), or swamp fever, is mechanically transmitted to horses and other equines by horse fly bites. The other symptoms in animals include lethargy, weight loss and sometimes death.

- Anaplasmosis disease is found among cattle which causes symptoms of anemia, fever, weight loss and mortality.

- Localized swelling and an itchy red area around the *Tabanus* bite. Persistent itching and scratching of bite wounds that can cause secondary bacterial infections if the bite is not kept clean and disinfected. Since horse flies inject anticoagulant-containing saliva during blood feeding, some serious reactions may occur in people that are highly allergic to the anticoagulant compounds. Symptoms may include a rash on the body, wheezing, swelling around the eyes, swelling of the lips and dizziness or weakness.

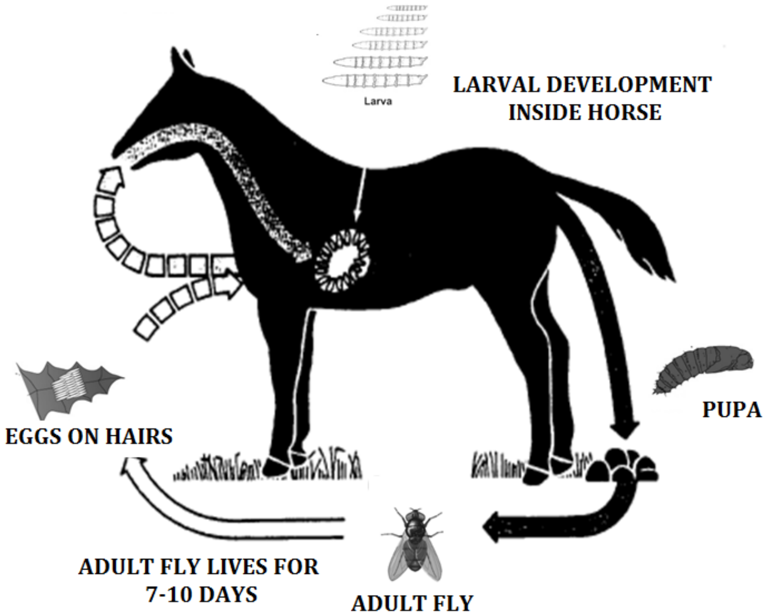


Figure- Life cycle of Horsefly

CONTROL

- Use of traps
  - *Light traps-* The lights on these traps are especially chosen to attract unwanted insects. When the insect lands on the light, it is either trapped on glue cards or zapped and killed instantly.

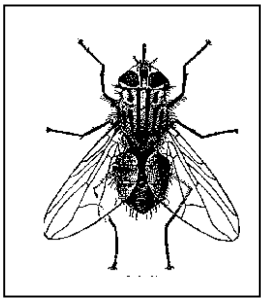
- *Flypaper*- This paper contains an adhesive that both attracts and traps house flies and horse flies.
- *Flies-be-Gone fly trap.* This trap holds fly food in a plastic bag for bait. The fly must enter the bag through funnel. Once inside the bag, the fly cannot escape.
- *Horse Pal fly trap*- These large traps have a target specifically designed to attract primarily visual hunters such as horse and deer flies. When the flies approach the target and see that it is not prey, they get trapped in the metal portion of the trap and die from the heat of the sun on the trap.

- **Chemical control -** Certain chemicals are used to control hourse flies
    - **Pyrethroids** (cypermethrin, fenvalerate, permethrin, resmethrin, tetramethrin, s-bioallethrin, sumithrin)
    - **Organophosphates** (coumaphos, dichlorvos, malathion, tetrachlorvinphos)
    - **Organochlorines** (lindane, methoxychlor)
- Use of aircraft, loggers, hydraulic sprayer or mist blowers to dispense the chemicals pesticides.
- Keep the animal areas clean by removing manure, old bedding and spilled feed. If needed, we can spray manure pile with insecticide to keep larvae from developing.
- There should be proper drainage systems in order to eliminate standing water.
- Horse flies can find a suitably moist and cool breeding ground in tall grasses and weeds. To avoid this, keep grasses trimmed and weed on a regular basis, especially along ditches.
- A barn, stable or doghouse should be shaded and windows and doors should be screened to prevent horse flies from entering.
- Use of ear nets, face masks and repellant tags or tapes for domestic animals.
- There are no effective biological control programs for controlling tabanids. There are native beneficial insects that target tabanids. Eggs are parasitizied by such Hymenoptera families as Trichogrammatidae,

Scelionidae and Chalcididae. Diapriidae and Pteromalidae (Hymenoptera) and Bombyliidae and Tachinidae (Diptera) parasitize the larvae and pupa. Tabanid adults are used as provisions for nest building wasps. Cattle egrets and killdeer are also tabanid feeders.

9.7 Stomoxys calcitrans, Linnaeus, 1758 (Stable Fly, biting flies)

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Diptera

Family: Muscidae

Genus: *Stomoxys*

Species: *calcitrans,* Linnaeus, 1758

DISTRIBUTION

Stomoxys calcitrans is a cosmopolitan insect, it can be found worldwide as long as suitable food and weather conditions can be met. Stable flies are worldwide pests of livestock and man. *Stomoxys calcitrans* is presently distributed worldwide and present in mostly all regions of India. The habitat of the stable fly, as its common name indicates that it is almost anywhere that horses, cattle, and other agricultural animals can be found especially inside barns and stables.

Stable flies are active during the summertime and are the most important pests of dairy and feedlot cattle in the state. Stable flies prefer to feed outdoors and rarely are found feeding or resting indoors. These flies are strong fliers and dispersion from one livestock facility to the next is common. Remain active into October, but the larval development slows as autumn temperatures decrease. At temperatures near freezing, larvae survive and continue to develop slowly in habitats such as piled silage or manure where fermentation generates heat.

HOST

The main host animals of stable flies are large mammals like cattle, horses, donkeys, dogs, swine, sheep, goats and camels, and other zoo animals. Stable flies also known as "biting flies" can deliver a painful bite. They bite people, livestock, pets and other mammals. The bites may feel like a needle stab and typically occur around the ankles and lower parts of the legs. Stable flies are very persistent when searching for a blood meal. They require the blood meal for reproduction. Stable flies overwinter in breeding sites and emerge the following spring as adults.

DESCRIPTION

The stable fly closely resembles the common housefly (*Musca domestica*). Unlike the common housefly, *Stomoxys calcitrans* have a broader abdomen. Adult stable flies average 8 mm in length, have a gray body, and can be identified by four characteristic longitudinal stripes across the thorax as well as several dark spots on top of the abdomen. On the vertex and frons there are three ocelli and two large compound eyes. Sexual dimorphism is clearly visible in this species, and there is more distance between the compound eyes in females.

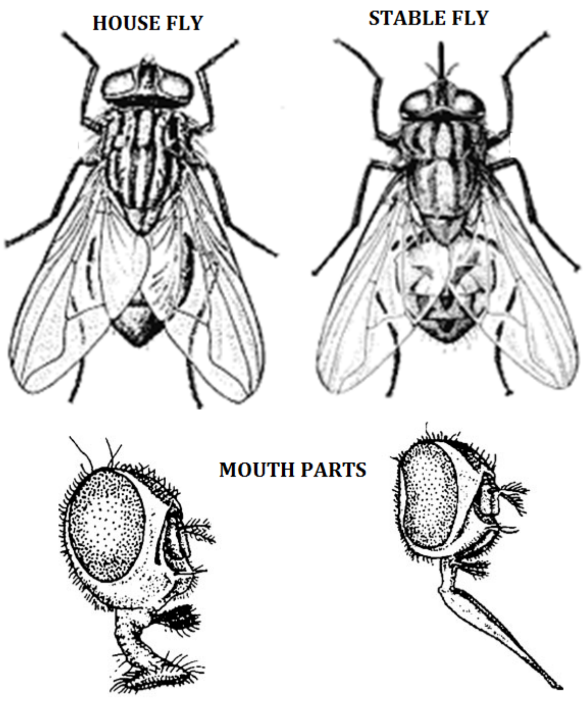


Figure – Comparison of House fly and Stable fly

The house fly and stable fly are similar in size, color and general appearance and they are often referred to as barnyard flies. On closer observation, these two flies are quite distinct in appearance, feeding habits and in the ways they annoy livestock, people, and pets. A distinguishing feature, visible to the naked eye that separates the two species is the distinct stiletto-like proboscis of the stable fly which extends forward beyond the head. This sharply pointed beak is used to pierce the skin and draw blood. The house fly cannot bite since it has sponging mouthparts. The proboscis of the stable fly is black, long, and thin, protruding from the front of the head. Its other mouthparts are modified, with the labellum having rows of teeth in order to pierce the skin of its host. The palps are one third of the length of the proboscis.

Stable flies are painful biting filth flies that resemble the house fly in appearance but just a tad bit smaller in size of approximately 5-7 mm long. The adults have a piercing and sucking proboscis that is used to extract a blood meal and seven circular black spots on a grey abdomen. Adult stable flies (Both the male and female) take one bloodmeal a day from the legs, sides, back and belly of large animals and the legs, head and ears of small animals. They are only in contact with the host for 2-5 minutes and then rest on surrounding buildings or vegetation.

LIFE CYCLE

After the mating, at least 3 complete feedings are required before egg laying can occur. Feeding requires 2 to 5 minutes, but since the flies are easily disturbed, several "bites" may be necessary to complete one feeding. Stable flies are capable of long flights in search of a blood meal. The early morning and late afternoon hours are commonly peak feeding times. Peak activity usually occurs during warm periods following rainfall.

Eggs are deposited in wet, organic materials such as straw, litter, manure mixed with straw or other bedding, vegetable or fruit matter, marine grasses on shore, grass clippings, waste silage or feed in feedlots or compost heaps. The female deposits 35 to 80 eggs at one time deep in the material, often in pairs or small clusters. Ten or 11 egg-laying periods occur during the life of 4 to 6 weeks of the stable fly.

Stable fly eggs hatch after 1 to 3 days into yellowish-white maggots. The eggs hatch in 1 to 3 days, and the young maggots immediately begin to feed, completing development in 14 to 26 days and grow beneath the surface of the breeding material. As in the house fly life cycle, the third-stage larvae seek drier environments for pupation, which lasts 5 to 26 days. Mature larvae are yellowish white maggots, and are a cylindrical shape that tapers anteriorly. The chestnut brown pupae have a reddish-to-dark brown exterior and are 4 to 7 mm long. The posterior spiracles on the puparia are black with three S-shaped yellow slits, and are lightly sclerotized.

Within an hour after emerging from pupa, the adult can fly and is ready to feed and mate soon afterwards. Females usually begin laying eggs 5 to 10 days after emergence. Total time of development from egg to adult averages from 21 to 25 days and several generations occur each year.

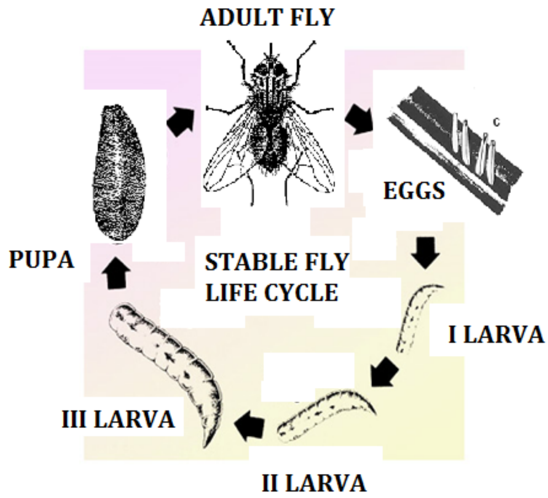


Figure – Life Cycle of *Stomoxys calcitrans*

MEDICAL IMPORTANCE

Stable flies are nuisance flies which inflict irritating bites. They can weaken livestock by their blood sucking activities. They also interrupt cattle's normal feeding and resting activities, which in turn reduces weight and milk production. Besides being vicious biters, stable flies may transmit animal diseases such as hog cholera. Cattle heavily infested with stable flies have been noted to become anemic and milking cows have been observed to show lower milk production. The stable fly bites humans at rest in the outdoors; generally the bite is almost painless. In many parts of the world, the species is a carrier of typanosomid parasites. Some of the reported parasites and diseases of which the stable fly might be a vector of include *Trypanosoma evansi* (the agent of Surra), *Trypanosoma brucei*, brucellosis, Equine infectious anemia, African horse sickness (AHS), and fowlpox. Stable flies are a developmental vector for *Habronema microstoma*, a spiruid nematode, which causes gastric and cutaneous forms of habronemiasis in horses throughout the world.

Stomoxys calcitrans is a daytime feeder. The adults of both sexes feed on blood. Although they feed mainly on the blood of cattle and horses but there is low host specificity. Adults locate a host by sight, and feeding is usually completed in two to five minutes. Stable flies like to feed on the lower parts of the hosts such as the legs and belly of horses and cattle. Cattle, horses, and people are typically bitten on the legs while dogs and swine are bitten on the ears. Even though, the female requires a blood meal in order to lay eggs, both male and female feed on blood.

After feeding the stable fly is sluggish, and remains motionless near the host. The stable fly will generally feed from many hosts before it is replete. Studies show that there is a rise in feeding during warm weather, whereas there is a decrease in feeding rates during rain. After hatching, the larvae begin feeding on local microbial flora and fauna.

CONTROL

- Trap can be used for control of stable fly adults. A Olson biting fly trap has a unique design that consists of a special fiberglass panel wrapped in a cylinder and attached to a stake 3-4 feet high. This trap is one of the only effective ways to collect stable flies when the sticky sleeve film is place around it. This trap are without pesticides for control measure of stable flies.
- Housing of domestic animals should be designed in such a way that there should be easy removal of manure and cleaning of stalls frequently. Waste should be disposed of properly by either burial, spreading in a thin layer on open fields, submersion in water, or aerobic composting.
- Use of baits, electric grids and traps may have some limited use for house fly control but are ineffective for the blood-feeding stable fly.
- Applications of different types of larvicides provide control against developing larvae. Products sprayed directly to the infested breeding sites can be utilized. Many of the larvicides on the market are known as IGR, insect growth regulators, and were developed specifically for horn flies and other filth flies developing in the manure, these do not affect stable fly larvae due to the fact that stable fly larvae do not grow in manure.
- Use of various Adulticides are very minimal and typically ineffective against stable flies. Due to the short amount of time spent on the animal and the location (legs), no products have a long enough residual to be effective when sprayed directly onto the animal. It is also difficult to

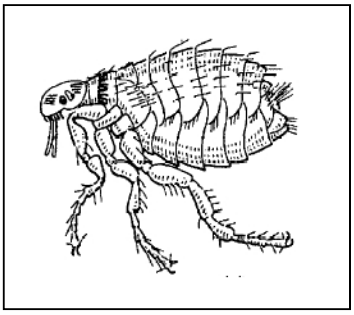
control stable flies by spraying building and vegetation, residual is low and without direct contact mortality is low.

- Knock-down sprays are effective in killing adult flies present at the time of application. The chemicals used for these applications are short residual insecticides having a quick knock-down and high contact toxicity. Several types of spray or fogging apparatus may be used for these applications. This method requires less time for application but has the disadvantage that it will only kill flies present at application.

- Beneficial organisms such as predators, parasites and natural competitors occur naturally in similar breeding locations of the stable fly larvae. These organisms kill the eggs, larvae and pupae of the stable flies providing assistance to the cause. Predatory mites, beetles, and other fly larvae feast on the developing stable fly larvae. Parasitic wasps, referred to as parasitoids, are particularly effective against horn flies and house flies but have shown poor results with stable flies thus far. Dry breeding grounds will encourage beneficial insect and mite development. Some parasitoid wasps can be purchased commercially to enhance the number of wasps present on your property.

9.8 Xenopsylla cheopis, Rothschild, 1903 (The Oriental Rat-Flea / Black Death)

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Siphonaptera

Family: Pulicidae

Genus: *Xenopsylla*

Species: ***cheopis*** *,* **Rothschild, 1903**

Fleas are the insects that constitute the order Siphonaptera. Fleas are wingless, with mouthparts adapted for piercing skin and sucking blood. Fleas are ectoparasites, living by hematophagy off the blood of mammals and birds. There are thousands of different species of fleas throughout the world, here are the most common ones. These creatures attack both pets and humans and inhabit their furs, our hair, and homes. Some of the main flea species are:

- Cat flea (*Ctenocephalides felis*)
- Dog flea (*Ctenocephalides canis*)
- Human flea (*Pulex irritans*)
- Moorhen flea (*Dasypsyllus gallinulae*)
- Northern rat flea (*Nosopsyllus fasciatus*)
- Oriental rat flea (*Xenopsylla cheopis*)

In this unit we will discuss in detail about the various aspects of oriental rat flea.

DISTRIBUTION

Xenopsylla cheopis is found worldwide in association with its primary hosts, *Rattus* spp. *Xenopsylla cheopis* usually inhabits tropical and subtropical habitats, although it has been reported in the temperate zone as well. The oriental rat flea is rarely found in cold areas since it requires a tropical or subtropical climate to pupate. Fleas are prevalent in many major cities. Species of *Rattus* typically found in city sewer systems and other human related habitats are excellent hosts for *X. cheopis*. Seaports and other rat-infested areas are also common habitats for *X. cheopis*.

Fleas are nidiculous parasites; they live in the host's nest. Clothing, beds and couches make perfect homes for many of these fleas. Fleas only attach to the host during sucking blood while at other times they are free-living in the host's nest.

HOST

Both male and female adults of *Xenopsylla cheopis* feed on blood. They bite *Rattus rattus* (Black Rat) and other mammals, including humans. *Xenopsylla cheopis* obtains the host's blood through a set of external mouthparts, which consist of the following maxillary lacunae and an epipharynx. The purpose of each structure is to aid in the sucking up of blood. After biting, the fleas suck blood from a pool (telmophagy), unlike some other insects like mosquitoes that feed directly from the blood vessel (solenophagy).

Piercing of the host's skin is achieved by the back and fourth action of the maxillary laciniae. After the skin is cut the epipharynx enters the wound and injects salvia. Saliva contains special chemicals, which prevents the host's blood from coagulating. A canal formed by the maxillary laciniae and the epipharnyx then sucks up blood. Further down the gut a specialized organ called the proventriclus then breaks down blood cells enabling the *X. cheopis* to digest the blood meal. The average capacity of *Xenopsylla cheopis* is 0.5 cubic millimeters.

The larvae of *X. cheopis* have mandibles, which they use to feed on detritus and the feces of the adult fleas, which are found in the nests of hosts.

DESCRIPTION

The flea's body is only about one tenth of an inch long, about 2.5 mm and have a laterally compressed body. Adults vary from light brown to dark brown in order to camouflage themselves in the host's fur. A flea's body is constructed to make it easier to jump long distances. The flea's body consists of three regions: head, thorax, and abdomen. The head and the thorax have rows of bristles (called combs) and the abdomen consists of eight visible segments. A flea's mouth has two functions: one for squirting saliva or partly digested blood into the bite, and one for sucking up blood from the host. This process mechanically transmits pathogens that may cause diseases the flea might have. Fleas smell exhaled carbon dioxide from humans and animals and jump rapidly to the source to feed on the newly found host. A flea is wingless so it cannot fly, but it can jump long distances with the help of small powerful legs. A flea's leg consists of four parts. The part that is closest to the body is the coxa. Next is the femur, tibia and tarsus. A flea can use its legs to jump up to 200 times of its own body length approximately about 20 in or 50 cm.

Males and females are sexually dimorphic. Females have dark-colored spermatheca that resemble small sacs, a distinguishing characteristic of this species. Males have complex genitalia that are easily distinguishable from the females. Larvae of rat flea are 4.5 mm long and resemble worms; they are slender, white, eyeless, and legless. Each has fourteen bristled segments. During the last larval instar, they moult and form cocoons that are silky and covered in debris from surroundings

LIFE CYCLE

Fleas are holometabolous, which means they go through four life-cycle stages: egg, larva, pupa, and adult (imago). Breeding takes place throughout the year as long as the temperature and humidity are favourable for egg-laying but it is somewhat slowed down in cold weather. The eggs are either deposited in dust, dirt or bedding of the human host or laid while the female is on an animal. *Xenopsylla cheopis* is distinct from other fleas in that it has a very large egg, eggs obtain extra nutrients from their mother, hence explaining the abnormally large egg. Once eggs are laid, however, they receive no further support from their parents. The eggs lie loosely on the hairs and usually slip into the ground where they incubate for 2-14 days. They are short, ovoid, relatively large and are laid in small numbers, although the total egg production by a single female may be several hundreds.

The young larvae are legless, eyeless and very slender and are whitish. With their chewing mouthparts, they feed on the excreta of adult fleas or on that of mice, rats and other rodents. *Xenopsylla cheopis* passes through three molts during the larval stage, which usually lasts about nine to fifteen days, but can last up to 200 days in unfavorable conditions.

The full-grown larva spins a small, oval, silky cocoon where it remains until it is finished pupating. During the pupal stage the flea's development rate is greatly affected by its surroundings. Changes in temperature and humidity outside the cocoon can inhibit emerging for up to a full year. From cocoon it emerges as an adult after 1-5 weeks, although it may pass the entire winter in the pupal stage. It has been observed that it may take 2 weeks to 2 years for a generation of fleas to complete its development under different conditions.

After copulating with a male the female is ready to lay her eggs. She does this at frequent intervals while feeding. *Xenopsylla cheopis* prefers temperatures of 65 to 80°F with about 70% humidity for egg laying. Higher or lower temperatures inhibit females from laying their eggs. Eggs usually do not hatch on the hosts, rather on their nests since fleas are nidiculous parasites which means parasites which lives on host's nests.

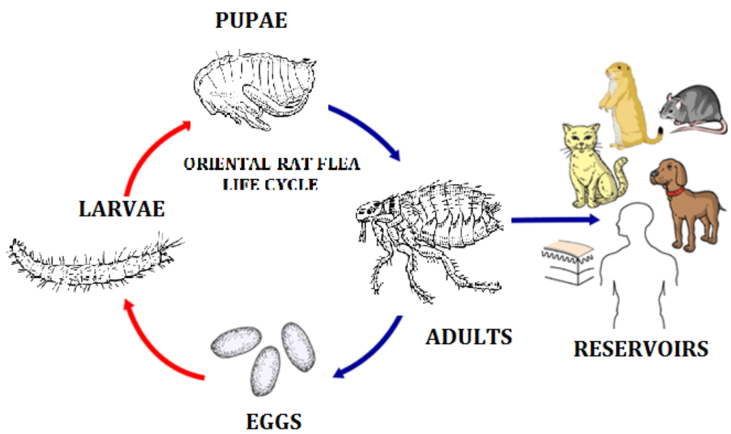


Figure- Life cycle of *Xenopsylla cheopis*

MEDICAL IMPORTANCE (DISEASES)

The adult fleas, which feed only on blood, cause damage to human beings in 2 ways :

1) By piercing skin bites which cause irritating and itchy skin lesions, especially on the extremities.
2) The principal vectors in the transmission of certain important infectious diseases of man, such as the bubonic plague and murine endemic typhus.

This species can act as a vector for plague, *Yersinia pestis*, *Rickettsia typhi* and also act as a host for tapeworms *Hymenolepis diminuta* and *Hymenolepis nana* (dog tapeworm and rodent tapeworm). *Xenopsylla cheopis* is a parasite of many mammalian species, including Rattus and humans. Because of its parasitic nature, *Xenopsylla cheopis* is a vector for pathogens such as *plague bacilli, Yersina pestis*, and murine typhus, *Rickettsia typhi*. Transmission of the pathogen occurs as bacteria enter the flea's gut and multiply rapidly. Soon the flea's proventriculus is blocked by a mass of bacteria and it cannot fill its stomach, causing the flea to search for a new host. After biting the host, the blood of an uninfected host mixes with bacteria in the flea's stomach; the flea expels infected blood back into the wound consequently, infecting a new host. *Xenopsylla cheopis* goes from host to host infecting the uninfected. Hosts may also become infected either from consuming fecal matter or dead remnants of an infected *X. cheopis*. Diseases can be transmitted from one generation of fleas to the next through the eggs. All diseases are a threat to humans and other animals that encounter them.

CONTROL

- By regular vacuuming which can remove 60% flea eggs, 27% larvae and definite number of flea adults or by cleaning of carpets, upholstered furniture and floorings, removing clutters underneath beds and other furniture, frequent cleaning and changing of pet bedding; and filling up cracks and crevices of buildings.

- The houses should be kept rat-free by keeping cats or by frequent poison baiting.

- The houses should also be kept clean, well swept and ventilated, with occasional spraying of floors with insecticides.

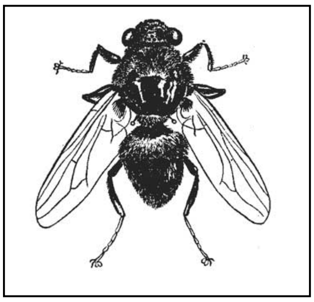
- DDT is the most commonly used insecticide against rat fleas. It is sprayed as powder form in areas frequented by rats and their burrows. Spraying should be done on the floor and on the walls up to a height of 1 foot. The DDT powder gets adhered to the fur coat of rats and kill the fleas.
- In areas where plague is endemic, fleas have acquired resistance to DDT and BHC. In these areas, malathion or carbaryl can also be used. Other host animals like cats and dogs and their premises should also be treated with insecticide dusts or sprays

- According to safety and environmental factors, suitable insecticide formulations such as solution, dust or fogging mist must be used to eradicate the fleas.
- By use of Repellants
    - Diethyl toluamide is a good flea repellent. Clothes treated with it repel fleas up to 1 week.
    - Benzyl benzoate can also be used as repellent

9.9 Hypoderma lineatum Devillers (The Bot / Warble Flies / Heel Flies, Gadflies)

***Hypoderma lineatum* Devillers (The Bot / Warble Flies / Heel Flies, Gadflies)**

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Diptera

Family: Oestridae

Genus: *Hypoderma*

Species: *lineatum*

DISTRIBUTION

The common bot fly occurs naturally in cattle in at least 50 countries in Africa, Asia, Europe and North America, but principally in the region of 25 and 60 degrees latitude in the Northern Hemisphere. The southern limit is reached in the Punjab of India, Libya, northern Mexico and Hawaii.

The sheep or goat-bot fly, *Oestrusovis*, is distributed throughout the Indian Subcontinent and its larva is the familiar, head maggot of the two domestic animals. The larva of *Rhinoestrus purpureus* has been recorded from the nasal passages of horses in the Punjab. *Hypoderma lineatum* is the well-known warble fly on cattle, which is occasionally found on goat also. It attacks the skin and is responsible for deterioration in quality of the hide. There are instance when larvae of *Hypoderma* and *Gasterophilus* have been collected from the skin of man and are known to cause ‘creeping myiasis’.

HOST

The typical hosts of bot flies are cattle and old World deer. They can parasitize horses and humans. It is also reported from American bison. Goats and sheep are occasional hosts, but full development is not completed in these hosts. The bot flies in the larval stage act as parasites on the flesh of various domestic animals. They attack cattle, horse, sheep, goat, elephant, rhinoceros, etc., and feed in the alimentary tract, the nasal and pharyngeal cavities and in subcutaneous tumours formed by their bites.

DESCRIPTION AND LIFE CYCLE

botfly, common name for several families of hairy flies whose larvae live as parasites within the bodies of mammals. The horse botfly secretes an irritating substance that is used to attach its eggs to the body hairs of a horse, mule, or donkey. When the animal licks off the irritant, the larvae are carried into the host's mouth and later migrate to the stomach. They attach themselves to the lining, where they feed until ready to pupate, and then drop to the ground with the feces. The larvae, which may cause serious damage to the digestive tract and weaken the animal, can be eliminated by a veterinarian. Sheep botflies lay their eggs in the nostrils of the host without alighting. The larvae work their way up into the head cavities causing fits of vertigo known as blind staggers; failure to eat because of irritability may result in death. Old World species of this family attack camels, elephants, horses, mules, donkeys, and deer. The warble flies, also called heel flies, or bomb flies, parasitize cattle and other animals. The larvae, called cattle grubs or cattle maggots, penetrate the skin of the host immediately after hatching; they migrate through the flesh, causing irritability, loss of weight, and decreased milk production, and then settle under the skin of the back, producing cysts, or warbles. Breathing holes made in the warbles by the larvae damage the hide. A species of human botfly found in Central and South America attaches its eggs to a bloodsucking mosquito that it captures and then releases. When the mosquito comes in contact with humans or other warm-blooded animals, the fly eggs hatch and the larvae fasten to the mammal's skin. The larvae bore into muscle tissue; infestation is called myiasis. For control methods, see bulletins of the U.S. Dept. of Agriculture. The botflies are classified in the phylum Arthropoda, class Insecta, order Diptera. Horse botflies are classified in the family Gasterophilidae; sheep botflies and warble flies are classified in the family Oestridae; the human botfly is classified in the family Cuterebridae.

The parasitic forms of bot flies which live in the alimentary canal of animals deposit their eggs among the body hair, from where their larvae are swallowed through licking. The larvae of the forms that parasitize the naso-pharynx are deposited in the nostrils. Those found in the skin lay their eggs on the legs of host. On emergence from eggs, the larvae penetrate inside and after passing through various tissues reach the back of the host.

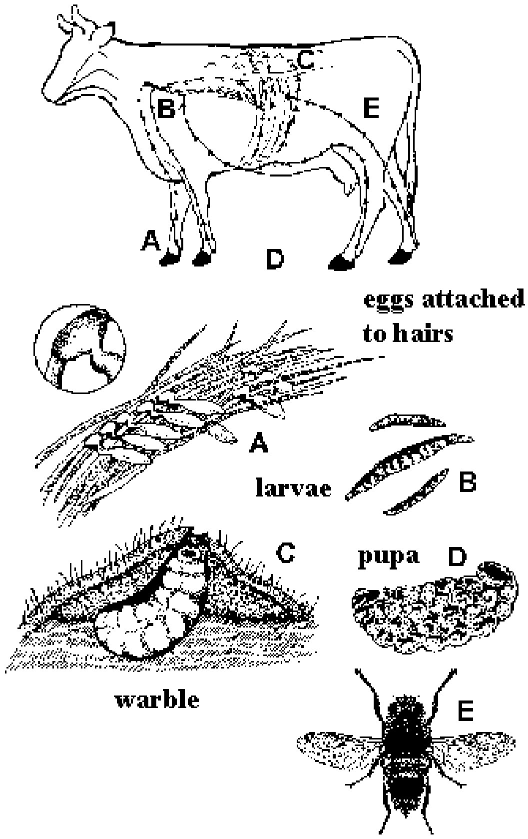
The warble fly, Hypoderma lineatum, is common in the western parts of India and causes tumours in the skin of cattle and buffaloes, thus spoiling the hide. The adult fly is 12-14 mm long and has a wing expanse of 23-25 mm. The body is black, banded with yellowish and orange hairs. Legs are well covered with hairs of black and orange colour. The wing veins are black. The dull-yellowish-white eggs, which have a smooth shining surface and are about three quarters of a millimetre in length, are deposited on the body hair in groups of 5-12. The total number of eggs laid by a female fly varies from 200 to 500.

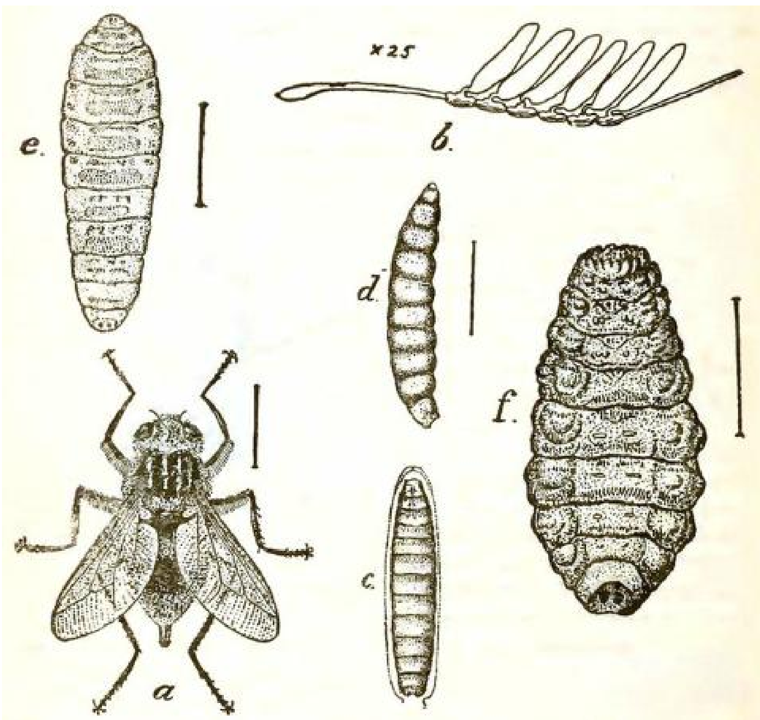
The eggs hatch in 4-5 days, and the young larvae penetrate the skin through hair follicles. Within 2-3 months, they reach the wall of the oesophagous and later on by way of the thoracic cavity they reach the back where characteristic warbles are produced in about 7 months. There are three larval instars. The final instar larva cuts a small hole in the skin covering the warble for breathing air from outside. This results in damage to the hide. The mature light brown larva wriggles, out of the warbles through a hole and drops on the ground to pupate in soil. After a pupal period of 6-8 days the adult fly emerges. It lives only for a few days for mating and reproducing. In the plains of north-west India, the egg-laying season of ox-warble-fly extends from March to June. Warbles appear on the back of the cattle from October to January. There is only one generation of this fly in a year.

Adults: The adults are about 13 mm in length. The flies are hairy, with no functional mouthparts, and must mate and reproduce solely on the energy derived from stored reserves. Adults live three to five days. The hairs on the head and the anterior part of the thorax are yellowish-white. The abdomen is covered with light yellow hairs anteriorly, followed by a band of dark hairs, and the posterior portion bears orange-yellow hairs. **Eggs:** The eggs are about 1 mm long and are fixed to the hairs of the host by means of small terminal clasps. Eggs are found on the host animal's legs and sometimes on the body. Females deposit a row of six or more eggs per hair. The flies are very persistent in approaching host animals, and one female may lay 800 eggs on one individual. **Larvae:** The eggs hatch in four to seven days and the larvae crawl down the hair to the skin, which they then penetrate. In doing so, they cause considerable irritation. They wander in the subcutaneous connective tissue, usually up the leg and then forward to the diaphragm, gradually increasing in size. The larvae find their way into the esophageal wall, where they come to lie in the submucous connective tissue for the rest of the summer and autumn, growing to about 12 mm in length. Eventually, during January and February, they travel towards the dorsal aspect of the body and reach the subcutaneous tissue of the back.

When the parasites arrive under the skin of the back, swellings begin to form, measuring about 3 cm in diameter. The skin over each swelling becomes perforated, and the larvae then lay with the posterior stigmal plate directed towards the pore for the purpose of respiration. Here the larvae molt, and this stage lasts about 30 days. The younger larvae are almost white, changing to yellow and then to light brown as they grow older, and finally almost black. Two molts occur during the development of the larvae, producing a total of three instars. Full-grown larvae are 25 mm long. Flat tubercles and small spines are present on all segments but the last.

Pupae: In spring, the mature larvae wriggle out of the cysts and fall on the ground, Â where they penetrate the soil and pupate. Pupation is almost immediate. The insect will not mature if the moisture content is higher than 10 percent. The pupal case is black and the fly emerges from it after 35 to 60 days by pushing open an operculum at the anterior end. The total duration of the life cycle is approximately a year, with the major portion of this time being spent in the body of the host. The timing of appearance of the grubs in the host’s back, emergence of the mature larvae and pupation in the ground, and adult emergence are a response to varying weather conditions. However, the time when these occur will tend to be similar from year to year for a given region. The adult flies occur in summer, especially in June and July. They are most active on warm days, when they seek cattle to lay their eggs.





MEDICAL IMPORTANCE (DISEASES)

When the flies approach to lay eggs the cattle become nervous and attempt to escape the attack by running away, and will even go into water. Because the flies are persistent, the animals are constantly irritated and do not feed properly, which results in an appreciable loss of weight and decrease of milk yield. The animals may also hurt themselves severely, or at least become wounded and damage their skins.

The larvae irritate the tissues around them, causing the flesh to become greenish-yellow and infiltrated, especially along the tracks where the larvae have wandered, and thus depreciated in value. The penetration of the larvae into skin causes irritation and later on hypodermal rashes are produced. The flesh around the mature larva gets inflammed and becomes unfit for consumption. The larva lies in a cyst, which also contains a yellow purulent fluid. Calves and young cattle are more frequently and more severely infected than older animals. It is possible that cattle develop a certain degree of resistance to the larvae. However, older animals may become sensitized during earlier infections through the absorption of body fluids of larvae that die, and these animals may show anaphylactic reactions when subsequent larvae die or are broken during extraction. Even abortions have been noted in such cases.

The losses produced are:

1. Reduction of milk secretion, which is estimated at from 10 to 20 percent of the normal yield
2. Loss of weight due to the increased activity by the animals attempting to escape from the flies and the irritating larvae
3. Depreciation of the value of the carcass, which becomes greenish yellow and jelly-like in appearance at the points where the grubs are located and unfit for consumption
4. Injury produced to the hide which becomes "grubby" or full of holes where the grubs emerged.

CONTROL

- **Mechanical removal of larvae**. Mature larvae may be squeezed out of the warble swelling. This is more successful when the larvae are mature. Rupture of the larvae during extraction may lead to a localized inflammation and abscess formation.

- **Insecticide treatment**. The advent of systemic organophosphorous insecticides in the 1950's gave cattle producers the first opportunity to control cattle grubs on a large scale at a reasonable cost. The use of systemic insecticides allows control of larvae while they are in the early stages of migration and before they reach the backs of the animals. The insecticides are used during the autumn and early winter with the aim of killing the younger larval stages. The compounds may be given orally, or in dips, sprays, drench or bolous form, but one of the more convenient methods is "pour on" dressings in which a small volume of concentrated insecticide is poured along the animal's back. Enough insecticide is absorbed through the skin to kill the larvae. These compounds should be avoided in January and February because severe reactions may occur due to the death of larvae in the wall of the esophagus or spinal canal.

- Drinking water treatments of insect growth regulators generally do not prevent cattle grub larvae from reaching backs of cattle, but may prevent adults from eclosing from pupae, thus preventing reproduction. Insecticide-impregnated plastic strips applied to legs of cattle during the heel fly season prevented the appearance of cattle grub larvae in backs of treated cattle.

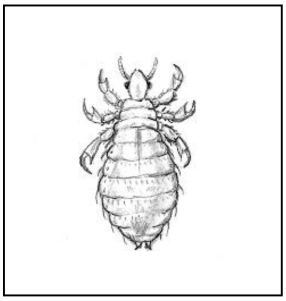
- Perhaps the most promising control technology for use in suppression of *Hypoderma* spp. has been the development of avermectins (a chemically modified form of a fermentation product of *Streptomyces avermitilis*). In the early 1980s this antiparasitic compound was established as one of the most effective materials ever developed for systemic use against cattle grubs. This product possesses unique characteristics not seen in organophosphorus systemics. The first of these is an ability to kill migrating larvae, but unlike systemics, it is also highly efficacious against second- and third-instar larvae in warbles at extremely low dosages. The latter activity permits use of this material as a late-season or pour-on treatment for grub-infested cattle that is not possible with traditional systemic insecticides, which are not effective, once the larvae are inside their warbles.

- **Vaccines.** Generally, fewer *Hypoderma* spp. larvae appear in the back of older cattle than in calves or yearlings, which implies the development of some type of immunity with age. Initial investigations, using extracts of *Hypoderma* spp. larvae as candidate vaccines, have led to concerted attempts toward the development of a defined vaccine against cattle-grub infestations using the hypodermin A (one of the three enzymes which are secreted by the first instar larvae during its migration). The advantages of a vaccine over chemical control are great: less damage to the environment, complete and lifetime conversion of susceptible animals to resistant status, and use in animals such as dairy cattle for which systemic insecticide application is prohibited during lactation. The immunization with hypodermin A, associated with various adjuvants, could provide protective immunity for calves when challenged with natural grub infestation. However, these experimental vaccines have not been widely field-tested against naturally occurring populations of *Hypoderma* spp.

- **Integrated management**. The first attempt at integrated management of *Hypoderma* spp. resulted from the suggestion to adapt the sterile male-release technology that was developed for eradication of the screwworm from North America and Mexico. The results of a preliminary trial in Alberta, Canada were very encouraging, and consequently, the Joint US-Canada Cattle Grub Project was initiated in 1982. The chemical reduction phase proved to be very successful using readily available systemic insecticides combined with 100% producer cooperation. However, the sterile fly component was less succesful because there was no efficient technique for large-scale in vitro rearing of *Hypoderma spp*.
- Smoke bombs and anti mosquito sprays in stables are effective.

9.10 Pediculus sps. (Human Louse and Head Louse)

SYSTEMATIC POSITION



Phylum: Arthropoda

Class: Insecta

Order: Anoplura

Family: Pediculidae

Genus: *Pediculus*

Species: *humanus*

DISTRIBUTION

Human and head lice may occur in any part of the world inhabited by man. Head lice (*Pediculus humanus capitis* DeGeer) and Human Lice (*Pediculus humanus humanus* Linnaeus) are tiny, wingless parasitic insects that live in human hair and feed on the human blood. The body louse tends to be less common in the tropics, however, probably because of the lesser amount of clothing due to higher temperatures. Unlike body lice, head lice are not a health hazard, a sign of uncleanliness or a cause of disease. This pest is almost world-wide, especially in over-crowded slum tenements, military barracks, prisons, orphanages, etc. The habitat of the human louse is solely on the human body or in the clothes whereas the infestation of head lice is commonly encountered in hairs of pediatric population in the age group of 6 - 12 years. In rural areas, prevalence rate ranges from in the age group of 3 - 13 years, ranges varies from 13.3% to 49%. Girls are 2 to 4 times more frequently infested than boys, especially in rural and developing areas owing to their hair length.

HOST

Apes and monkeys in captivity become infested with these lice, man is the primary host. Human lice have been found on people of all socioeconomic levels. There are mainly three kinds of lice which are parasitic on man: *Pedicules humanus capitis*, the head louse, living on the skin and hair on the scalp, *Pediculus humanus corporis* deGeer, the body louse living on garments adjacent to the body and the *Phthirus pubis* Linnaeus, the crab louse which infests human hair in the pubic region.

*Head lice (*Pedicules humanus capitis*)*

The head louse is a grey-white animal about 2 mm-3 mm in length approximately about the size of a sesame seed. The life span of the female louse is about one month. During this time, she will produce between seven to 10 "nits" per day and attach them firmly to the hair shaft region close to the scalp or body. These nits, which resemble dandruff, are attached with a glue like, water-insoluble substance that makes them difficult to remove. After six to 10 days, the nits hatch as nymphs and become adults in 10 days. Head lice are the most common form of lice infestation.

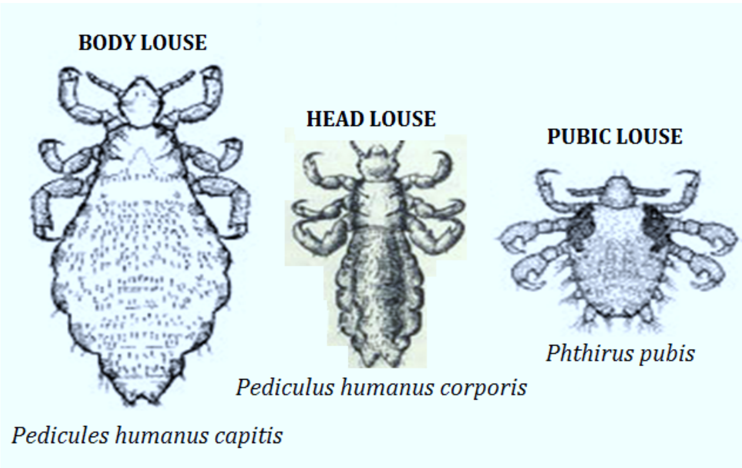
*Body lice (*Pediculus humanus corporis*)*

The body louse is slightly larger than the head louse but has the same general appearance. Unlike the head louse, which lives on its human host, the body louse lives in clothing and then transfers to the human host to feed. The life cycle of the head louse and the body louse are similar in character and duration. An important difference, however, is the ability of the body louse to survive for up to 30 days away from its human host. Body-lice infestation is a prominent public-health problem in communities with large populations dealing with poverty, overcrowding, and poor personal hygiene. Reused mattresses and bed linens as well as communal beds are risk factors.

Pubic lice (Phthirus pubis)

The pubic louse or "crab louse" is distinct morphologically, it is rounded with three pairs of legs on either side of the body from which it takes its descriptive name from the head and body louse. The female life span is slightly shorter she produces fewer eggs per day (three) . The eggs attach to the base of the pubic hair shaft for approximately six to eight days before hatching.

In adults, pubic lice is transmitted by direct sexual contact; children generally contact the infection via nonsexual transmission from their parents. Intense itching of the pubic area is characteristic. Axillary regions, eyelashes, and even the scalp may be involved. Nighttime symptoms are may be more intense. After being bitten, a bluish-colored sore may develop in the involved areas. The diagnosis is established by demonstration of crab-shaped lice attached to the hair shaft



FOOD HABITS

Lice are obligate ectoparasites. They live off of the blood of humans. They have specially designed mouth parts for piercing the skin of humans and retrieving the blood that is present. The human lice are blood-sucking insects which cause irritating skin lesions and are important in the transmission of certain rickettsial diseases, notably typhus fever.

DESCRIPTION

Pediculus humanus is a small insect with a large abdomen and legs equipped with sharp claws for holding onto hair and clothing fibers. The head of the louse is slightly narrower than the body. These wingless insects have short, 5-segmented antennae and have piercing mouthparts for digging into the skin and draining out the blood. These insects also have heavy legs with a single, sharp, hooked claw. Head lice and body lice are two races of the same species. The head louse, *Pediculus humanus capitis*, is normally 1-2 mm long, while the body louse, *Pediculus humanus humanus,* also known as the "cootie" is usually slightly larger, 2-4 mm.

LIFE CYCLE

The female of the head louse lays its eggs attached to the hairs on the head behind the ears or on the back of the neck, whereas the body louse lays her eggs hidden on the clothing. Breeding phase usually goes on throughout the year in over-crowded, poorly ventilated and comparatively warm dwellings. A female lays 8-10 eggs daily until 50-100 are laid by the head louse and 200-300 by the body louse. The "nits," or eggs are oval, whitish, about 1 mm in length and have a distinct pebbled lid at one end. Both types of eggs (head and hair lice) hatch in about one week. Lice nymphs feed two to six times per day for 1 to 4 weeks. During this time, they molt three times and develop through three instars before becoming adults. The young lice are often called "red backs," due to the red color they are because of the blood in them. They turn a grey color once digestion takes place, and is where they get the name "gray back". The adults live for about one month or more.

All life stages may be present during any season of the year. Unfed body lice rarely survive beyond 10 days. Body lice that have fed may survive for 30 to 40 days away from a host in moist clothing. Body lice are spread by contact among persons or clothing. The incidence of this species has declined in recent years because people no longer wear the same clothing for prolonged periods of time.

MEDICAL IMPORTANCE (DISEASES)

P. humanus species are transmitted from one person to another by direct contact, by clothes or a brush, or by fallen hair. Any object that has a nit or a female on it will transmit the infestation. The bites of body and head lice are irritating, and scratching may cause infection or the irritating itchy skin lesions, in the area of the bite. These bites have relatively little direct effect on its hosts.

Bites itch, but do not generally cause other harm. However, lice can be vectors for important diseases. The three most important diseases they can carry are typhus, trench fever (both caused by bacteria in the genus *Rickettsia*), and relapsing fever (caused by another bacteria species *Borrelia recurrentis*). These bacterial diseases can now be treated successfully with antibiotics, but in the past, they caused the death of millions of people. Major epidemics strongly affected the political and economic history of Europe and Asia, and lice were the main agents in the spread of these diseases.

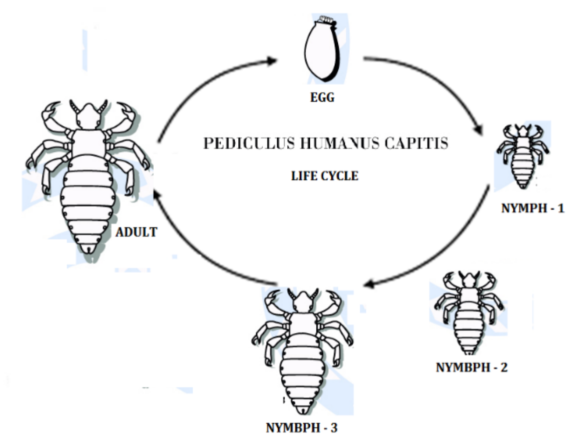


FIGURE: Life cycle of *Pediculus humanus*

CONTROL

The following are steps that can be taken to help prevent and control the spread of head and body lice:

- Head-to-head / hair-to-hair contact must be avoided during play and other activities at home, school, and other activities like sports activities, playground, slumber parties, camp.
- Clothing such as hats, scarves, coats, sports uniforms, hair ribbons, or barrettes should not be shared with each other.
- Combs, brushes, or towels should be kept only for personal use. In order to disinfest combs and brushes used by an infested person soak them in hot water (at least 130°F) for 5–10 minutes.
- Do not lie on beds, couches, pillows, carpets, or stuffed animals that have recently been in contact with an infested person.
- Machine wash and dry clothing, bed linens, and other items that an infested person wore or used during the 2 days before treatment using the hot water (130°F) laundry cycle and the high heat drying cycle.

Clothing and items that are not washable can be dry-cleaned OR sealed in a plastic bag and stored for 2 weeks.

- Vacuum the floor and furniture, particularly where the infested person sat or lay. However, spending much time and money on housecleaning activities is not necessary to avoid reinfestation by lice or nits that may have fallen off the head or crawled onto furniture or clothing.
- Do not use fumigant sprays or fogs; they are not necessary to control head lice and can be toxic if inhaled or absorbed through the skin.
- A powder containing malathion 2 per cent or lindane 1 per cent is useful as a delousing treatment. For the control of infested head or body, the applications of malathion 5 per cent dust two times at 10 days intervals or the use of lindane 0.2 per cent mixed with hair oil is very effective. Personal cleanliness is essential for obtaining constant relief.
- To control a head lice outbreak in a community, school, or camp, children should be made aware to avoid activities that may spread head lice.

9.11 Summary

Due to improper storage management, in India, unscientific storing, rodents, insects and microorganisms accounts every year a big loss is caused to stored products. Food storage continues to be an important problem from the time man learned to grow crops. Millions of tons of food-grains are either damaged or lost for want of adequate scientific knowledge and methods of storage. The loss is not merely in terms of quantity but also in quality of the food-grains. The qualitative loss is attributed to change in the various essential chemical constituents who retard the nutritive significance of the grains. Grain quality is severely reduced by insect damage. Stored-grain pests attack, consume, contaminate and make the grains unfit, either as food or as seed.

Insect pests also increase costs to grain growers both directly through the expense of control on the farm, and indirectly through the costs incurred by grain handling authorities in controlling weevils in bulk storages.

Insects have a great impact on human and domestic animals health and welfare directly and indirectly. These organisms have the capacity to inflict injury, disease, discomfort, or distress. They can be a direct cause of illness, pain, and suffering through bites and stings, infested wounds, or allergic reactions. They

feed on blood or body tissues and they may transmit deadly pathogens or parasites.

9.12 Self Assessment Questions

1. Write a short note on stored product pests management.
2. Describe the Biology, nature, extent of damage and control of *Sitophilus oryzae*
3. Describe the Biology, nature, extent of damage and control of Lesser Grain Borer
4. What do you mean by pests of medical & veterinary importance?
5. Explain the details of different species of Mosquitos?
6. Describe the different measures for stored grain pest control.
   Describe the distribution, hosts, description, life cycle, nature of damage, medical importance and control of human louse and head louse.
7. Describe the distribution, hosts, description, life cycle, nature of damage, medical importance and control of *Xenopsylla cheopis.*
8. Describe the distribution, hosts, description, life cycle, nature of damage, medical importance and control of Horse Fly.
9. Describe the distribution, hosts, description, life cycle, nature of damage, diseases and control of *Musca domestica.*
10. Describe the distribution, hosts, description, life cycle, nature of damage, medical importance and control of *Stomoxys calcitrans.*

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Unit - 10

Beneficial insects

Structure of the Unit:

10.1 Objectives

By the end of the chapter, the student will be able to understand about

- The different types of beneficial insect- Biology, habit and habitats, Host trees of *Laccifera lacca,* pruning, inoculation, lac cropping techniques and harvesting, different types of enemies of lac insect and their control.
- Economic importance, behaviour, habit and habitats of different Indian species of Honey bee of genus *Apis*; Bee keeping techniques, bee pasturage, Artificial bee hives and equipments related to Apiculture, different types of bee enemies, including diseases and their control, *Megachile* spp.
- Different aspects of Sericulture and its management, Life cycle of silkworm *Bombyx mori,* different types of silkworm species, their

systematic position and salient features, Rearing techniques of Mulberry, Muga, Eri and Tassar silkworms, Rearing house and appliances related to sericulture, silkworm breeds, Seed production and its economies, Different types of enemies and diseases of silkworms and their management.

- Different types of Insects Pollinators, the role of insects in controlling weeds, soil fertility improving insects, different recycling insect scavengers. Medicinal uses of insects and insect products. Entomophagy – use of different insects as food.

10.2 Introduction

Beneficial insects

Insects are crucial components of many ecosystems, where they perform many important functions. Insects can be found in every environment on Earth. Insects have adapted to a broad range of habitats, successfully finding their own niche, because they will eat almost any substance that has nutritional value. They aerate the soil, pollinate blossoms, and control insect and plant pests.

Insects have tremendous economic importance. Many insects, especially beetles, are scavengers, feeding on dead animals and fallen trees, thereby recycling nutrients back into the soil. As decomposers, insects help create humus, top soil, the nutrient-rich layer of soil that helps plants grow. These insects are important for soil formation, destroyers of fallen leaves, dead wood, dung etc. Burrowing bugs, ants and beetles, dig tunnels that provide channels for water, benefiting plants. Bees, wasps, butterflies, and ants pollinate flowering plants. The big-eyed bug and praying mantis plays an important role in biocontrol of certain insect populations, such as aphids and caterpillars, which feed on new plant growth. Finally, all insects fertilize the soil with the nutrients from their droppings.

Some insects produce useful substances, such as honey, wax, lacquer, and silk. Honeybees have been raised by humans for thousands of years for honey. The silkworm greatly affected human history. When the Chinese used worms to develop silk, the silk trade connected China to the rest of the world. Adult insects, such as crickets, as well as insect larvae, are also commonly used as fishing bait. Honeybees, silkworm moths and Chinese oak silk moths, Indian lac insects and cochineal insects these are examples of semi-domesticated insects, bred by man for the sake of products obtained from them. A very valuable product shellac is produced by Indian lac insects living on certain kinds of trees in South East Asia. Wax-like substances secreted by them have very good insulating qualities and are widely used in radio engineering. Some insects also plays a very important esthetical role of butterflies, moths, dragonflies, and other insects that beautify our nature.

10.3 Lac Culture

Laccifera lacca

Introduction

Lac is one of the most valuable secretion of a tiny insect, *Laccifer lacca* to man. It is also unique material in as much as it is the only resin of animal origin. The English word lac derived from the Sanskrit word Laksh meaning a lakh or hundred thousand. . Since Vedic period, it has been in use in India, its earliest reference is found in Atherva Veda. There, the insect is termed as 'Laksha', and its habit and behaviour are described. The great Indian epic 'Mahabharata' also mentions a 'Laksha Griha', an inflammable house of lac, cunningly constructed by 'Kauravas' through their architect 'Purocha' for the purpose of burning their great enemy 'Pandavas' alive. As it is obtained from numerous insects therefore it is termed as Laksh or Lakh. Since ancient times, Greeks and Romans were also using lac. The cultivation of lac insects has a long history in Asia, it is as old as 4000 years in China where its cultivation accompanied the development of the silk industry.

Lac is Nature's gift to mankind and the only known commercial resin of animal origin. It is the hardened resin secreted by tiny lac insects belonging to a bug family. To produce 1 kg of lac resin, approximately 300,000 insects are killed. The lac insects yields resin, lac dye and lac wax. Lac resin, dye etc. still find extensive use in Ayurveda and Siddha systems of medicine.

Lac culture is a source of livelihood of tribal and poor inhabiting forest and sub-forest areas. With increasing universal environment awareness, the importance of lac has assumed special relevance in the present age, being an eco-friendly, biodegradable and self-sustaining natural material. Since lac insects are cultured on host trees which are growing primarily in wasteland areas, promotion of lac and its culture can help in eco-system development as well as reasonably high economic returns.

Systematic Position

Phylum	Arthropoda
Class	Insecta
Order	Hemiptera
Suborder	Homoptera
Super family	Coccoidea
Family	Lacciferidae
Genus	*Laccifer*
Species	*lacca*

Lac insect belongs to group of scale insects in super family Coccoidea. These insects attach themselves in great numbers to plants. The mouth part of these insects is piercing and sucking type. They can be very destructive to tree-stunting or killing twigs and branches by draining the sap. Mainly there are six genera of lac insects, but only five can secrete lac, and commercial lac can be secreted by only one, i.e. *Laccifer*. The commonest and most widely occurring species of lac insect in India is *Laccifer lacca* (Kerr) which produces the bulk of commercial lac. Lac insect of South East Asia is referred to as *Kerria chinensis*.

First time scientific account of the lac insect was given by J. Kerr in 1782 which was published in Philosophical Transaction of Royal Society of London. The first scientific name given to it was *Tachardia lacca* following the name of French Missionary Father 'Tachardia'. It was later changed to *Laccifer lacca* Kerr. The other name given to it has been *Kerria Lac* Kerr.

Habit and Habitats

The lac insects can flourish and feed on certain species of the tropical trees, it is found distributed in South-East Asian countries. Lac is currently produced in India, Thailand, Malaya, Lao Myanmar, and Yuan province of China. India and Thailand are main areas in the world, while India has prime position in relation to lac production. Lac cultivation is introduced into Thailand from India.

In India over 90% of lac produced comes from the states of Bihar, Jharkhand, West Bengal, Madhya Pradesh, Chhattisgarh, Eastern Maharashtra and northern Orissa. Some pockets of lac cultivation also exist in Andhra Pradesh, Punjab, Rajasthan, Mysore, Gujarat, and Mirzapur and Sonebhadra districts of Uttar Pradesh.

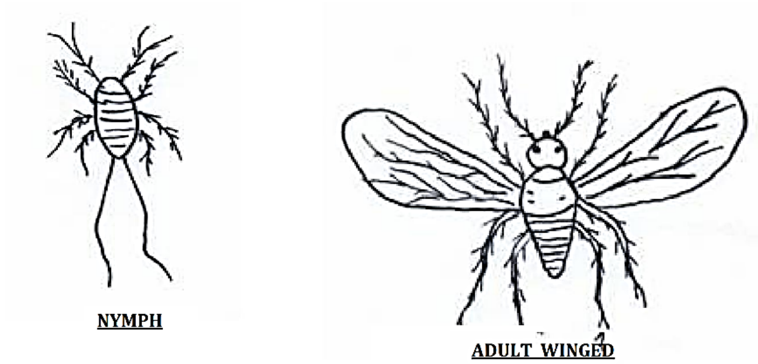


Figure – *Laccifer lacca* Nymph and Adult winged stage

Lac insect is a minute crawling hemipteran scale insect which grows and secretes resinous lac from the body. Its own body gets covered with structure called as Cell made up of resinous substance lac. It is a means for protection from enemies.

Lac Insect is reddish in appearance and male insect body length is from 1.2 - 1.5mm. It has reduced eyes and antennae. Thorax bears a pair of hyaline wings. Female appears larger than male, and length is from 4-5 mm and has a pyriform body. The head, thorax and abdomen are not clearly distinct. The antennae and legs are in degenerated form, and wings are absent.

Biology (Life Cycle)

The lac insect completes its life cycle in about six months. The main stages are egg, nymph instars, pupa and adult. The lac insects have an ovoviviparous reproduction. Female lays 200-500 eggs which are ready to hatch means that the embryos are already fully grown in eggs when these are laid. Eggs hatch within a few hours of laying, and a crimson-red first instar nymph come out. These are called as called crawlers**.** The crawler measures 0.6 x .25 mm in size. The process of emergence of nymph is called as swarming, and it lasts for 5 weeks. The nymphs crawl on branches and after reaching on succulent twigs, the nymphs settle down close together in groups of 200-300 insects per square inch. At this stage, both male and female nymphs live on the sap of the trees. They insert their suctorial proboscis into plant tissue and suck the sap. After a day or so of settling, the nymphs start secreting resin from the glands distributed under the cuticle throughout the body, except mouth parts, breathing spiracles and anus. As soon as the resin comes in contact of air it becomes semi-solid and hardens to make a protective covering. The nymphs moult thrice inside the cells before reaching maturity. The time period of each instar is dependent on different factors, like temperature, humidity and host plant etc.

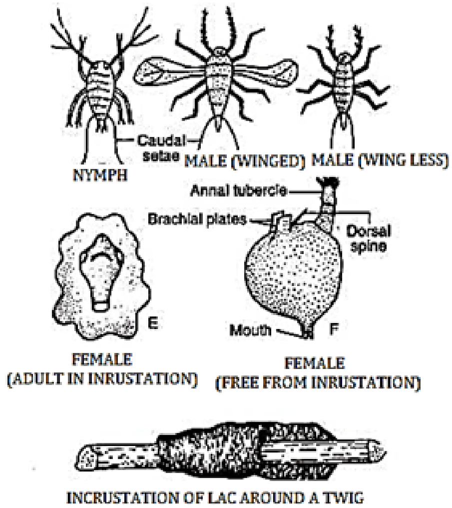


Figure – Life cycle of *Laccifer lacca*

After the first moult, both male and female nymphs lose their appendages, eye and become degenerate. While still inside their cells, the nymphs cast off their second and third moult and mature into adult. Approximately in eight weeks both the male and female larvae become sexually mature. Only the male one undergoes a complete metamorphosis or transformation into another form; it loses its proboscis and develops antennae, legs and a single pair of wings. It is contained in a brood cell somewhat slipper like with a round trap door (operculum) through which it emerges. The adult male is winged and moves to the other females to fertilize them.

The female brood cell is bigger and round in shape which remains fixed to the twig. The female retains her mouth parts but fails to develop any wings, eyes or appendages. During development female becomes completely an immobile organism with little resemblance to an insect.

The female rises in size to house her growing number of eggs. Lac resin is secreted at a faster rate, and a continuous layer grows into one body. After fourteen weeks, the female contracts in size allowing light to pass into the cell and the space for the eggs. At this stage two yellow spots appear at the rear end of the cell. The spots enlarge and become orange coloured. The space in which the female oviposit a large number of eggs is called as Ovisac. The ovisac appears orange due to crimson fluid called lac dye which resembles cochineal. It indicates that the eggs will hatch in a week time. When the eggs hatch, larvae emerge and the whole process begins all over again

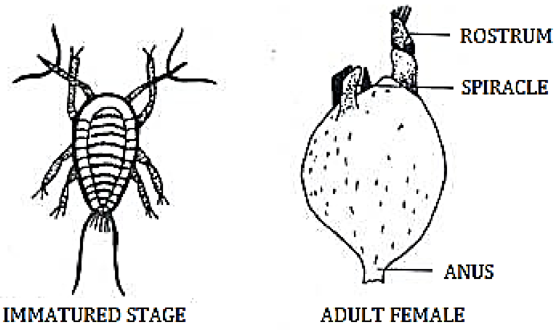


Figure- Loss of vegetative parts in an adult female lac insect

After the cycle has been completed and around the time when the next generation begin to emerge, the resin encrusted branches are harvested. They are scraped off, dried and processed for various lac products. A portion of brood lac is retained from the previous crop for the purpose of inoculation to new trees.

Host plants

Lac insects flourish on twigs of certain plant species, feeds on the plant sap, and grow all the while secreting lac resin from their bodies. These plants are called host plants. Although lac insect is a natural pest on host plant but they are not considered as pest. This is because they yield a useful product, the host plants are economically not so important and the insects cause only temporary and recoverable damage to the host plants. Although there are numerous host plants of lac insect but some of the common host plants in India are *Butea monosperma* (Palash), *Zizyphus* spp (Ber), *Schleichera oleosa* (Kusum), *Acacia catechu* (Khair), *Acacia arabica* (Babul), *Acacia auriculiformis* (Akashmani), *Zizyphus xylopyrus* (Khatber- grown in part of M.P. & U.P.), *Shorea talura* (Sal grown in Mysore), *Cajanus cajan* (Pigeon-pea or Arhar), *Grewia teliaefolia* (Dhaman preferred in Assam), *Albizzia lebbek* (Siris/Gulwang), *Flemingia macrophylla* (Bholia), *Ficus benghalensis* (Bargad), *Ficus religiosa* (Peepal)etc.

Palas, Kusum, Ber and Khair are of major host plants, while others are of regional and minor importance. The quality of lac depends on the host plant and to the strain of lac insects. The Kusumi lac is better and fetches higher price in market. The ber tree, siris (*Albizzia* sp.), *Prosopis juliflora*are identified as good host for kusumi brood lac. These three hosts viz., ber, siris, semialata are expected to enhance kusumi lac cultivation.

Strains of lac insect

In India, mainly there are two distinct strains of Lac insect: kusumi and rangeeni. The kusumi strain is grown on kusum or on other host plants using kusumi brood. The rageeni strain thrives on host plants other than kusum. The life cycle of lac insects take about six months, hence, two crops a year can be obtained.

In case of kusumi strain, two crops are:

i) Jethwi (June / July)
ii) Aghani (Jan. / Feb).

In case of rangeeni, tow crops are:

i). Karrtiki (Oct. / Nov.)

ii). Baisakhi (May / June).

The crops have been named after Hindi months during which these are harvested. The lac of rangeeni crops is harvested while it is still immature. Aghani and baisakhi of rangeeni strain are the main corps contributing about 90% of lac production, remaining 10% is contributed by kusumi crops. However, the kusumi crop lac is considered superior resin, because of the lighter colour of resin, and it fetches better price.

Pruning, Inoculation, Lac Cropping Techniques and Harvesting

Method of cultivation

Lac cultivation is a simple process and very limited labour is required for this, the yield is fairly remunerative to the cultivators. Cultivators should have complete, systematic, scientific knowledge for success.

The main steps involved in the cultivation of lac are:

d) Pruning,

e) Inoculation,

f) Harvesting and

g) Proper care for elimination of the enemy insects.

Pruning

In this stage the Palas tree is mature and ready for the production of lac at anage of eight to ten years.Proper pruning is extremely important as it helps the growth of new and short shoots suitable for settlement of lac insects. Old and hard branches can never give a satisfactory production. The following points should be borne in mind during the pruning

- There should be no excessive pruning in order to maintain the good health and strength of the tree.

- Proper cutting should be done in such a way that there should be a good shape of the tree for plenty of space for the growth of new shoots.
- Branches exceeding 2”in diameter should not be cut. The most satisfactory results are obtained by cutting at a thickness of 1-2” in diameter and the thin branches under ½” diameter should be cut.
- Dead and diseased branches should be removed and split or broken branches should be cut below the split or break.

Normally, the time of pruning is January-February, for inoculation in June-July, and April-May, for inoculation in October-November.

Inoculation

Infection or inoculation is the method by which the lac insects are introduced on to ahost plant. Inoculation should be done on trees which are being prepared for such purpose by pruning in due time. For Palas trees. The quantity of broodlac required for a tree depends upon the kind of tree and the size and number of suitable branches. Approximate weights of broodlac required for inoculating one medium sized tree of the following hosts are: Palas – 0.5-1.0 kg; ber – 1-2 kg; khair – 1-2 kg; kusum – 5-10 kg.

The general time period for the inoculation of lac insect is June-July -- Inoculation of Palas trees from the Bysacky brood to produce Katki Crop, October-November -- Inoculation of Palas trees from the Katki brood for production of Bysacky Crop

During inoculating, the following points should be carefully followed by the cultivators:

(1) Fully matured and healthy broodlac, free from enemy insects should be used. This will ensure maximum infection of the trees and also reduce enemy infestation of the ensuing crop.

(2) Broodlac for inoculation cannot be kept long and should be used immediately after cutting. Usually most of the lac larvae emerge from the brood within a week or ten days from the time of first emergence and to get best result inoculation should not be delayed beyond 2-3 days of noting larval emergence from the broodlac.

(3) Usually self-infection should be avoided unless forced by circumstances. If there is scarcity of labour in June-July, or there is a

very hot localities, self-infection of trees should be done.

(4) While carrying out artificial infection, fully mature and healthy brood lac, free from enemy insect infestation should alone be used. This will ensure maximum infection of the trees and also reduce enemy infestation of the ensuing crop

(5) Brood lac meant for infection cannot be kept long and should, preferably, be used immediately after crop cutting. Ordinarily, most of the lac larvae emerge from the brood lac within a week to ten days from the time the first emergence is observed, and hence, on no account infection should be delayed beyond 2 to 3 days of noting the larval emergence from brood lac.

(6) Correct amount of brood lac, neither less nor more, should be used for infection. Ordinarily a well-covered healthy brood lac stick gives adequate larval settlement over 15 to 20 times its length, on the twigs of the tree to be infected and hence, brood lac at this rate should be used for infection.

(7) Selected brood lac in lengths of about 6 to 12 inches should be first tied into bundles of 2 to 3 sticks and then such bundles tied on to the branches of the trees at such places that the twigs above (with 15 to 20 times the total length of brood sticks used in the bundle) get full infection. This will ensure full and uniform distribution of the brood and consequently full and uniform infection of the tree.

(8) While tying brood bundles, care should be taken to tie them securely on to the upper surface of branches and in such a way as to give maximum contact of the bundles with the branch. This prevents sagging or falling of brood bundles from the trees and allows the lac larvae to crawl to the tree easily.

(9) Brood lac bundles should be kept on the tree for the minimum period required for complete infection. Ordinarily, it may not be necessary to keep the brood lac on the tree for more than two or three weeks. If kept longer i.e. even after the complete emergence of the lac larvae, there is the danger of a large number of enemy insects emerging from the empty (phunki) brood lac sticks and starting heavy infestations in the field.

(10) While inoculation is going on, sometimes it will fall to the ground due to a different reasons such as the activity of squirrels and rats, and therefore, there is a need to keep proper watch on infected trees and then and put such fallen bundles back on the tree.

(11) The quantity of broodlac used usually depends on the size of the tree. In case of Palas trees, 300 gms while in cases of small trees upto about 1 Kg lac is obtained

Cropping

While harvesting the lac crops, the following points should betake care:

I. Lac crops should be obtained only after maturation.

II. The premature cutting of lac will affect the quality of brood lac, since the female lac insects still alive and ready to lay eggs get cut off from their food supply from the host tree, and hence give rise to weak, emaciated and unhealthy progeny.

III. Cropping of host trees like kusum and certain species of *Ficus* at the time of harvesting also serves the purpose of pruning. In pruning or cropping atree, the overall consideration should be that the general health of the tree must be maintained and its frame increased as far as possible.

IV. All dead and diseased branches should be cut off.

Cultivation of lac has been carried on by farmers in forest, sub-forest and hinterland areas where suitable host plants exist, as a subsidiary occupation. The more important areas of lac production are: Bihar – Chota Nagpur division, Santhal Pargans and Gaya districts; Madhya Pradesh – Bilsapur, Raipur, Balaghat, Chindwara, Jabalpur, Surguja, Mandla, Raigarh, Seoni, Durg, Hoshangabad, Malda and Bankura districts; Asam – Khasi and Jaintia hills, Garo hills, Mikir hills, Nowgong, Kamrup and Sibsagar forest division; Orissa – Mayurbhanj, Sambalpur, Bolangir, Dhenkenal, Kalahandi and Keonjhar districts; Maharasthra – Bhandara, Chanda, Panchmahal and Baroda districts; Uttar Pradesh – Mirzapur, district and Lucknow and Varanasi forest divisions. Small quantities of lac are grown in Punjab (Hoshiarpur dist.), Karnataka and Tamil Nadu (Madurai dist.) States; the lac produced is consumed locally.

Lac Enemies

Like the other agricultural crops, the main enemies of lac crop are the insects. These insects are serious and damaging pests to the lac crop also,. These insect pests destroy 30-40% of lac. The insects damage the lac crop is two ways:

As *Parasites*: Lac insects are parasitized by small winged eight species of insect belonging to family chalcidae order Hymenoptera. These insect pests lay eggs in lac cells. Their grubs on hatching feed on lac insects within the cells. Loss due these parasites is 5-10%

As *Predators:*

The predators causes major damage (up to 35%) to lac crop. There are three main insect predators on lac:

(1) *Eublemma amabilis* Moori: commonly known as white lac moth, orderLepidoptera
(2) *Holocerca pulverea* Meyr : commonly known as black lac moth, orderlepidoptera
(3) *Chrysopa spp.*: Commonly known as lac wing fly, order Diptera

The white lac moth is more destructive on trees; while black lac moth, on the stored lac. These predator moths and fly lay their eggs on the lac encrusted twigs. On hatching, their larvae make their way inside the lac encrustation and feed on the lac insects as well as on lac encrustations.

In addition to insect pests, squirrels and monkeys also damage lac. The rodents could damage greatly. These pests gnaw the mature lac encrustations on the trees or brood lac sticks tied for inoculation, and thus, consuming gravid females. The brood lac can be made to fall on the ground by these animals preventing inoculation.

Forest fires too often break out in deciduous forests in summer season and destroy both lac insects and their host plants.

Control Measures for the control of insect enemies of lac are:

- Only healthy pest-free brood lac should be used for inoculation.
- Enclosing of broodlac for inoculation in 60-80 mesh wiregauze baskets, c. 30 cm x 7 cm in size. This method is particularly used for areas where lac cultivation is being introduced for the first time. The baskets permit free exit to lac larvae but exclude enemy insects. Proper management of host plants with a view to ensure their vitality and vigour helps to reduce damage by parasites.
- The twigs for inoculation should be cut just before swarming to get healthy brood.
- Avoiding cultivation of early and late maturing varieties of lac, at least for brood purposes, in the same locality to prevent the spread of pests
- Scrapping of encrusted lac from twigs should be done as soon as

possible, and lac, thus obtained should be immediately converted into seed lac and not left near the inoculated lac hosts.

- Immersion of freshly harvested sticklac, not wanted for brood, as well as phunki lac (i.e., broodlac after larval emergence is complete) in running or deep stagnant water
- Scraping of lac from twigs immediately after harvesting and killing larvae and pupae of the pests by burning, crushing, drowning or by fumigation with carbon bisulphide (1 oz./10cu.ft. of space) before storage.
- Infected stick lac should be destroyed along with predators and pests.

Manufature Of Hand-Made Shellac

After proper blending, seedlac is filled into a long, narrow cloth bag. One end of the bag is held in front of the charcoal oven while the other end attached to a windlass is gradually turned. The heat of the oven melt the lac which is forced out through the cloth by the pressure extended by the windlass leaving impurities inside the bag. The molten lac is scraped out and mixed thoroughly to ensure uniformity and transferred to a block of molten lac on the surface of a smooth porcelain cylinder filled with hot water. The molten mass is spread on the cylinder by means of a strip palm leaf and pulled off as a sheet of about 1/8” thickness. Standing in front of the fire, the workman so manipulates the sheet as to heat it uniformly and then scratches it with his hands, legs and mouth. It is pulled in all directions to produce a sheet of about 5’x4’ with a varying thickness from 1/16” at edges to about 1/1000 of an inch in the center. The sheet is removed from the heat which is quickly cools and hardens. The thicker edges are broken off and remolted while the rest is crushed into small pieces and sold in the market as handmade shellac. This process requires considerable manual skill and long experience.

Another variety of handmade shellac known as Buttonlac is manufactured by dropping the molten lac on to a piece of galvanized iron sheet to form circular discs(buttons) 2-3” in diameter and ¼” thick. The residue left inside the cloth bag is another variety of refuse lac known as Kirilac. Kirilac obtained through handmade process contains lac to the tune of 60-70%. The handmade shellac has an impurity content varying from 1-2.5%.

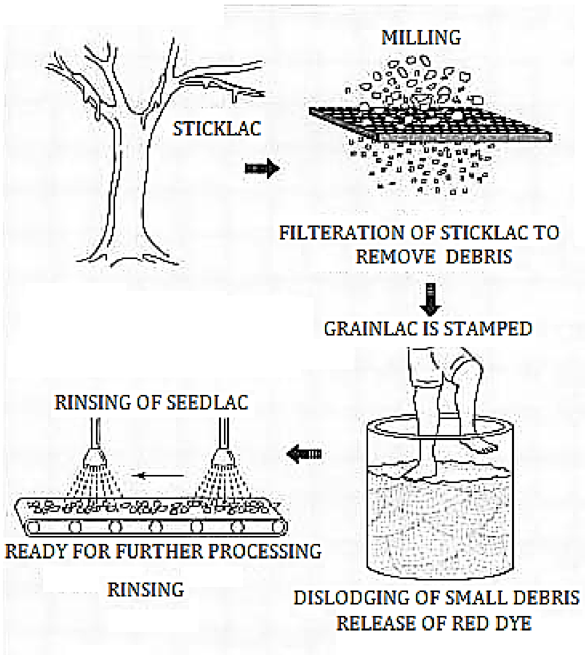


Figure – Processing of Lac

Manufacture of machine made shellac

When seedlac is produced by machine generally two methods are used—by heat process same as in the case of handmade shellac and the second is solvent process where pure shellac is extracted from seedlac by using suitable solvents.

1. **Heat Process**

   In this process the pure lac is isolated from melting seedlac by steam heat and squeezing the soft molten lac through filter by means of hydraulic pressure. The molten lac is then stretched by means of rollers into long and continuous sheets which is broken into pieces to from the machine made shellac under heat process. This shellac has an impurity ranges from 0.5 to about 1”. The residue remaining on the filter forms the Kirlac which has a lac content varying from 40-50%.
2. **Solvent Process**

   In this method insoluble impurities are isolated by dissolving the lac in a suitable solvent, usually industrial alcohol, after this the solution is filtered through fine cloth and the alcohol is recovered by boiling the solution. The molten shellac is then stretched to the required thickness on a roller followed by stretching machines. The solvent process manufactures different types of shellac containing varhying percentage of shellac wax. Dewaxed or partly dewaxed shellac may be manufactured by this process. Very high grade of shellac dewaxed, decolourised, least impurity containing shellac can be produced by this method by using activated carbon as the decolourising agent.

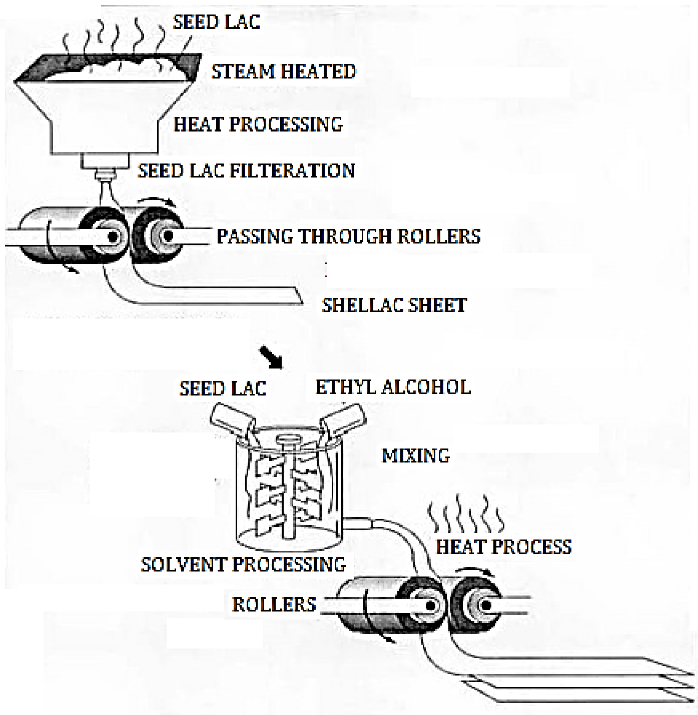


Figure – Processing of Lac

Lac Composition

- The major constituent of sticklac is the resin (70-80%). Lac resin is a polyester complex of straight- chain hydroxy fatty acids of C14 – C18 carbon chain, mono- and di – hydroxy acids along with hydroxy terpenic acids.
- The Resin can be fractionated into soft and hard components by exhaustive extraction with ether; the former constitutes 30% of the original resin and is brown in colour. Both soft and hard resins can be further fractionated by successive extraction with organic solvents.
- One fraction of soft resin contains free acids and neutral materials including the yellow dye, erythrolaccin. The second fraction possibly comprises of equivalent amounts of aleuritic acid, an isomer of aleuritic acid and lacollic lactone.
- Other constituents present are: dye, sugars, proteins, and soluble salts,

wax, sand, woody matter, insect bodies and other extraneous matter, a volatile oil is present in traces.

1. **Wax** – The wax present is sticklac is usually obtained as a by-product inthe manufacture of dewaxed shellac; it is known in the trade as Shellac Wax.
2. **Colouring matter**–A water soluble red dye, laccaic acid, andan alkali and spirit soluble yellow dye, erythrolaccin is present in lac; the latter is possibly a etrahydroxymethyl anthraquinone. Laccaic acid (C20H14O10) is a hydroxy-anthraquinone caroboxylic acid. Lac dye is obtained by extracting sticklac with water and sodium carbonate solution and precipitating with lime. It gives bright red and scarlet shades which are somewhat faster than cochineal.
3. **Refining** – Crude lac, as obtained by scraping the resinous encrustationsfrom harvested twigs, is known in commerce as sticklac. It is seldom used without refining.
4. **Seed Lac** Sticklac is crushed by hand or power operated roll mills and washed with water in cup-shaped stone vats or steel barrels. It is then dried on cemented floors away from the direct rays of the sun and finally winnowed. The water soluble colouring matter is removed during washing. Washed lac or seedlac, thus obtained is in the form of grains (10 mesh/in or less), yellow or reddish brown in colour. Adhering impurities amount to 3-10%.
5. The lighter impurities float on the surface and form a scum which can be easily removed. The coloured water containing lac dye is drained out. The washing is repeated until the dye and most of the impurities are removed. The lac thus cleaned is spread on large, clean open air floor to dry. After drying, it is winnowed and sieved to get the commercial variety of seedlac. The dusty lac which is eliminated by sieving is known as Molamma lac and falls under the category of Refuse lac, it contains approximate 55-80% lac.

Lac products and their use

- **Lac dye**

  Lac dye is used to colour wool and silk. Its colour varies between purple red, brown and orange. It is a mixture of anthroquinoid derivatives. It is used in food and beverages industry for colouring. But, now-a-days because of awareness on use of eco-friendly and safe material there is a great demand of lac dye as a colouring material in spite of using synthetic dye.

- **Lac wax**

  Lac wax is a mixture of higher alcohols, acids and their esters. It is used in various products like polish of shoes, floor, automobiles etc, Food and confectionary, and drug tablet finishing, lipsticks, children colourful Crayons

- **Shellac**

  Shellac is a natural gum resin used in numerous industries. It is natural, nontoxic, hard, tough, amorphous, brittle, physiologically harmless and edible resin. Shellac is a resin containing small amount of wax and a substance responsible for its characteristic pleasant odour. The lac resin is an intimate mixture of several components. Shellac is slightly heavier than water. Its natural colour varies from dark red to light yellow. When slowly heated, it softens at 65-70^{o}C and melts at 84-90^{o}C. Shellac is insoluble in water, glycerol, hydrocarbon solvents and esters, but dissolves readily in alcohols and organic acids.

It has the following extra ordinary properties:

1. It is thermoplastic and also used for various applications in the food industry.
2. It is UV-resistant.
3. It has excellent dielectric properties, dielectric strength, a low dielectric consent, good tracking resistance etc.
4. It has excellent film forming properties. Its film shows excellent adhesion to wide variety of surfaces and possess high gloss, hardness and strength
5. Shellac is a powerful bonding material with low thermal conductivity and a small coefficient of expansion.
6. Shellac under tropical conditions of storage, may soften and form a solid block, without adverse effects on its properties.
7. When shellac is heated for a long time above its melting point, it gradually loses its fluidity and passes through a rubbery stage to hard, horn-like and infusible.

Use:

- It is used in fruit coatings, e.g. for citrus fruits and apples, parting and glazing agents for sweets, marzipan, chocolate etc. Also used as binder for foodstuff stamp inks, e.g. for cheese and eggs.

- Jewellers and goldsmiths use lac as a filling material in the hollows in ornaments.
- It is also used in preparation of toys, buttons, pottery and artificial leather.
- It is also used commonly as sealing wax.
- It is used as binder for mascara, nail varnish additive conditioning shampoo, film forming agent for hair spray, micro-encapsulation for perfumes.
- It is used for enteric (digestive juice-resistant) coatings for tablets
- It is used in manufacturing of photographic material, lithographic ink and for stiffening felt and hat material.
- It is utilized in preparation of gramophone records.

Bleached shellac

Use

- In medicines for coating of pills, tables and gel caps and coating for controlled release preparation.
- Used in coating of confections, chewing gums, marzipan chocolates, nutties, jelly- and coffee-beans etc.
- As a wood finishing agent in wood coatings and wood stains and as a wood filler or sealer agent for porous surfaces and cracks.
- In French polish used for antique frames for paintings and Wood polish.
- In different fireworks and pyrotechnics.
- In different electric equipments as a binder for lamp cements.
- In field of electronics as an insulation materials, serves as additive to moulding compounds. Mass coating for print-plates and is adhesive for si-cells.
- Used in paints as a primer for plastic parts and plastic film.
- In Aluminium industry as a primer for Aluminium and Aluminium foils.
- Flexographic printing inks

- Barrier coating for processed food, vegetables, fruits and dry flowers.
- Used as textile auxiliaries.
- In various cosmetics products like hair spray, hair and lacquers, hair shampoos, and binder for mascara.
- In primer for plastic parts and films.
- As an additive to natural rubber.
- In leather auxiliaries.

Dewaxed bleached shellac

Dewaxed shellac is a bit harder, shines a bit brighter, is completely free from wax from normal shellac. Bleached lac has super characteristics and qualities i.e. adhesive, binding, hardening, gloss, odorless. It has good film forming properties, a high gloss and excellent adhesion to various substrates including the human hair.

Use:

- In different cosmetic products like hair sprays, hair setting lotions, hair shampoos, mascara, eyeliners, nail polishes, lipsticks, micro encapsulation by coacervation of fragrances and perfume oils.
- In coating of various food products like confections, chewing gum, candles, cakes, eggs, citrus fruits and apples, and printing inks for eggs and cheese.
- Coating of fruits and vegetables, tablets &capsules, aluminium foil, paper etc.

Apis spp (honeybees): Economic importance, bee species and their behaviour, habit and habitats; Bee keeping: bee pasturage, hives and equipments, seasonal management; Bee enemies, including diseases and their control.

10.4 Apiculture

Apiculture is the science of beekeeping. In this we do rearing of the honeybees in natural or artificial conditions. Beekeeping is one of the gentlest agro-industries. Bees and beekeepers are found throughout the world. Honey industry involves honeybee, flowering plants that provide food to the bees and to the beekeepers who manipulate bees according to the climate and vegetation for their own benefit. Beekeeping creates employment, income and a measure of economic security and well-being. Bees have been reared by man originally for harvesting honey. Today, apiculture industry is not restricted to honey alone. It also involves production and harvest of all hive products, like beeswax, bee collected pollen, royal jelly, bee venom and propolis. Honeybees are also involved in pollination to increase the yield of agricultural and horticultural crops.

History of the apiculture

In India, usefulness of honeybees has been known from the prehistoric times. the association between man and honeybee has a long history, as evidenced by oldest records of honey industry in the form of paintings by prehistoric man in the rock shelters. Honey was the first sweet food tasted by the ancient Indian roaming in these forests. They hunted bee hives for this gift of Nature. The bees have been mentioned in the Vedas, the Ramayana, the Quran and other holy books. Figures and carvings of honeybees, their combs and hives are found on the tombs, coffins, crown and maces of kings and on the coins of both ancient and modern empires. Honeybees have been used as a weapon in the World War I when infuriated swarms were released to hamper the entry of forces in Belgium. The medicinal property of bee venom of relieving muscular pain and aches of sciatica, rheumatism and arthritis has also been known for a long time. While primitive methods of beekeeping have been used in all over the world from a very old time. According to Einstein if the bee disappears from the surface of the earth, man would have no more than four years to live. No more bees, no more pollination, no more plants, no more animals, no more man.

The first rewarding scientific method of movable Frame Hive in 1851 was discovered by Revd. L.L. Langstroth. In India, this method first came to Bengal in 1882 and then to the Punjab in 1883. The Imperial Entomologist started beekeeping work at Pusa in 1907 and continued with it up to 1919. The beekeeping was taken to the South by Revd. Newton in 1911. After the recommendations of the Royal Commission on Agriculture to develop beekeeping as a cottage industry, (1928), the practice got a fillip in Madras (1931), the Punjab (1933) and U.P. (1938). Nevertheless, beekeeping in India has remained very much behind countries like the USA, Canada, Europe, Africa, Australia and New Zealand. Whereas in these countries beekeeping by individuals is a popular pastime, in India it is almost unknown despite the fact that it being a tropical country can provide flowers of one or the other kind all-round the year making individual beekeeping as profitable as poultry farming. It is time that this sweet and rewarding pastime is popularised in our country too.

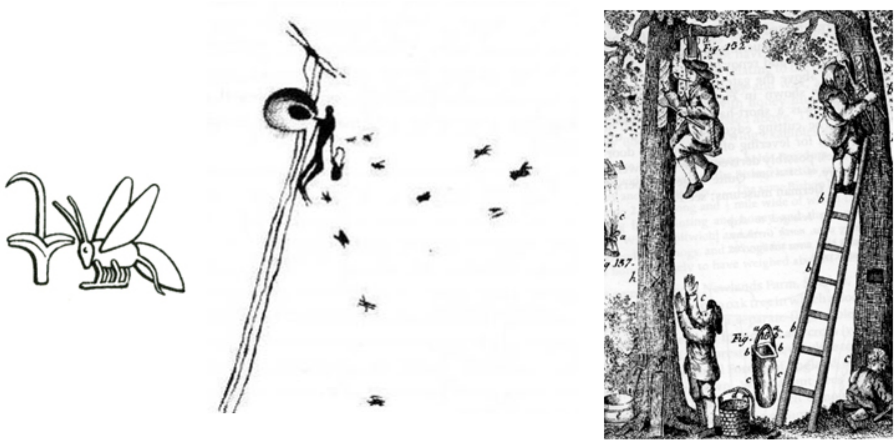


Figure- Ancient paintings showing beekeeping

Habit, habitats and behaviour of *Apis* bee species

There are some 20,000 kinds of bees, all belong to order Hymenoptera of insect group that shows evolutionarily advanced features in body structure and in life cycle. Of them, three families of social bees are honey producing: Bombidae, Apidae and Meliponidae. The Bombidae are mainly temperate which keep their broods and honey in separate waxen pots, not in combs. The Meliponidae are stingless bees, some of them making waxen pots, some others horizontal combs and just one, *Trigona staudingeri* of Africa making vertical combs. The Apidae, is the main honey-producing family. Its four species, *Apis dorsata, Apis indica, Apis florea* and *Apis mellifera* are most popular with beekeeping industry. Of them, the first three are Indian and the last, European species that has been introduced into every country of the world due to its good honey-gathering quality.

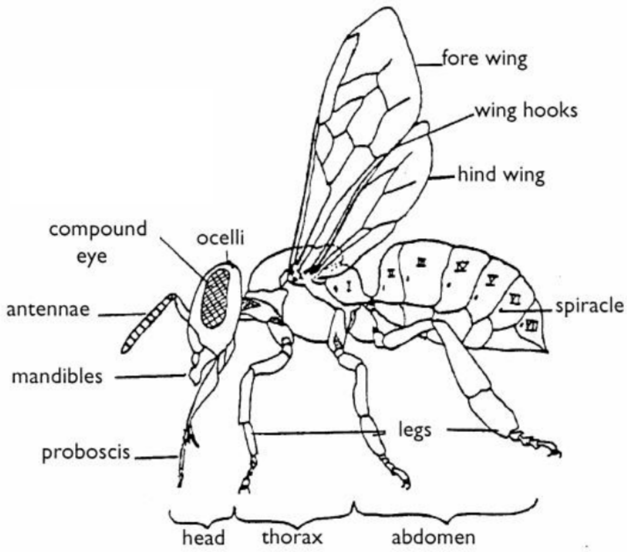


Figure – Morphology of honey bee (Source – R.E. Snodgrass)

Systematic Position

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Hymenoptera
Family:	Apidae
Subfamily:	Apinae
Tribe:	**Apini** Latreille, 1802
Genus:	***Apis*** Linnaeus, 1758

Dwarf bee, *Apis florea* (F.)

Apis florea is the smallest honeybees and is called appropriately the dwarf or the little honeybee. It does not sting easily and so mistaken for Stingless bee. It is generally found in plains or low lands in tropics and sub-tropics. It is rarely found in altitudes above 450 m. The nests are built in bushes, densely leaved small trees in gardens and orchards, eaves of buildings or wall niches in urban areas and on closely placed stalks of crop plants like Sorghum (jowar).

The dwarf bee is able to survive in very hot and dry climate. The comb (size 40 x 45cm) architecture is similar to that in other *Apis* species, except the comb shows a distinct honey portion that is situated at the top, and where the support is free from above. The honey cells are constructed around the support. The dwarf bees perform short flight but the maximum distance for foraging is often up to 750 m. In view of this, the honey stored by it is generally unifloral.

Rock bee, *Apis dorsata* (F.)

Rock bees, also known as giant bee, are common in plains and hills tracts up to 1200 m altitude in the country. The nests of the rock bees are built in the open and are fixed underneath a broad support such as a rock cliff, branch of a tree, or eaves of a building. A usual feature of the rock bees is aggregation of their nests (about 100 colonies) on terrestrial and arboreal supports. In thick forests, rockbee colonies are built on branches of lofty trees at heights up to 50 meters. Rock bee's nests are found even on multistoried buildings, large overhead water tanks and towers, ceilings and arches of temples, engineering workshops in towns and cities.

Rock bee hive is the largest hive, often 100 cm broad and 80 cm high, but sometimes measuring up to 200 x 150 cm. The combs are semi-circular, vertically attached to the support above, from where it hangs down. The comb has a midrib and two layers of cells connected to it on either side. The nest population is 60,000 to 100,000 bees in well-developed colonies.

Like the dwarf bee, rockbee is migratory in nature, but the stay of nests in any one place is usually long and often their movement is restricted to two times in a year. It is said that rock bees can forage even during moonlit nights. Its flight range is more than 5 km. Honey hunting in forests is related mainly with rock bees.

Indian hive bee, *Apis indica*

The Indian hive bee is also considered as sub-species of the Asian or Oriental or Eastern hive bee, *Apis cerana* F. In India, two varieties: the hill variety or 'Gandhiana' which is darker and larger and the plain variety and 'Indica' which is smaller and yellow, and various ecotypes are recognized. It makes parallel combs on trees, termtaria, hollows of rocks and all kinds of cavities. It can be domesticated. The Indian bee is often blamed for its desertion or absconding tendency.

European bee, *Apis mellifera*

European bees, originated in Italy, and have been introduced into all the countries of the world where they formed the well-recognized races. In India, it was successfully introduced in 1965; the race is *A. mellifera*. The original stock at Punjab has been multiplied, and the progeny distributed in other states by the All India coordinated Project on Honey Bee Research and Training, ICAR, Central Bee Research and Training Institute, and Khadi and Village Industries Commission. It can yield 4 - 5 times as much honey as the Indian bee. It makes its nest in enclosed spaces in parallel combs and is endowed with all the good qualities of a hive bee, i.e. it has a prolific queen, swarms less, gentle tempered so domesticable, good honey gatherer and can guard its nests against enemies, except wasps. It has adapted itself well to modern methods of movable frame hives and, therefore preferred for beekeeping industry the world over.

Apis florae *Apis dorsata* *Apis cerana indica* *Apis mellifera*

Figure – Indian *Apis* Bee Species

Social organization of honeybee colony

Honeybee is a social insect because it lives in hives or colonies with a division of labour. Each colony is a society of different castes: the worker bee, queen bee and drone or male bee. There is a perfect co-ordination in the functioning of the following three castes in the colony.

Queen Bee (functional female)

The queen is a fertile female larger than the other two castes. Its abdomen is swollen with eggs. Each colony contains one queen bee as its head. After birth, the queen stays inside the colony for about 5-10 days to grow to maturity. Later, it goes out of the colony on mating or nuptial flights followed by several drones. During the mating process, the stock of sperms of male bee goes into the spermatheca of the queen, where they can survive for over 3 years. The mated queen returns to the hive and starts its role as the queen mother, i.e.

laying eggs. A queen can lay up to 15,000 eggs per day.

It is fed on royal jelly, a highly proteinous, enzyme- and hormone-rich food produced by the worker bees. Egg laying is controlled by the availability of food royal jelly. Although the queen bee can live for 2-3 years, its effective life to lay fertilized eggs for the survival and continuation of the colony is much shorter; usually 2 years. The queen bee can lay fertilized or unfertilized egg depending upon the size of the brood cell. The worker brood cells receive fertilized eggs, while the larger drone cells receive unfertilized egg. The former hatches into worker bee larvae and the later into drone larvae.

A queen bee differs from a worker bee in its morphology, development period, life span, and behaviour. The queen develops reproductive organs, while the worker bee develops organs related to its work such as pollen baskets, stronger mandibles, brood food glands and wax glands. Unlike workers, the queen never participates in any common hive activities.

Worker Bee (sterile female)

Worker bees are infertile female developed from fertilized eggs. A bee colony is called weak or strong according to number of workers it has. A bee colony of *A. cerana indica* has 15,000 workers and a strong one has 80,000. The workers (sterile females) are smaller than drones and queen. These have underdeveloped reproductive organs due to the influence of the pheromones produced by the queen. At any given time, a colony may have 2 or more batches of worker bees, having different male parentage.

A worker bee has a life span of 6 weeks. For about three weeks following birth, they do the indoor duties, like feeding the drones (if they are still need), nursing the young, secreting royal jelly and bee wax, feeding and attending queen bee, cleaning the cells and hive, repairing the damaged combs, construction of new combs, ventilating, cooling, guarding and defence of the colony, evaporating nectar and stored honey. During the next 3 weeks, they take to outdoor field duties of foraging to collect water, nectar, pollen and propolis, and ripening honey in its proventriculus (honey stomach). Older forager bees turn also into scout bees that search for new sources of food and new nesting sites for the hive.

A worker bee does not have an individual existence, as it lives for the good of entire colony. It dies in harness during flight to flowers. The average worker bee can make only one-twelfth of a teaspoon of honey during its lifetime. The worker bees must tap over two million flowers to make about one pound of honey, flying a distance equal to more than three times around the world.

Drone (male)

The drones are male developed from unfertilized eggs parthenogenetically. The male bees are produced in the colony for the purpose of mating and fertilizing the queen bees. The larvae that develop from unfertilized eggs are fed royal jelly and give rise to drones. Worker bees feed and take care of the drone bees till the virgin queen in their colony is mated. After mating with the queen, the drone dies. When queen bee returns mated to hive, the worker bees neglect the drones.

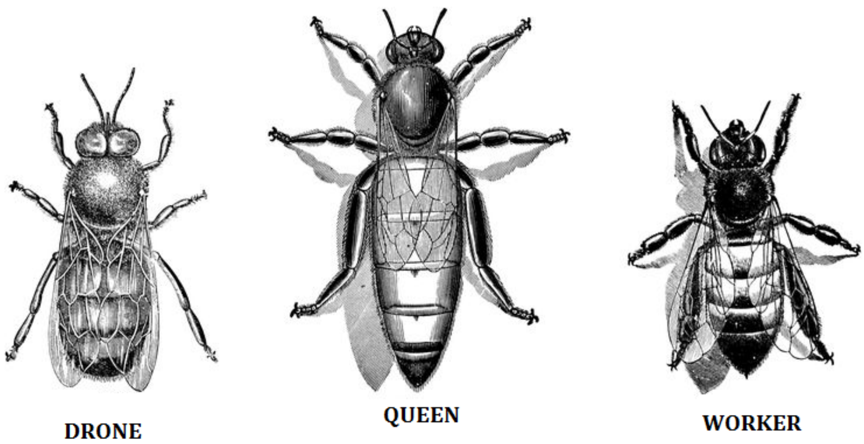


Figure - Morphology of worker, drone and queen castes of honey bee

Life Cycle

During nuptial flight, the queen receives spermatophores from drone and store in its spermatheca. The queen walks over the combs deciphering the cell size (largest of queen, smallest of worker and in between of drone) and depositing one egg in bottom of each cell. The eggs are small, oblong and bluish white. The eggs may be fertilized to produce females or unfertilized to produce drone parthenogenetically, and these are accordingly deposited in the cells of required size.

The transformation of 3 castes depends upon the amount of ‘Brood food’ or ‘Royal jelly’ produced by pharyngeal salivary glands of worker fed to larvae. The cells of queen, worker and drone are sealed, i.e. capped with wax on 8, 9, 10 day of emergence, respectively. The cap of drone cell is convex with a central hole, and those of worker, queen, honey and pollen are flat.

Figure – Life cycle of Honey bee

Social behaviour

The various behavioural features of bees within the hive and in the field are important for the smooth functioning of the colony as a unit.

(For more details please refer to Unit – 12)

Swarming and Colony Reproduction

Swarming is a method of reproduction. A part of the colony migrates to a new site to reproduce a new colony. When food is available in plenty, the worker bees take up activities that result in colony reproduction. They build drone cells in which the queen lays unfertilized eggs. These hatch into drones. After this, the bees construct queen cells and fertilized eggs are laid in these cells. The worker bees feed the larvae in the queen cells with royal jelly, larvae develop into fertile females, viz. queen bee. Before a virgin queen emerges from the sealed queen cells, the mother queen leaves the hive with a part of the worker bees as a prime swarm. Then the virgin queen emerges and after a while rushes out of the hive with another batch of worker bees to form after swarm that establishes itself into a colony at a new nesting site. The swarm settles in a selected nesting site. Worker bees begin to construct combs, forage and gather food, and to rear the brood. As the new worker bees emerge, the hive develops into a full-fledged colony.

Nest Site Selection and Nest Construction

The nest site selection depends upon various factors like the availability of food source nearby, distance of water source and adequate space to accommodate the nest. Other factors are temperature, humidity, and availability of sunlight, ventilation, and protection from rain, predators and enemies. Among the honeybees, rock bees prefer associations in the nest site, while other species build their nest in independent sites in isolation.

Honeybees will occupy any cavity which is weatherproof or can be easily made so by them, offers protection against enemies, does not become too hot in the sun and provides adequate ventilation. The most common nesting place is a hollow tree; other are holes under rocks, caves, hollows of termitaries, electricity poles, if hollow, chimneys, cupboards and boxes. If the selected place has cracks through which the bees cannot pass, they seal them with propolis, a resinous substance with which they varnish the inside of the hive. If the entrance is larger than the bees can guard safely, they block it with the same material leaving only a number of small holes which they can both guard and use to regulate circulation of air in the hive.

Following selection of nest site, worker bees produce beeswax by consuming nectar or honey. Wax is secreted by the 4 pairs wax glands located on 3rd – 6th abdominal sterna. The wax is secreted in liquid form and hardens into thin flakes or scales. The wax scales are removed from there with the help of legs, kneaded into required shapes by the spatulate mandibles and stuck to the top of nesting cavity and extended downwards bit by bit. Several bees hang like a string to do this job of nest construction. Beeswax is also used to seal the cells with wax cap.

The comb

The comb provides accommodation for raising of the young bees and the storage of food. The combs are built with beeswax which is secreted by 4 pairs of wax glands located on 3-6 abdominal sterna. The wax, secreted in a liquid form, collects in the intersegmental regions, hardens into thin flakes that are picked up by the legs and passed on to the spatulate mandibles for being kneaded and stuck to the top of nesting cavity and extended downwards bit by bit. Several bees hang like a string to do this job. First to be constructed is the midrib on both surfaces of which are also made hexagonal cells for the broods and food. After the first or central comb is completed, adjacent combs are made 1 3/8 inch apart in the case of A. mellifera and much larger in the hill varieties of A. indica but a little less in the plain varieties. As the combs increase in number, they are attached to the sides of the cavity as well as to the top but seldom to the extreme bottom. As already mentioned, the nests of A. dorsata and A. florea are made of single vertical comb, those of A. mellifera and A. indica comprise a series of parallel (horizontal) combs. There is a definite sequence in the locations of the cells for different functions. Usually the cells meant for honey storage are located uppermost near the point of attachment of the comb below which are pollen cells spread in 2" wide band, further down are worker brood cells which is followed by the drone and queen cells. New queen cells are built only when the old queen being ineffective to rule is to be replaced by a supersedure queen or if the queen accidentally dies and an emergency queen has to be produced or when the colony has the urge to reproduce by swarming. As mentioned earlier, the worker cells are the smallest, drone cells larger than the worker cells and queen cells, the largest. Workers and drone cells are directed sideways, queen cells vertically with open ends downwards. Cells of the size of worker and drone cells used for storing honey and pollen. Cells are capped or sealed after the purpose of which they are meant is over. Cells containing unripe honey or developing brood are uncapped; those with fully ripe honey and fully fed grubs are capped and pollen cells are generally not capped. Only drone cells, as noted above, have a dome-shaped or convex caps with a central hole; others have flat caps.

Nursing and Food Sharing

Young worker bees normally attend to the duties of nursing and feeding. They can detect the young or old larvae, and feed them accordingly with royal jelly or with beebread (a mixture of pollen and honey). The transformation of 3 castes depends on the amount of 'royal jelly' or 'brood-food' produced by the pharyngeal by the pharyngeal salivary glands of the workers. Bees consume pollen and nectar or honey, which helps in secretion of a special highly protein and hormone rich food, called royal jelly. The chemical composition of royal jelly is lipoproteins, neutral glycerides free fatty acids, sugar, amino acids and all the B vitamins. For the first 2 ½ days all larvae are given plenty of this food (obligatory feeding) after which those destined (chosen) to become workers and drones (identified by the size of their cells) are given rationed (controlled) food for 6-7 days and those destined to become queens continue to receive abundance of brood-food for 4 ½ - 5 days (facultative feeding). On the 8^{th}, 9^{th} and 10^{th} day of emergence, the cells of the queen, worker and drones cell is convex with a central hole, those of the worker, queen, honey and pollen cells are flat.

Pheromones

Pheromones plays the key role in honey bee colony for several functions. The distinctive colony odour resulting from these chemicals helps in recognition of hive mates, and locating their nest on return from forage flights. The chemicals are called pheromones and control the functions and behaviour of other individuals. The queen bee pheromones regulate the smooth functioning of the colony. It inhibits development of ovaries in worker bees, and prevents them from rising into new queen bees. When a virgin queen goes out on a mating flight, its pheromones help the drones to locate and reach her. The brood pheromones induce worker bees to feed the brood, and gather food from outside. Similarly, alarm pheromones induce them to attack the enemy or intruder in the colony. There are several such pheromones produced by the three castes that selectively control the behaviour of the inmates of the hive.

Queen's Retinue

A group of house bees form a circle around the queen and attends its feeding, cleaning and assists her in egg laying. Bees in this retinue constantly lick the queen's pheromones and share this substance with other house bees. The individuals in the retinue regularly are changed, as they leave the retinue to attend to other house duties and new individuals take their place.

Supersedure and Emergency queen

Supersedure is queen replacement without colony division. A failing queen who is unable to lay as many eggs as required, or who begins to run out of spermatozoa and lay a high proportion of male eggs will need to be superseded by supersedure queen. The worker bees are induced to build supersedure cells which are 2 or 3 large queen cells in the middle of the nest, unlike a dozen of comparatively small queen cells build at edges of nest during the swarming period.

In absence of queen substance due to death of queen, the workers are stimulated to get set for producing an emergency queen. The eggs or larvae less than two and half day old in worker cells, which are still being fed on abundance of brood food, are selected. Their cells are enlarged and extended downwards and the larvae are fed in the same way as in queen cells to develop into emergency queen.

Absconding and Migration

Complete desertion of a hive is known as absconding. It may occur due to lack of water, food store, overheating due to poor insulation and ventilation of nest, constant attack of pest and even by excessive interference of beekeeper.

Prior to absconding, the bees drink whatever honey their nest has and then migrate leaving behind empty combs. Absconding can be prevented by providing water or sugar solution near the hive particularly in summer. The experienced beekeepers always take this precaution, since absconding is complete loss to him.

Guarding and Defence

Bees have defence mechanisms against enemies and predators. Use of propolis is one of them. Dammar bees use propolis also to regulate nest entrance. Dwarf bees use glue like special propolis to guard their nest from ants. Bees developed stinging behaviour to face threats to the nest from enemies and predators. A batch of old house bees guards the entrance of the hive. They warn the hive mates of an impending danger to the nest, by releasing alarm pheromones. When a guard bee stings or bites an enemy, alarm pheromones are released that alert and instigate other workers to mount a collective attack on the enemy.

Flying and Foraging

Initial flight of bee is restricted to the surroundings of the nest, and is called orientation or play flight. Bees use the play flights also to void themselves of faeces and other waste products of their metabolism. Bees exhibit highly efficient methods of collecting food, learning the intricate patterns of the flowers and of reaching the food. They are excellent navigators and can reach their nest after foraging at long distances.

Nectar foragers suck nectar with their proboscis. The nectar gets into the honey stomach, where it gets mixed with bee's digestive enzymes. When adequate quantity of nectar is collected, the bee returns to the hive. Here, it regurgitates the nectar and gives it to nectar soliciting house bees. Both nectar and water are carried by separate bees.

Pollen foragers manipulate anthers of flowers to dislodge the pollens. Bees walk quickly or fly over the flowers, getting the pollen on their body parts. Pollen grains on any part of the body are gathered and packed together into pellets with the help of legs that have undergone extensive modification. The tibia of mid legs bears a spine at inner end, which is used to remove wax-flakes from the abdominal sterna bearing wax glands. The tibia of hind legs is broadened with concave outer surface fringed with long curved spines, the lower one of which acting as pollen rakes. The outer concave surface of tibia acts as a pollen basket. The basitarsus has pollen brushes. The pollens collected off the body the fore- and mid- legs are placed in pollen basket. Pollen baskets hold the pellets. When the pellets are big enough, the forager returns to the hive and deposits them in a pollen store cell.

Communication

Bees have a unique language (bee dance) to communicate among themselves about the distance and direction of food source. Experienced forager bees function as scout bees. They search vegetation in surroundings for food source. On locating a good source, the scout bee performs a dance on the surface of the comb. Through this dance, the scout bee communicates with potential foragers in the hive the information about the location in respect to Sun, the quality and amount of food.

Bee dance is of two types: Round dance and Tail-wagging dance. The communication dance is a sequence of elaborate movements of the posterior abdomen and of the bee in circles or other patterns. The vigour of dances and the frequency patterns of movements depend upon the quality, quantity, and distance of the food source.

Economic Importance of bees

Pollination can be accomplished by many types of birds, insects, bats, wind etc. Bees are one of the most well-known and important types of pollinator, both in agriculture and natural ecosystems. Pollination by bees occurs when a foraging bee brushes against the anthers causing pollen to stick to her body. When the bee touches the stigma while searching for nectar at the center of the flower, some pollen grains are left on its sticky surface. Bees also use pollen as a food source; it is collected from the anthers into an area on their legs called the corbiculae, which contain specialized hairs that hold the pollen in place.

Indian agriculture is characterized by a predominance of small and marginal farmers, who account for 80% of all farmer households. Agriculture has been plagued by declining productivity over the last few decades. Recognising that the benefit of beekeeping is 40 times more than the value of honey and beeswax, the first National Commission on Agriculture (1976) in India had recommended beekeeping purely as an agricultural input and put forth a plan for apiculture until 2000. However, subsequent agricultural policy unfortunately did not give beekeeping the importance it deserves.

Recognising the crucial role that low cost beekeeping could play in increasing agricultural yields for the small farmer in Maharashtra, Gujarat and Madhya Pradesh to promote low cost beekeeping with the indigenous bee, the *Apis*

Cerana Indica, to increase agricultural yields, diversify and improve rural livelihoods.

Commercial beekeeping especially that promoted by various government agencies focuses on the hybrid bee *A.mellifera*. The latter is a good producer of honey but has to be procured from outside and is often at risk of disease. From a small farmer's point of view, the *A. mellifera* is expensive to maintain and also requires migration as it does not pollinate all local crops. *A.cerana* on the other hand is locally available, does not require migration and is an excellent pollinator of local crops. This is an area where agriculture is rainfed and is of subsistence nature. Average annual incomes are around Rs 20,000 – 25,000 per annum. The economic value of crops grown for the family's consumption like rice, finger millet, niger and other pulses is another Rs 20,000 per annum.

Beekeeping is the actual commercial part of apiculture. Unfortunately, it is not very popular in India as it is in the western countries. Many people here even do not know that it can be as engaging and profitable a profession as say poultry farming, horticulture, pisciculture etc. The reasons are that it is firstly not eye-catching and secondly, people are not familiar with the techniques of this trade.

In India, due to the diversity in flora, topography and activities of people, beekeeping and management is diverse. Here, beekeeping has been adapted to various ecosystems, socioeconomic profiles and habitat preferences. From commercial beekeepers in Himachal Pradesh to local honey collectors in the hills and forests of Tamil Nadu to migratory beekeepers of Kanyakumari, the rich forest regions along the sub- Himalayan mountain ranges and the Western Ghats they all practise some form of beekeeping. Rural beekeeping has a role to play as not all can become commercial beekeepers. This rural sector needs to be enhanced by appropriate tools, support systems and bring them to the forefront. It is this informal sector which is providing up to 70 per cent of the honey and beeswax market in India.

AGRICULTURAL CROPS	% INCR. IN YIELD
Mustard	128.1-157.8
Rapeseed	12.8-139.3
Sunflower	21-3400
Niger	60.7-173
Berseem (Seed)	24.3-33150
Buckwheat	62.5
Egyptian cotton	16-24
Coffee Beans	16.7-39.8
Pulses (Arahar, Moong, Urd, Masoor, Peas, Beans, etc.)	10-38.7
This increase in yield is in addition to the value of honey	

Table - Increase in Yield Due to Bee Pollination

Bee keeping

Humans have collected honey from wild bee hives for more than 8,000 years, as shown in Mesolithic rock paintings dating from 6000 B. C. E. By 2500 B. C. E. Egyptians were keeping bees in artificial hives. Hives exploit the honeybees' natural tendency to build nests in cavities, and allow apiculturalists to easily move (via boat, wagon, truck) and manipulate bee colonies. This mobility has allowed beekeepers to introduce honeybees around the world: The first hives were brought to the New World in the 1620s by European settlers.

Primitive hives were made of hollow logs, holes built in mud walls, or cones of mud, earthenware, or thatch. A modern apiary hive is a series of stacked boxes. The bottom box serves as the brood chamber where larvae develop; the upper boxes provide a space to store honey. Each box contains eight to twelve frames, which are set so they approximate the distance between combs in a natural hive. Bees then build their comb on the frames, which can be removed individually. Beekeepers remove the wax caps that cover each cell of the comb and let the cells' contents drip out by gravity, or use a specialized machine to spin the frames and draw the comb contents out by centrifugal force. The honey is then filtered and stored. Honey quality is determined by its flavour, clarity, and colour.

Bee Pasturage

Apiculture is concerned with the efficient use of natural resources to produce natural material useful to man. The materials required for honey industry come from the flowering plants. Plants provide pollen and nectar having all the essential nutrients for their growth and survival of honeybees. These materials are processed by bees into honey, beeswax, royal jelly and other items, for immediate consumption or for storage and for later use.

Beekeeping in India has been by and large forest based. Our country, India, has large area and varied geographical characteristic. The natural flora of Indian forests is more varied because of the climatic conditions. There are several thousands of species flowering plants indigenous to India and many more have been introduced as crops of economic importance, or as ornamental plants. The forest natural vegetation of Western and Eastern Himalayan, the Western Ghats, the Sunder ban and the Assam region are more suited to bee life.

Beekeeping with the European honeybee (*A. mellifera*) that introduced in India in 1965 depends mainly on cultivated crops. Among such species are coconut, areca nut, red oil palm, date palm, cacao, mango, custard apple, jujube, cinnamon, clove, cashew, fodder legumes, coriander, cumin, dill seed, fennel, fenugreek, garlic, turmeric, ginger and other spice crops. The road side plantations like Eucalyptus, Karanj, Tamarind, Gulmohar, Peltaphorum and Soap Nut also contribute to honey production. Hedges and fence plants like Mehndi (Indian privet), Duranta, Mulberry, Justicia and Jatropha do also add to the bee forage value.

Many pulse and oilseed crops are also good sources of bee forage. Among the plantation commercial crops, Coffee, Orange and other Citrus Fruit, Apple and other Pomaceous fruit species, Cardamom and Rubber tree are important from the beekeeping point of view. The rubber plantation in Southwestern and Northeastern parts is the single largest source of nectar in India. Next in importance is litchi tree. The entire north India has large areas under litchi orchards that constitute an excellent source of nectar during March to May. Cereal crops, in general, are not very useful as sources of bee forage. However, Jowar, Bajra and Maize are valued for their pollen.

Methods of beekeeping

Traditional beekeeping

Traditional beekeeping is a natural consequence of forest beekeeping. The different traditional hives are used for the purpose. Rural people in southern India have been keeping bees in clay pots. A few such pots with holes and smeared beewax inside are kept in the garden as decoy hives, i.e., devices that attract swarms of bees. Swarms occupy the decoy hives. When the colony becomes strong, one or two shallow pots serving as super are kept inverted over it one above the other. When the monsoon sets in, the pots are overturned, the combs are taken out and honey is extracted.

Tree trunks or Logs (40 x 60-100cm) are hollowed out by removing the inner wood and used as log hive at altitudes above 1800 m. Wall Hives are empty spaces, left in east side wall of houses The wall hives are quite common from Jammu & Kashmir to the north-eastern Himalayan states. In addition, packing cases, empty wooden boxes, wicker –work and woven bamboo baskets of suitable size are also used as hives through the country.

Figure – Collection of bees swarms from the field.

Modern beekeeping

Modern Hives

In modern beekeeping, bees are kept away from their natural homes in man-made hive as comfortable as possible. Modern hive is a wooden rectangular box and it is movable from one place to other. In modern hive, frames are kept parallel to each other, have free space all around them that is twice the body size. This is called the **bee space**. It was Langstroth who took notice first in 1851 about the bee space and originally designed the frame hive. Bee space is the major practical concept in the modern hive. The eggs, larvae and pupae are together called brood. The frames used for rearing brood are called brood frames and wooden box holding the frames are called as brood chamber.

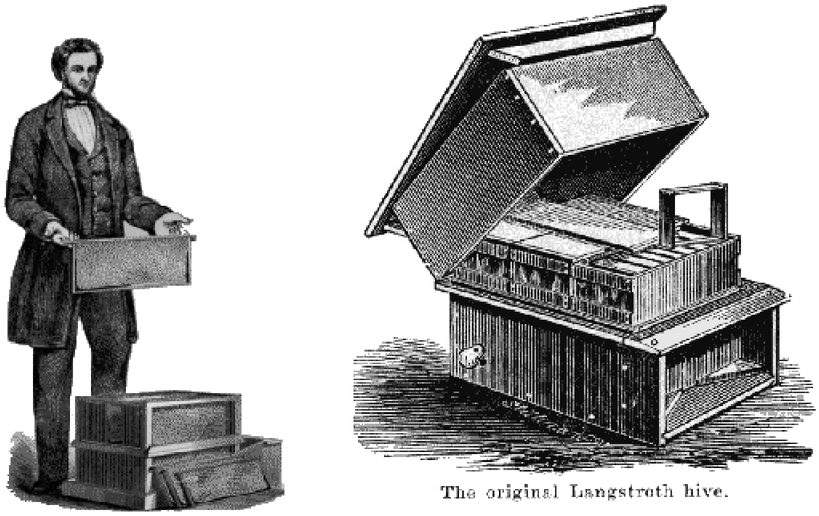


Figure- Langstroth’s Beehive model

Various types of frame hive varying in number of frames and bee space are used: Smith, British commercial, Langstroth, Modified Dadant, Newton, Honavar, Sodepur, Villager type etc. In 1956, Indian Standards Institution (ISI) constituted an Apiary Industry Sectional Committee to consider and bring out standards for bee - hives and other equipment. Based on the recommendations, two types of hives - ISI Type A and ISI Type B - were adopted.

A movable hive has the following parts:

i) **Stand**: It is four legged structure with dimension to support the floor board.

ii) **Bottom Board**: It is a tray with all its four sides raised by side runner. In the front, side runner is replaced by alighting board.

iii) **Brood Chamber**: It is a rectangular box without top and bottom. One inch scooped shelves are cut along the length core of brood box to receive the ends of top bar of hive frames.

iv) **Hive frames**: These frames are wooden. The sides or chore named as top-, side-and bottom-bars. The ends of top bars extend beyond to rest on the scooped rabet of brood box and undersurface is grooved to receive the edge of comb foundation. There are four wires fixed between side bars to support the comb foundation which act as mid rib. Bee constructs their cells on both side of frame. These frames are spaced apart to leave the bee space (ranging from 6-9 mm depending upon type of bee to be reared).

v) **Queen Excluder**: It is wire frame with suitable size perforation that enables the worker to pass through but not the queen. It excludes the queen to stay in the brood box. It is placed in between the brood chamber and super chamber.

vi) **Honey Super** : A hive could have 2-3 supers depending upon strength. The supers also have hive frames similar to brood box except in the shorter height. In super chamber frames only honey is stored. Hence, this chamber also called as Honey Chamber, and the frames in it as honey frames.

vii) **Covers**: On the top, there are two covers: inner and outer. Inner cover is a wooden plank of the size of box. It has one or two holes in middle that allow bee to go out but not to re-enter. The inner cover protects the bee nest and helps to regulate temperature and humidity within hive. The top or outer cover fits telescopically and acts as a roof for the hive to protect from sun and rain.

Generally, it has two slopping planks. Ventilation holes are present on planks.

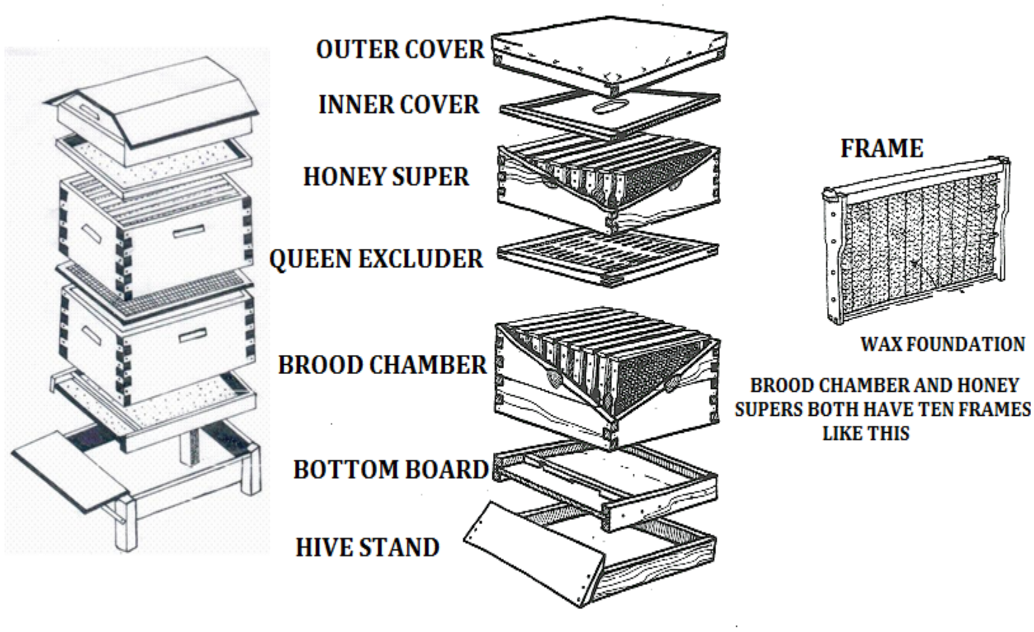


Figure – Artificial Beehive Parts

Beekeeping practices

Capturing

Capturing of the colony consists of removing the combs and bees from the natural nest and hiving them in the moveable frame hive. This is done early in the mornings or in the evenings when sun is not severe and the weather clear. After ensuring the presence of worker bees, brood in various stages of development and the queen bee, the combs are carefully cut one by one with a knife. These are tied to the frames and the frames are then kept in the brood chamber. Alternatively, receptacles called decoy hives are kept in suitable places on trees in forests, where swarms of bees are likely to settle. These are called decoy hives. After a swarm occupies the decoy hive, it is taken down and the colony transferred to a normal bee box. The presence of queen is necessary, because the workers do not stay in the hive without queen. In the case of beekeeping with the European bee, a colony can be procured from another beekeeper and hived in a bee box. The colony so procured should have worker bees and a young laying queen bee.

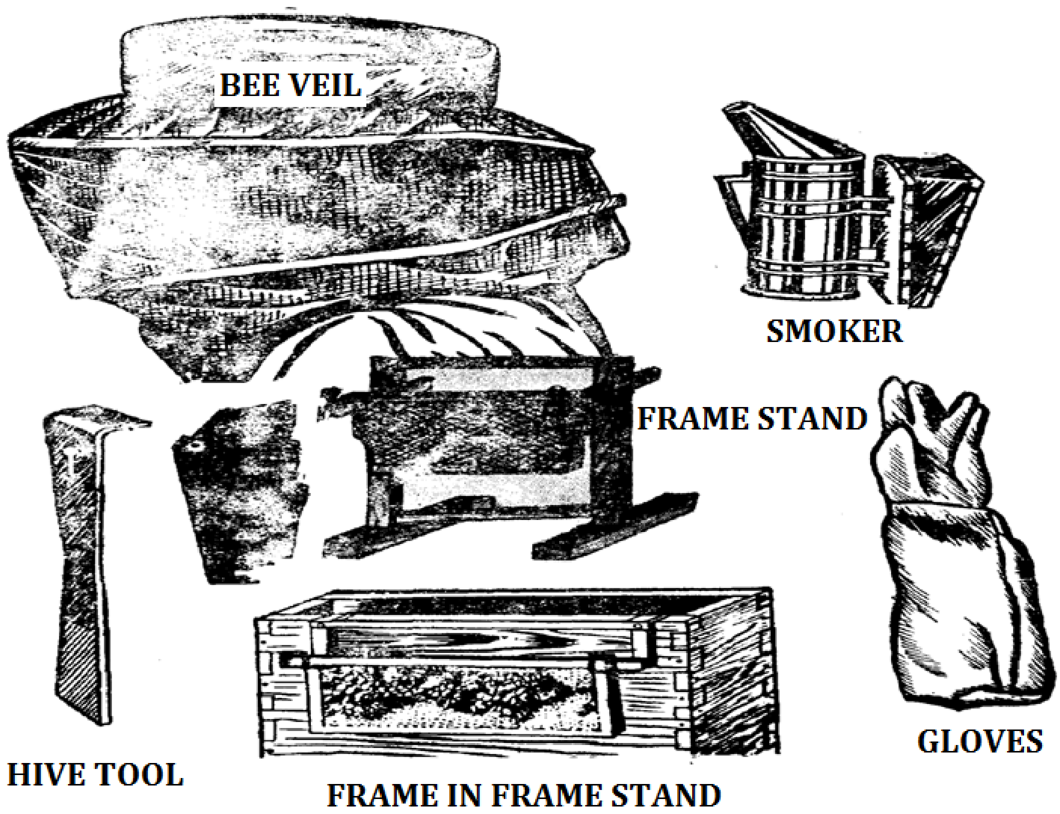


Figure – Beekeeping Instruments

Queen rearing and Requeening of colonies

Normally mated queen bees exhaust their sperm supply within a year, and queen begins to lay unfertilized eggs. This brings down the strength of the colony and its normal working. It is uneconomical to maintain such colonies. The colony can be revived by replacing the old queen with a new young and vigorous mated one. This process is called requeening. Beekeepers are advised to requeen about half of the colonies every year.

In a colony, Queens are produced under the swarming or supersedure impulse or under emergency condition. In the commonly adopted method of grafting for queen, a combination of these impulses is created and queens are raised from larvae of selected stocks. The grafting technique involves preparation of queen cell cups into which young larvae are grafted, and these are given to strong colonies from which the queen is removed a day earlier. Under the queen less condition, the bees accept the grafted larvae and raise them into queens.

Uniting

Colonies are united when these are too weak to continue as efficient units. In uniting two colonies, the older queen is removed a day earlier. The two colonies are gradually brought near to each other; the weaker queenless is placed above the brood chamber of the other colony, with a newspaper in between them. The newspaper is smeared on both sides with sugar syrup and small holes are punched in it. Bees enlarge the holes and mingle with each other without fighting. Small pieces of paper outside the entrance and absence of dead bees in front of entrance indicate successful uniting.

Swarm - prevention and control

Swarming is the natural process of reproduction. But, it is uneconomical to beekeepers. In swarming, nearly half of its work-force of foragers leaves the colony with the swarm, and the colony thus made weaker, is no longer able to gather nectar and make honey.

During the season of swarming, the strong colonies are inspected frequently to check for any queen cells. The queen and brood combs of the colony are removed. The queen is removed, it is kept in a queen cage in its own colony, and all queen cells are destroyed. Presence of the queen within the colony encourages food gathering. The queen is released after about 10 days by which time the swarming fever passes, and the colony concentrates on food gathering activities.

Desertion control

Bees desert their hive due to starvation because of the absence of floral sources in the area, continuous disturbance by pests and enemies. The time of desertion varies from place to place and from season to season. During floral dearths, brood rearing ceases. Bees abscond or leave the hive in search of a place where food is available. In such cases, providing artificial feeds, i.e. sugar syrup, can prevent desertion. A more beneficial and economical method is to migrate colonies to places where food is available.

Migration

For a beekeeper interested in honey production, migration of colony is undertaken during floral dearths or adverse climatic conditions, to areas where bee forage is available, or the environmental conditions are more favourable. The Central Bee Research and Training Institute, Pune developed appropriate schedules for migration of bee colonies for different agro-climatic regions of the country.

Figure – Different steps of Bee Keeping Process

Harvesting of honey

There are two main sources of honey in India: (i) Forest honey that is obtained from wild colonies in forests, including honey produced by traditional methods of beekeeping and (ii) Honey produced in apiaries.

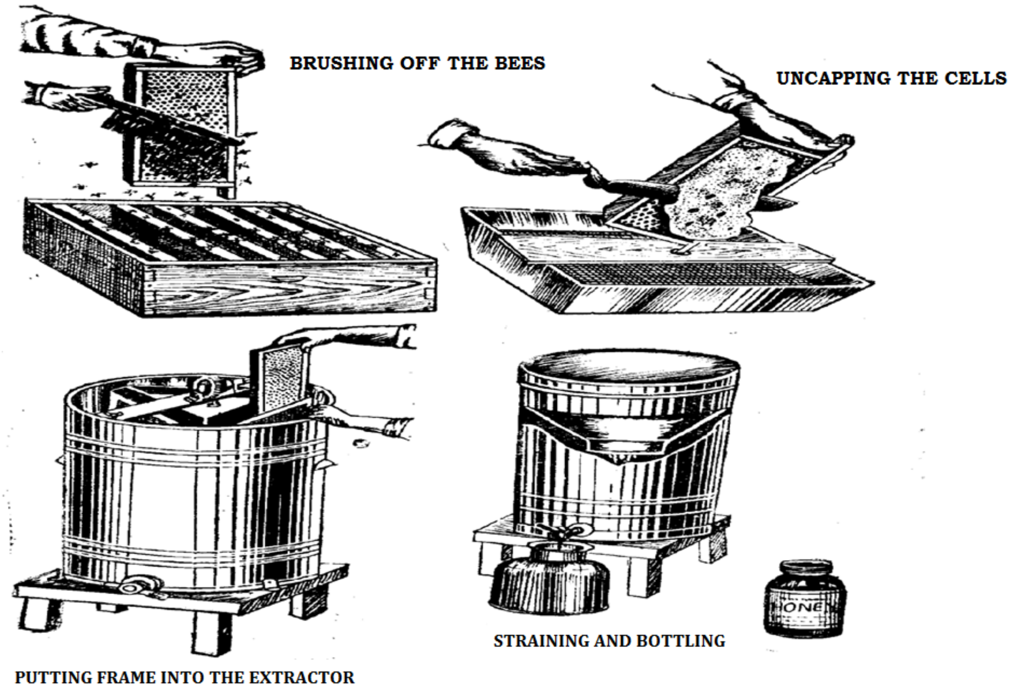


Figure- Different steps of Bee keeping Process

Harvesting of honey from these sources is described below:-

Forest honey from rock cliffs

Rockbee hives and wild nests of the Indian hive bee are the usual sources of forest honey. More than 90 per cent of the forest honey is collected from the rockbee colonies generally by tribals and other forest dwellers called honey hunters. Honey is an important minor forest produce. The honey hunting expedition is undertaken once or twice in a year, usually at the end of spring or in late summer or in autumn. The hunting operation is safer in night only, as bees cannot see in the dark. The hunting group leaves in the evening with the following equipments needed for honey hunting:-

1. A fiber rope ladder (50m long) or other strong fibered climbers.
2. Narrow bamboo sticks
3. Bamboo baskets or plastic vessels to collect comb pieces
4. A sharp and long knife with long handle.

A fire is lit on the ground below the nest location, and smoke is generated. When the nest site is quite high, a smoke torch is used in place of the ground fire. A sufficiently long rope is tied to the torch. A fire is made in the torch and as the smoke billows out from it, the torch is let down to reach the nest. The smoke continues to emanate for 30 to 45 minutes, during which time the hunter completes the operation.

The smoke and heat from the fire below confuses the bees. Bees get disoriented, leave the comb temporarily and hover around the nest area. The hunter first cuts away the brood portion and then the honey portion. A basket made of bamboo or reeds, or a vessel is used to collect the honey and comb pieces.

Honey extraction in traditional beekeeping

A few puffs of smoke applied on the nest. In the case of pot hive, the pot is broken to get the combs inside. In all the cases, the honey filled combs are removed. They are pressed in a piece of cloth and honey is extracted.

Honey harvesting in Modern beekeeping

The honey or super chamber is an important provision in the modern moveable frame hive. Ideally, when all the combs in the super chamber are full and the honey in them is being ripened, another super is kept below the filled super and immediately above the brood chamber. When the second super is full, a third is given in the same way. This facilitates ripening of honey in a natural way.

Combs with a majority of cells sealed indicate that honey is ripe and can be extracted. A little smoke is given while handling the bees to subdue them. Bees on the comb are dropped down into the hive by a sharp jerk of the frame. Honey frames from all colonies are collected and brought into a room for the extraction operation.

Each frame of honey is held in one hand, and with a long uncapping knife the sealing of the cells is cut, just above the level of honey. The frames after uncapping are kept in the honey extractor. The extractor is operated by a handle at a speed of about 300 r.p.m. The frames are rotated in the process and honey comes out of the combs by the centrifugal force. The combs remain intact, and frames are returned to hive for use again. There are two types of honey extractors used: Radial and Tangential.

Harvesting and extraction of beeswax

Wax is also a valuable commodity of beekeeping. It is used by the beekeeper to form the foundation, but it also has high commercial value in domestic and international market. The beekeeper should save all old combs and aim to replace about 20 percent of brood combs each year. Capping, wild deserted combs and squeezed combs from honey hunting should be collected for wax extraction. The combs are cut into small pieces and boiled in water for wax melting. The boiling mixture is then poured into a gunny cloth bag strainer. Pressure is applied over the bag with a pair of wooden rollers to squeeze out clean fluid. The liquid is received into a vessel having cold water. As the liquid cools the wax solidifies as a cake at the top of the water. Further purification is done by melting the wax cakes again in boiling water; liquid wax floating over the water is drained into a vessel containing cold water. Pure wax hardens into a cake that floats above the water. It may be also poured into suitable molds made of tin.

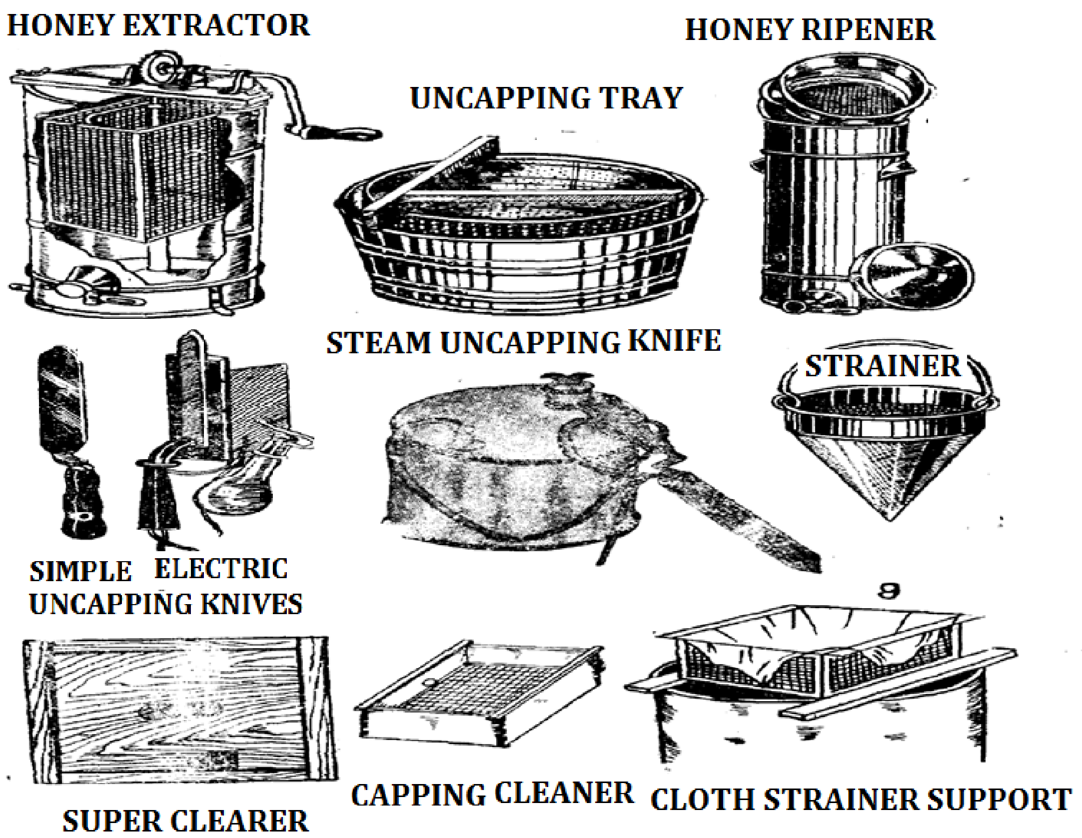


Figure – Honey Extraction and Straining Equipment

In modern apiculture, a commonly recommended extractor is **solar wax extractor** that uses natural sunlight for melting beeswax. It is a rectangular wooden box with a lid of double glass panes. The ratio of the area of glass to volumetric capacity is important and will determine performance. The extractor should have sloping sides and, when in use, should be positioned with the sloping sides facing the path of the sun. The extractor contains a metal tray with sloping sides in which to capture the wax. The molten wax gets filtered by the strainer as it flows down from the tray into a receptacle below. This lower receptacle contains water. Wax floats on the water and solidifies.

Other Beekeeping Equipments

- **Ant well**: The four legs of hive stand are placed in the ant wells filled with water. This prevents ants and other crawling insects entering the hive. Ant wells are simple tin or Aluminium bowls (15 cm in diameter).
- ***Nucleus Box***: It is a small bee box having about 4 frames and used to house a nucleus colony -- a small man-made colony of bees. As the nucleus colony grows, it is transferred to a normal bee box.
- ***Dummy Board***: It is a wooden board of the size of a frame and used to reduce the size of the bee nest in a hive. Dummy board is used to reduce the free space in the hive that helps the bees in containing heat within the nest.
- ***Feeders***: It is simple Aluminium bowls are used to provide sugar syrup as feed to the bees during periods of nectar scarcity.
- ***Queen Cage***: It is used for transport of queen with a few attendant worker bees in packages.
- ***Queen introduction cage***: The *queen introduction cage* is made of simple woven wire mesh, (3 mm size). The mesh is bent round in the form of a square section tube of about 9 cm length and 2.0 x 1.3 cm cross section. One end of the tube is plugged with a wooden block, and the other end is open.
- ***Wire embedder***: This is used for embedding wire in the comb foundation to give strength to the combs.
- ***Hive tool***: It is a flat piece of steel of varying design and size used to separate the brood and super chambers, to loosen the frames for taking them out, or to scrape hive corners, frames and other hive parts.
- ***Smoker***: It is appliance to produce and apply smoke to the bees while handling them. There are different designs of smokers and different methods of smoking.
- ***Bee veil***: This is an essential wear of the beekeeper for protecting face from bee stings during the handling of bees. In

principle a bee veil should have a cloth hood with an arrangement to hold a hat, and a screen in front of the face to allow free vision of the bees and colony.

- ***Gloves***: These are used soft leather gloves with canvas gauntlets to the elbow are the best for use to protect hands and arms, while inspecting and handling colonies.
- ***Swarm net***: It is used to hold a swarm of bees and transport it to the apiary. It consists of a mosquito net bag about 50 cm long and 40 to 45 cm wide, with one side open. The open side has a rope to close the bag after capturing the swarm.
- ***Bee brush***: It is a soft hairbrush to remove bees from honeycombs taken out for extraction of honey.
- ***Uncapping knife***: It is used to cut off capping of honeycomb before putting it in the honey extractor. Two types of uncapping knife, cold- and steam-uncapping knife are in use.
- **Comb cutter**: With comb cutter, old and worn out corns are cut and removed.
- **Scraper**: It is a flat piece of steel with one end broad and sharpened and the other end with a wooden handle. It does the same work as hive tool, but more efficiently.

Seasonal management of Bees

In India because of the peculiarities of climate and vegetation in different ecological zones, there is seasonal variation in bee forage and water, therefore based on this the seasons for apiculture are divided into: -

- Dearth period
- Build-up period
- Honey-flow period
- Harvesting period

Dearth period:

This is a time of the year when nectar and pollen are not available to the bees. Egg laying activities decreases or stops as there is no food to feed the brood. Dearth period may be caused by:

- Prolonged dry season which will not permit flowering

- Very heavy rains, which prevent bees from foraging.
- The combination of prolonged dry season followed by very heavy rains.
- Very cold weather which prevents bees from going out to forage; instead they cluster to produce heat.

In this season bees are manage by following steps-

- In hot areas, put the hive under shade so that bees have time to search for their food source instead of wasting time trying to cool the hive.
- Shelter hives to keep them dry where rains are heavy and provide proper ventilation
- Enhance pest control measures since the colonies are most vulnerable at this time.
- Provide water if there is scarcity and feed the colony if necessary.
- It may be necessary to provide supplementary feeding

Build-up period:

- This is a time when bee plants start flowering and bees start to bring in pollen and nectar.
- During this period all the stores are used for comb building, egg laying and brood rearing.
- At this time, there should not be less than two top bars full of honey so that the queen may lay eggs to maximum capacity and brood rearing may not drop.
- Feed any colony that runs short of food.
- The more stores of honey, the greater the number of foraging bees that would be available to collect the crop thus the bigger the harvest.

In this season bees are manage by following steps-

- Remove all combs which are wrongly built.
- Check that the brood are in compact blocks on the combs. This indicates a good queen.
- Look for hiding places for small hive beetles and wax moth larvae, which the bees cannot remove.
- Merge queen less and small colonies to medium sized ones.

- Help the bees to expand their brood nest by putting an empty top bar in between the brood bar and the top bar containing honey and pollen.

Honey Flow period

- Bee plants are in full bloom during this period.
- Bees bring in nectar and pollen in greater quantities for their daily requirement and therefore utilise the period for storing.
- There will be a daily increase in stores if the colony was properly prepared in the build-up period. Otherwise the colony will use the honey flow period to build-up instead of collecting excess nectar and pollen.

In this season bees are manage by following steps -

- At this time the queen should be restricted to the brood area (by using a queen excluder) to leave the other combs to be used for storage.
- In case of a Langstroth hive, give extra supers when the colony is ¾ full. They will serve both for the distribution of the colony population, which will control swarming, and to store excess food.
- In the case of a Kenya Top Bar Hive, harvesting can be done to create space.

Harvest period:

Beekeepers should inspect their apiary regularly to know when the colonies are ready for harvesting. This is the most certain way of telling hive that's ready for harvesting. A colony ready for harvesting will have the following signs

- The bees become aggressive in guarding the hive, and can sting at the slightest provocation.
- Presence of worker bees outside the hive in large numbers
- The honey harvesting period starts about ten days after blooming.
- By then the honey is ripe and ready for harvesting.

Products of Bee keeping:

Honey

Honey prepared from the nectar of a single flower source is called unifloral or monofloral honeys, while honeys prepared from nectars of several sources is called multifloral. Honey is extremely variable in its properties and composition It has characteristic flavours and aromas depending upon the plant source. Freshly extracted honey is a viscous liquid and hygroscopic. It is the low surface tension of honey that makes it excellent humectants in cosmetic products. Colour in liquid honey varies from clear and colourless (like water) to dark amber or black and depends on the botanical origin, age and storage conditions. Crystallization is another important characteristic. The crystallization results from the formation of monohydrate glucose crystals.

Use

- In virtually every culture, evidence can be found of its use as a food source and as a symbol employed in religious, magic and therapeutic ceremonies.
- A major part of the production is presently consumed as food or food ingredient. About 10 per cent of the production is used in industry mainly in Ayurvedic preparations, pharmaceuticals, bakery, and confectionary and tobacco industries.
- It is valued for its nutritive value, giving energy, health, strength and vigour. It facilitates better physical performance, resistance to fatigue, higher mental efficiency. It also serves as a general tonic for newborn infants, the young and the elderly, the convalescent.
- A recent scientific study on human, that honey is reported to slow down the oxidation of LDL (low density lipoproteins) and checks atherosclerotic plaque deposition in blood vessels.
- Honey is a potential dietary antioxidant to counter reactive free radicals.
- Honey is used in preparation of pickles, jams, jellies, marmalades, squashes, sauces and ketchups, and sweetmeats like tarts, pancakes, pastries, pries and pudies and confectionery like sweets, candies, toffees, eclairs and chocolates, and in bakery products, like breads, biscuits, cakes and cookies.
- Traditionally, honey has been used as vehicle in Ayurveda, Siddha, Unani, and other indigenous systems of medicine. It is anti-microbial and antiseptic and helps in healing of wounds and burns in a natural way.
- □□It has a mild bleaching action on skin and used in facials,

shampoos and other cosmetics.

Beeswax

Beeswax is a metabolic product of honeybees. Worker honeybees of less than two weeks of age produce beeswax in a process of synthesizing esters in the fat body behind the wax glands. Rockbee wax is usually dark yellow to brownish in colour. Beeswax from the hive bees is white

to pale yellow in colour. The melting point of rockbees is -59.6^{o}C, and that of the stingless bees,

66.5^{o}C, and that of the European bee is 62.5^{o}C. Beeswax is a highly complex mixture of hydrocarbons and esters of monohydric alcohols combined with straight chain fatty acids and hydroxy-acids. The total unsaponifiable matter (hydrocarbons and alcohols) is about 58 per cent in both the Indian and European beeswax.

Use

- Beeswax is consumed by beekeepers for the making of wax foundations, which are given to the bees as a guide for construction of their combs.
- Its very special characteristics like medicinal benefits, plasticity and aroma ensure its continuing use. Beeswax is in high demand for commercial purposes.
- Being inert, beeswax is safe for human consumption as an ingredient in human food. It is used for coating for drugs or pills and also to fill capsules with equal amounts of drugs or other ingredients of various granule sizes.
- High quality beeswax obtained from capping is compatible with cosmetic ingredients and frequently used in ointments, cleansing creams cold cream and lotions, emollient and barrier creams, depilatories, lipsticks, nail creams, sun protection products, eye and face make up, and foundation creams.
- Beeswax is used in preparation of candles, in metal castings and modeling because due to its plasticity.

Royal jelly

Royal jelly is a special liquid food, rich in proteins, hormones, vitamins, organic acids and minerals, secreted by the hypopharyngeal gland of young worker (nurse) bees. Royal jelly is whitish in colour with yellow tinge with a pungent phenolic odour and a characteristic sour flavour. It is partially soluble in water. It is acidic (pH 3.6 to 4.2). About two thirds of it is water. By dry weight, proteins (73.9%) and sugars are the largest fractions. A total of 29 amino acids and their derivatives have been identified. A number of enzymes are also present including glucose oxidase, phosphatases and cholinesterases. The lipid fraction consists of free fatty. The major mineral salts of K, Ca, Na, Zn, Fe, Cu and Mn.

Use

- The spectacular fertility and long life-span of the queen fed on royal jelly, has suggestively led people to believe that royal jelly may produce similar effects in humans too. People have experienced it as a general tonic and stimulant improving general well-being, resistance to fatigue, learning capacity and memory, appetite, and general health improvement.
- Royal jelly improves immune response and general body functions.
- Royal jelly is used as ingredient in medicine-like products. It is usually mixed with medicines, tonics, beverages and cosmetic products soon after its production or sometime it is freeze dried.
- A mixture of royal jelly in honey (1-3 % royal jelly) is probably the most common way in which royal jelly is used as a food ingredient.
- Probably the largest use of royal jelly is in cosmetics and dermatological preparations.

Pollen

In India, Rock bees collect enormous quantities of pollen. The Central Bee Research and Training Institute, Pune made pollen supplements using rock bee pollen. After harvest from bee colonies, pollen loads are carefully air-dried or fresh-frozen for preservation and packed in airtight glass bottles. Pollen is also sold as tablets, in capsules mixed with honey.

The major components are proteins and amino acid, lipids and sugars. The minor components are more diverse including flavonoids, carotenoids, vitamins, minerals, terpenes, nucleic acids and nucleosides, enzymes and growth regulators. All essential amino acids are found in pollen.

Use

- The major use of pollen today is as a food or food supplement. Tribals eat the combs pollen while harvesting honey.
- Pollen is used in medicine for treatment of diseases like chronic prostatitis, bleeding stomach ulcers, respiratory infections and in control of allergy reactions.
- There is good number of non-scientific reports of benefits, cures or improvements in athletic performance, digestive assimilation, rejuvenation, general vitality, skin vitality, appetite, hemoglobin content, and sexual powers by use of bee-collected pollen.
- Pollen has only recently been included in some cosmetic preparations with claims of rejuvenating and nourishing effects for the skin.

Propolis

Propolis is a mixture of the beeswax and the resins collected by honeybee from plants. In the process of collection of resins, it is mixed with some saliva as well as with wax. Propolis is used by worker bees to line the inside of nest cavities, brood combs, to repair combs, seal small cracks in hive, reduce the size of hive entrances and to seal brood cells. These uses are significant, because they take advantage of the antibacterial and antifungal effects of propolis. Propolis ranges from yellow to dark brown in colour. At temperatures of 25 to 45^{o}C, propolis is a soft and very sticky substance. Typically, propolis will become liquid at 600 to 700^{o}C, but for some samples the melting point may be as high as 1000^{o}C.

Use

- The Greeks, Romans and Egyptians already knew that propolis would heal skin abscesses. In sub-Saharan Africa, propolis is still used today in herbal medicines.
- In Africa, it is still used today as a medicine, an adhesive for tuning drums, sealing cracked water containers or canoes.
- It has been incorporated in special varnishes.
- Its anti-bacterial, anti-fungal, anti-viral, anti-acne, anti-inflammatory and anti-oxidant characteristics provide many benefits of its applications in medicines, dermatological and cosmetic treatment.

The antioxidant, antimicrobial and antifungal activities of propolis also offer scope for its applications as a preservative in food technology.

Venom

Honeybee venom is a clear, odourless, watery liquid. Honeybee venom is produced by two glands associated with the sting apparatus of worker bees. Sting is evolved from ovipositors. Its production increases during the first two weeks of the adult worker's life and reaches a maximum when the worker bee becomes involved in hive defence and foraging. About 88% of venom is water. The glucose, fructose and phospholipid contents of venom are similar to those in bee's blood. At least 18 pharmacologically active components, including various enzymes (Phospholipase A2, Hyaluronidase, Acid Phosphomonoesterase, Lysophospholipase and B -glucosidase), proteins and peptides (Melittin, Pamine, Mast Cell Degranulating Peptide - MCD), Secapin, Procamine, Adolapin, Protease inhibitor, Tertiapin, and various small peptides), and amines (Histamine, Dopamine and Noradrenalin) have been described in venom.

Use

- Bee venom has long been used in traditional medicine for the treatment of various kinds of rheumatism.
- Ointments can be prepared by thoroughly homogenizing bee venom with white Vaseline, petroleum or melted animal fat, and salicylic acid, in the ratio of 1:10:1.
- Its use in cure of the diseases, like arthritis, chronic pain, epilepsy, rhinosinusitis, polyneuritis, neuralgia, migraine, multiple sclerosis, asthma, and tropical ulcers etcis reported.

Bee enemies, including diseases and their control

1) **Brood diseases:** Brood diseases are characterized by discoloured larvae, dark punctured and sunken capping, scattered brood inside the cells and the foul smell. These are caused by various viral, bacterial and fungal pathogens. These are five types:-

- American foul brood: - It is caused by *Bacilli* bacteria.
- European foul brood: - It is also caused by bacteria, *Bacillus* and

Streptococcus. Incidentally these two diseases are not reported from tropical country.

- Chalk brood: - It is caused by the fungus, *Pericystis apis*, which converts larvae into chalk-white masses of mycelium.
- Stone brood: - It is also a fungal disease caused by *Aspergillus flavus*. The spores of this fungus germinate in the alimentary canal of larvae and adults.
- Sac brood: - Disease is viral. The larvae become sac-like with tough skin and die.

2) **Nosema disease: -** The causative agent is the sporozoan, *Nosema apis.* This pathogen infects the lining of stomach causing dysentery. The spores of pathogen passed out with faeces of infected bees. The disease occurs in winter and quickly depletes the bees' population.
3) **Amoebic Disease:** - The causative agent of this disease is *Malpighamoeba mellificae*. It infests malpighian tubules. The cysted amoebae passed into intestine and thence to exterior with faecal matter. It also results in dysentery. Sterilization of brood boxes and frame hives with glacial acetic acid fumes or 40% formaline solutions can be taken as preventive measure for both the protozoan diseases.
4) **Acarine disease: -** It is also known as 'Isle of Wight'. The mite infests the tracheae and feeds upon the body fluids. The eggs are laid and reared inside the tracheae that get clogged and ultimately mortality of bee occurs.

Enemies of honey bees:

A large number of desertions of hives by bees are due to enemies, which may be robbers that take away honey, brood, pollen or may be breeders that make the hive their breeding ground. Several moths and beetles are the enemies of these two categories. Several species of the wasps, *Vespa*, are predacious on bees. Also the several species of ants (*Componotus* sp., *Dorylus* sp. and *Monorium* sp.) visit bee colonies and take away honey, brood, pollen, dead bodies and other debris). Lizards and many birds being insectivorous prey upon bees. Mammals like bears, badgers and of course man also comes in the category of enemies.

Threats to Apiculture

Unfortunately, there has been a major decline in native pollinators due in part to habitat loss and alteration, introduced species, and pesticide use. Habitat loss due to intensive agriculture, deforestation, and urban development reduces available food resources and nest sites for native bee species. Declines in wild bees due to competition for food resources from managed honeybees and displacement of native plants by introduced plant species have been shown to have severe effects on overall pollination. The use of pesticides to control agricultural pests does not discriminate between pest and pollinator, and is thus also a likely contributor to the dwindling populations of native pollinators. As a result of this decline in native pollinators and the spread of disease among domesticated honeybees, there is a current pollination crisis, both in agriculture and nature.

It is clear that the conservation of bees and other pollinators is an important issue. Our activities are destroying the diversity of all wildlife, and having an effect on our own food supply. Clearly a balance between the biodiversity of natural environments and a system of sustainable agriculture is needed. Farmers are beginning to turn to native pollinators as a viable option for crop production however, little is known about the majority of native bees. We must learn more about the ecology of these species and classify the many unknown pollinating species in order to assess the role of bees and other insects in pollination and put them to use in sustainable agricultural systems.

10.5 Megachile spp (leafcutting bees

Introduction

Megachile species of bees are important pollinators of various agricultural crops. They use cut leaves to construct nests in cavities (mostly in rotting wood). They create multiple cells in the nest, each with a single larva and pollen for the larva to eat. Leafcutting bees are important pollinators of wildflowers, fruits, vegetables and other crops. Some leafcutting bees, *Osmia* spp. are even used as commercial pollinators (like honey bees) in crops such as alfalfa and blueberries. The Megachilidae are a cosmopolitan family of (mostly) solitary bees whose pollen-carrying structure (called a *scopa*) is restricted to the ventral surface of the abdomen (rather than mostly or exclusively on the hind legs as in other bee families).

Megachile genera are most commonly known as mason bees and leafcutter bees, reflecting the materials from which they build their nest cells by soil or leaves, respectively while few collect plant or animal hairs and fibers, and are called carder bees. All species feed on nectar and pollen, but a few are cleptoparasites ("cuckoo bees"), feeding on pollen collected by other *Megachile* bees. Parasitic species do not possess scopae. *Megachile* bees are among the world's most efficient pollinators. The motion of megachile in the reproductive structures of flowers is highly energetic and swimming-like. This vigorous agitation releases large amounts of pollen. *Megachile* also require an average of ten times as many trips to flowers as other bee species to gather sufficient resources to provision a single brood cell.

Distribution

Leafcutting bees are found throughout the world and are common in various regions of Indian regions.

Description

Most leafcutting bees are moderately-sized around the size of a honey bee, ranging from 5 mm to 24 mm, stout-bodied, black bees. The females, except the parasitic *Coelioxys*, carry pollen on hairs on the underside of the abdomen rather than on the hind legs like other bees. When a bee is carrying pollen, the underside of the abdomen appears light yellow to deep gold in color.

Biology

Leafcutting bees, as their name implies, use 0.25 to 0.5 inch circular pieces of leaves they neatly cut from plants to construct nests. They construct cigar-like nests that contain several cells. Each cell contains a ball or loaf of stored pollen and a single egg. Therefore, each cell will produce a single bee. Leafcutting bees construct these nests in soil, in holes usually made by other insects in wood, and in plant stems. A diversity of cavities, such as shells of dead snails, holes in concrete walls like those produced for hurricane shutters and other holes in man-made objects are used as nesting sites.

Most leafcutter bees overwinter in these nests as newly formed adults. In the following spring these adults chew their way out of the nest. Leafcutters are solitary bees and do not live in large groups or colonies like honey bees. Leafcutters do not aggressively defend nesting areas like honey or bumble bees. Their sting has been described as far less painful than that of a honey bee. Leaf cutting bees will only sting if handled and therefore are not a stinging danger to people.

Host Plants

Leafcutting bees are important pollinators of many wildflowers. They also pollinate fruits and vegetables and are used by commercial growers to pollinate blueberries, onions, carrots and alfalfa. Leafcutting bees use the leaves of almost any broadleaf deciduous plant to construct their nests. Some species of leafcutting bees use petals and resin in addition to leaves. These bees will commonly cut circles from ornamental plants such as roses, azaleas, ash, redbud, bougainvillea and other plants with thin smooth leaves. This decreases the aesthetic value of these plants.

Sericulture

Introduction

Silk is Nature's gift to mankind and a commercial fibre of animal origin other than wool. Silk has been under use by human beings for various purposes since ancient times. Silk is one of the finest and most beautiful natural fibres of the world and is known as "the queen of fibres." Being an eco-friendly, biodegradable and self-sustaining material; silk has assumed special relevance in present age. Promotion of sericulture can help in ecosystem development as well as high economic returns. Different rearing techniques are applied in different parts of the world for large scale production of silk threads of fine quality. This is known as sericulture.

History of Sericulture

According to Chinese legend approximately 4000 years ago, a Chinese Empress named Si-ling-chi, brought a silkworm cocoon from her garden and accidentally dropped it in her hot cup of tea. The hot tea softened the threads which were recovered and weaved into silk. Thus was born silk. Si-ling-chi devised not only the technique of culturing silkworm but also the method of reeling the silk and making garments out of it. She was later crowned as "The Goddess of Silk Worm". For a long time sericulture was considered to be a national secret by the Chinese and its industrial technique was not known in other countries. The silk was sold by the Chinese weight for weight in gold and its manufacture was kept a closely guarded secret for centuries. Leakage of the secret was punishable by death. Europeans becoming curious to know the mystery of silk, sent two spies to China in 555 A.D. in the garb of Buddhistmonks. The 'monks' discovered the secret and smuggled out silkworms (larvae) and cocoons in the hollows of their staff. The silk thus reached Europe where the first silk factory was established in the middle of the

6th century A.D. at Constantinople (in Turkey, now called Istanbul). In this way sericulture spread from China to other countries and silk became a precious commodity, highly sought after in all countries. In 139 BC the world's longest highway that stretched from Eastern China to the Mediterranean Sea was opened, which was called "Silk Route" due to trade in silk. French settlers started silk production in England only in 1688. At present Japan, China, Korea, Italy, Soviet Union, France, Brazil and India are the chief silk producing countries with as annual output of about 23 million kg.

Indian Sericulture

According to some sources, sericulture was introduced in India about 400 years ago and the industry flourished as an agro-industry till 1857, with an annual production of a million kg of silk fibre. In India, Lefroy (1905-1906) was the first to investigate about silkworms and sericulture at the Pusa Institute, Delhi. Sericulture is practiced in India from long time ago and India is the 2nd largest producer of silk in the World. It has been identified as employment oriented industry. All the sections of sericulture industry, viz. mulberry cultivation, silkworm seed production, silkworm rearing, reeling and weaving of silk and collection of byproducts and its processing provide a large scale employment, thereby a source of livelihood for the rural and tribal people. Sericulture industry is rated as the second largest employer in India.

Owing to this peculiar nature, the Indian planners have identified sericulture as one of the best-suited occupations for ideal growth and development of rural India. Mulberry sericulture has been traditional occupation in Karnataka, Tamil Nadu, A.P. and Kashmir; Tasar sericulture in M.P., Chota Nagpur Division and Orissa; Muga sericulture in Assam, Nagaland, Tripura and Eri one in Assam and West Bengal. North-eastern part of India is the only region in the world where all four varieties of silk are produced.

Central and State level Government Silk Departments are actively engaged in addressing the objective of promotion of sericulture in traditional as well as non-traditional regions. With the launching of massive developmental schemes, it is expected to gain an accelerated tempo of sericultural activities in the country, paving way for doubling the employment opportunities in phased manner, and thereby, it may set to bring a soothing touch to the burning problem of acute unemployment in rural India and thus can check the rural migration to urban areas to a certain extent.

Sericulture is an agro-based cottage industry involving interdependent rural, semi-urban and urban-based activities in which estimated participation of women is about 60%. Thus, in contrast to any other agro-based profession the role of women in sericulture industry is dominating which will be helpful for improving the status of women in family enterprises.

Silk

Silk is the product of a pair of silk glands which are nothing but the salivary glands of the larva present in its thoracic cavity. The secretions of these glands pass through a common anterior margin of the lower lip of the larva. The secretion is produced in a liquid form but on coming in contact with air, it solidifies into what we call silk. The silk (fibre) is composed of two proteins, fibroin and sericin. The fibroin which constitutes 75% of the material is tough, elastic and insoluble making the core of the silk filament in the form of two very thin fibres called brins. The sericin which along with traces of wax and carotenoid pigments constitute the rest of the material is a gelatinous (gummy), hot-water-solute protein that holds the brins together and covers them so that the segments (loops) of the cocoon also stick together. When mature, the ultimate (V) instar larva makes quick round movements of its head at the rate of 65 movements per minute while spinning its cocoon. The weight in grammes of 900 m long silk filament is called a 'deneir' and the size of a normal cocoon is 1.8 to 3 deneirs. A single cocoon weights 1.8 to 2 gms and its shell (without the enclosed pupa), only 0.45 gm. About 2500 cocoons yield 1 lb (0.45 kg) of silk.

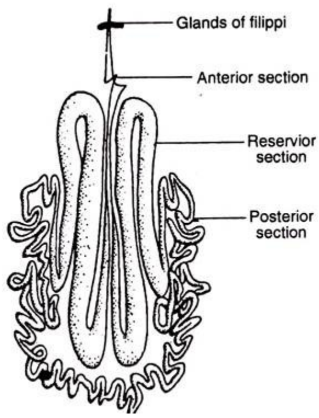


Figure – Silk glands of *Bombyx mori*

Silkworm species, their systematic position and salient features

Silk producing insects are termed as serigenous insects. Silkworm is a common name for the silk-producing caterpillar larvae of silk moths. Silk moths belong to Phylum - Arthropoda, Class - Insecta, Order - Lepidoptera, Super family - Bombycoidea. Bombycoidea comprises eight families of which only

Bombycidae and Saturnidae are the two important families the members of which produce natural silk.

There are several species of silkworm that are used in commercial silk production .Some of the major species are:

(Mulberry Sericulture)

(i) Mulberry silk worm

- *Bombyx mori* (Bombycidae)
- *Bombyx mandarina* (Bombycidae)

(Non- Mulberry Sericulture)

(ii) Tasar silk worm

- *Antheraea mylitta* (Saturnidae)
- *Antheraea pernyi* (Saturnidae)
- *Antheraea yamamai* (Saturnidae)
- *Antheraea paphia* (Saturnidae)
- *Antheraea royeli*(Saturnidae)

(iii) Muga Silkworm

- *Antheraea assama* (Saturnidae)

(iv) Eri silk worm

- *Philosamia ricini* (Saturnidae)

Salient Features

1. ***Bombyx mori meridionalis,*** the **Mulberry silk worm** (Lepidoptera: Bombycidae), feeds on the leaves of mulberry (*Morus alba)* to produce the best quality silk fibre. Four Indian species of mulberry, namely, *Morus alba, M. indica, M. serrate* & *M. laevigata,* are cultivated as main food plants of silkworm. In India where the temperature ranges from 16^{o}C to 31^{o}C, mulberry silkworm can be reared throughout the year. Mulberry Silkworm is native of Chinabut now it has been introduced in all the silk producing countries like Japan, India, Korea, Italy, France and Russia. Since the natural food of this worm is mulberry leaf it is called as mulberry silkworm. The silk produced by this moth is white in colour.

   Life cycle

Adult moths are about 2.5 cm long, creamy white in colour, without any markings and with feeble wings that do not permit flight. Adult's life-span is 2-3 days after emergence. Mating occurs soon after emergence. Female lays about 400 eggs Egg laying which would normally occur on the upper surface of the mulberry leaves is made to take place on sheets of paper or cards by sericulturists for the purpose of preservation and transport.

Egg

Egg is round and white. The weight of newly laid 2,000 eggs is about 1.0 g. It measures 1-1.3 mm in length and 0.9-1.2 mm in width. With time, eggs become darker and darker. Races producing white cocoons lay pale yellow eggs; while races producing yellow cocoons lay deep yellow eggs. In case of hibernating eggs laid by bi-voltine and uni-voltine races, the egg colour changes to dark brown or purple with the deepening of colour of the serosal pigments.

The eggs may be of diapause or non-diapause type. The diapause type of eggs are laid by the silkworms inhabiting in temperate regions; where as silkworms belonging to subtropical regions like India lay non-diapause type of eggs. During diapause all vital activities of the eggs cease.

Larva

After 10 days of incubation, the eggs hatch into larva called **caterpillar**. After hatching caterpillars need continuous supply of food, because they are voracious feeders. Newly hatched caterpillar is about 0.3 cm in length and pale yellowish white. The larval body in densely covered with bristles. As the larva grows, it becomes smoother and lighter in colour due to rapid stretching of the cuticular skin during different instars of the larval stage. The skin consists of cuticle and hypodermis. Cuticle is made up of chitin as well as protein and is covered with a thin layer of wax, which is capable of being extended considerably to permit rapid growth of the larva during each instar. Nodules are found all over the surface of the body, and the distribution pattern differs according to the variety of silkworm. Larva bears four pairs of tubercles: sub-dorsal, supra-spiracular, infra-spiracular and basal tubercle. Each tubercle carries 3-6 setae.

The larval body is composed of head, thorax and abdomen. The head consist of six fused segments. It carries the appendages: antennae, mandibles, maxillae and labium. Median epicranial suture, clypeus and labrum are well developed and prominent. Six pairs of larval eyes or ocelli are located a little above the base of antennae. Five segmented antennae are used as sensory organs. The mandibles are well developed, powerful and adapted for mastication. The maxillary lobe and palpi help in discriminating the taste of food. The prementum is also chitinized, and its distal part carries a median process known as spinneret through which silk is extruded out from the silk gland. The sensory labial palpi are found on both sides of the spinneret.

The thorax has three segments: prothorax, mesothorax and metathroax. Each of the thoracic segments carries ventrally one pair of true legs, which are conical in shape and carry sharp distal claws. These claws are not used for crawling but they help in holding the leaves while feeding.

Abdomen consists of eleven segments, though only nine can be distinguished, as the last three are fused together to from the apparent ninth segment. Third to sixth and last abdominal segment bear a pair of abdominal legs, which are fleshy, unjointed muscular protuberance. Eighth abdominal segment bears caudal horn on the dorsal side.

The abdominal segments carry the sexual markings on ventral side, which are developed distinctly during fourth and fifth instars in the eighth and ninth segments. In females, the sexual marking appear as a pair of milky white spot in each of the eighth and ninth segments and are referred to as Ishiwata's Fore Gland and Ishiwata's Hind Gland respectively. In males a small milky white body known as Herold's Gland appears ventrally in the centre between eighth and ninth segments. Nine pairs of spiracles are present: one pair on the first thoracic segment and eight pairs one on each side of the first to eighth abdominal segments, respectively.

The larval growth is marked by four moultings and five instar stages. The full-grown caterpillar develops a pair of sericteries or silk glands. Sericteries or silk glands are modified labial glands. These glands are cylindrical and divided into three segments: Anterior-, middle- and posterior-segments. The inner lining cells are characterized by the presence of large and branched nucleus. These glands secrete silk which consists of an inner tough protein, fibroin, enclosed by a water soluble gelatinous protein, sericin. In *Bombyx,* the fibrinogen which on extrusion is denatured to fibroin is secreted in theposterior segment of the gland and form the core of the silk filament in the form of two very thin fibres called brins. The sericin, a hot water soluble protein, secreted by middle segment of the gland, holds the brins together and covers them. The duct from another small gland called Lyonnet's gland, that lubricates the tube through which the silk passes, joins the ducts of the silk glands. Finally, the silk is moulded to a thread as it passes through the silk press or spinneret.

Pupa

Pupa is the inactive resting stage of silkworm. It is a transitional period during which definite changes take place. During this period, biological activity of larval body and its internal organs undergo a complete change and assume the new form of adult moth. The mature silkworm passes through a short transitory stage of pre- pupa before becoming a pupa. During the pre-pupal stage, dissolution of the larval organs takes place which is followed by formation of adult organs. Soon after pupation the pupa is white and soft but gradually turns brown to dark brown, and the pupal skin becomes harder.

A pair of large compound eyes, a pair of antennae, fore and hind-wings, and the legs are visible. Ten segments can be seen on the ventral side, but only nine are visible on the dorsal side. Seven pairs of spiracles are present in abdominal region, the last pair being non-functional. Sex markings are prominent and it is much easier to determine the sex of pupa. The female has a fine longitudinal line on the eighth abdominal segment, where as such marking is absent in case of male. The pupa is covered within a thick, oval, white or yellow silken case called cocoon. The pupal period may last for 8-14 days after which the adult moth emerges slitting through the pupal skin and piercing the fibrous cocoon shell with the aid of the alkaline salivary secretion that softens the tough cocoon shell.

Adult

The adult of *Bombyx mori* is about 2.5 cm in length and pale creamy white. After emergence the adult is incapable of flight because of its feeble wings and heavy body. It does not feed during its short adult life. The body of moth has general plan of insect body organization .The ocelli are absent. The antennae are conspicuous, large and bipectinate. The meso- and meta-thorax bear a pair of wings. The front pair overlapp the hind pair when the moth is at rest.

The moth is unisexual and shows sexual dimorphism. In male eight abdominal segments are visible; while in female, seven. The female has comparatively smaller antennae. Its body and the abdomen are stouter and larger, and it is generally less active than male. The male moth possesses a pair of hooks known as harpes at its caudal end; while the female has a knob like projection with sensory hair. Just after emergence, male moths copulate with female for about 2-3 hours, and die after that. The female starts laying eggs just after copulation, which is completed within 24 hours. A female lays 400-500 eggs. The eggs are laid in clusters and are covered with gelatinous secretion of the female moth.

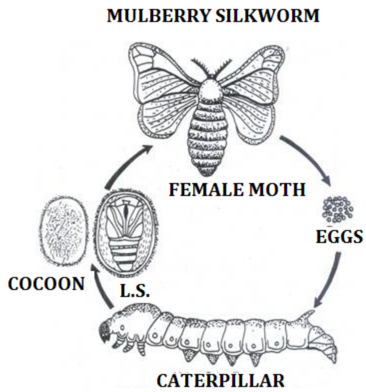


Figure –Life Cycle of Mulberry Silkworm

2. ***Antherea paphia or Antherea mylitta,*** the **Tasar silk worm** (Lepidoptera: Saturnidae), feeds on *Terminalia tomentosa* that occurs in the jungles of Bihar, Madhya Pradesh, UP and Orissa. Three species of *Antherea* are used for the extraction of tasar silk in India. They are *Antherea mylitta, A. perniyi* and *A. royeli*. Out of the total non-mulberry silk produced in India, about 400 tonnes is produced from *Antherea mylitta* in Madhya Pradesh, Orissa and Bihar. This silkworm feeds on *Terminalia tomentosa* and *Terminalia arjuna* found in the forests of central and north-eastern parts of India. The tasar silkworms is a wild species and hence cocoons are also collected by the tribal people from forests and silk is obtained. The first crop, usually called the seed crop is raised during May to July, whereas the commercial crop is raised during

October-November.The larvae are usually green in colour and moults four times before they complete their larval duration. However, yellow, blue and white larvae are also reported. At the end of the larval period, they spin a ring like structure around the twig and a long stalk from which the cocoon hangs. The cocoons are large and brown or yellow in colour. Moths emerge from the cocoons in June. To obtain silk, the cocoons are cooked in caustic potash and reeled to extract fibre and then spun to manufacture coarse thread.The recent introduction of *Antherea perniyi* and *A. royeli* on oak trees in Manipur has opened up new opportunities for the production of superior quality tasar silk in India. The cocoons of *Antherea perniyi* can be easily reeled and fibre of superior quality can be obtained. *Antherea royeli* occurs in oak jungles of the sub-Himalayan region.

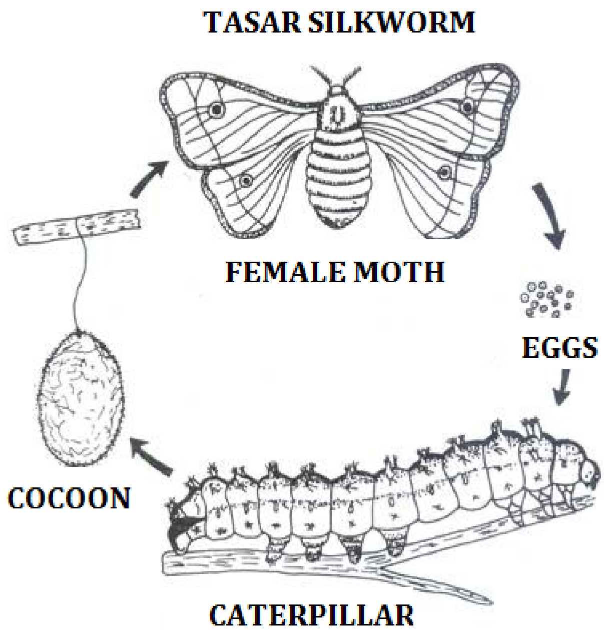


Figure – Life cycle of Tasar Silkworm

3. ***Antherea assama,*** the **Muga silk worm** (Lepidoptera: Saturnidae), is confined to the Brahmaputra Valley of India and produces the famous muga silk.It belongs to the family saturniidaae and common India, China and Sri Lanka. The caterpillar feeds on ber, oak, sal and fig plants. The cocoon produced by this moth is hard and of hen's egg size which produces reel-able brown coloured silk. Though it had been only a wild variety of silk moth since long, now by cross breeding it has been

possible to produce such varieties which are reared anyhow and domesticated. But the domestication of tasar caterpillars is not so easy so that cocoons have to be collected from the forest. The moths do not easily breed in captivity. Since breeding is not well controlled the tasar silk industry has not reached up to mark ass the mulberry silkworm industry.

The golden-yellow silk produced by *Antherea assama* is found only in the Brahmaputra Valley of India. This species of silkworm is semi-domesticated as the larvae which crawl down of trees at the end of their larval period are collected and allowed to spin cocoons in captivity. *Antherea assama* produces golden yellow silk that is of high quality which is expensive. The worms feed on Som (*Marchilus bombycina)* and Soalu *(Litsaea polyantha)* trees. At the end of the larval period, when the worms are ready to spin cocoons, they crawl down the tree in search of suitable places for making cocoons. To obtain silk, the cocoons are boiled in soap and soda solution and are reeled on a machine**.** The total production of muga silk in India is about 50 tonnes but there is plenty of scope for expansion of this industry.

A single Muga female moth lays 150-200 eggs after copulating with the male for 6-8 hrs. The larvae are yellowish with black markings on the body and have the habit of crawling down the trees in groups when all leaves are consumed on the trees and larvae have matured. If larvae have not matured and the leaves on the trees exhausted, they can be transferred to another tree. At the end of the larval period, when the worms are ready to spin the cocoons, they crawl down the tree in search of a suitable place for the construction of cocoons.

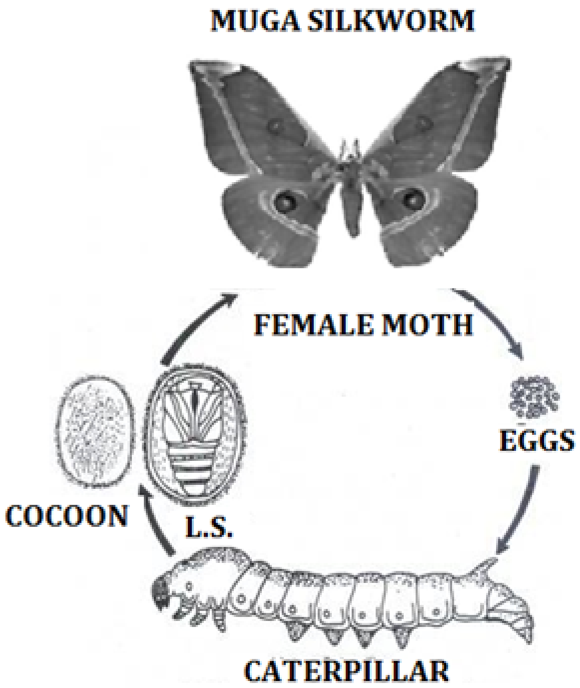


Figure - Lifecycle of Muga Silkworm

4. ***Phylosamia ricini,*** the **Eri silkworm** (Lepidoptera: Saturnidae), which feeds on castor *(Ricinus communis)* is raised in Assam, Madhya Pradesh, Rajasthan and Orissa commercially. It also belongs to the family saturnidae and produces silk in East-Asia. In India sericulture scientists are trying to produce silk in East-Asia. Sericulture scientists are trying to produce such cross breeds which can provide good quality of silk and can be reared easily. It feeds on castor leaf. Cocoons cannot be reeled as in mulberry cocoons. Therefore, it has to be spun. Its life history resemble with that of mulberry worms. The cocoons of this worm have very loose texture and the silk produced is called as Arand silk locally. The threads are not glossy but much durable.

   The silk produced by *Philosamia ricini* is called **Eri silk**. It is grown in Assam and in the eastern parts of India. The heavy rainfall & humid atmosphere in these parts are conducive to eri culture. The food plants for *Philosamia ricini* is castor. This silk worm is multivoltine and reared indoors.

   The eggs are white and hatch in ten days. The hatched larvae are mounted on castor leaves in the rearing-houses and are allowed to grow by feeding on leaves. The worms moult four times during the larval period of 30-32 days. Eri silkworm is generally hardy and not easily susceptible to diseases. At the end of larval period, the larvae crawl in search of suitable places to spin cocoons.

The cocoons of the eri silkworm cannot be reeled, as they are made up of several small fibres and hence the emergence of moths is allowed and the cocoons are spun like cotton to produce yarn. Approximately ninety tonnes of eri silk is produced in the country annually. Recent efforts to rear tasar silkworms on oak plants in the sub-Himalayan range and in Manipur have contributed to the production of a significant quantity of quality tasar silk. It has also opened up new avenues for improving sericulture and also enhanced the employment potential in the tribal hilly areas.

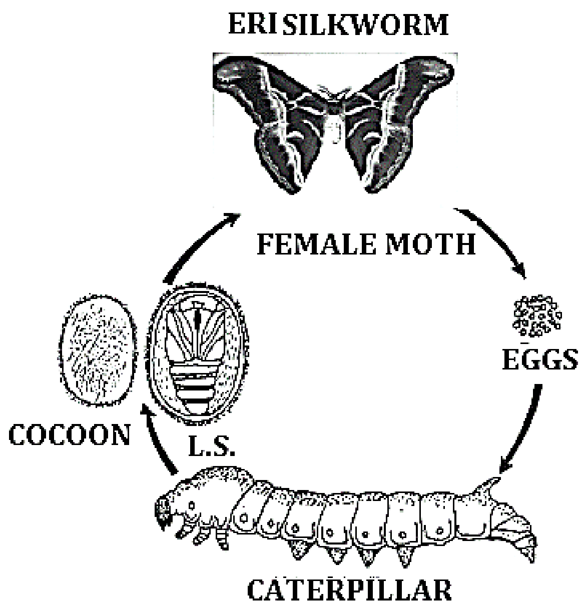


Figure - Lifecycle of Eri Silkworm

Sericulture and its components

Mulberry or Non-Mulberry Sericulture is an agro based industry mainly consists of the 3 main components:

1. Cultivation of food plants
2. Rearing of silkworms
3. Reeling and spinning of silk.

We can categorize the sericulture into mulberry and non-mulberry sericulture on the basis of variety of silkworms. In India both kinds of sericulture (4types of silkworms) are reared but the mulberry sericulture constitutes the major silk industry in the country.

Mulberry Sericulture

i) Cultivation of food plants (Moriculture)

a) Cultivation of mulberry plants is called moriculture. The Central Silk Board have developed high yielding varieties such as Kanva – 2, S-30, S-54 suitable for southern states like Karnataka, A.P. and T.N. and S – 162, S – 519, S –623 etc. suitable for the northern states like Punjab, Jammu and Kashmir, U.P. and W. Bengal. There are over 20 species of mulberry (family Moracea) of which 4 are more common. They are: *Morus alba, M.indica, M. serrate*, and *M. latifolia*. These plants grow both in tropical and temperate climates. An annual rainfall of 600-2500 mm in sufficient for its growth. Both quality and quantity of silk produced by silkworms depend on the quality of mulberry leaves fed to them. Therefore mulberry species plays a very important role in sericulture. The*M. indica*is quick growing, hardiness, and remaining flush throughout the year so it is generally preferred for sericulture.

Figure – Mulberry Tree and Leaves with fruits

b) **Planting methods of mulberry**

Mulberry culture can be done by seeds, root-grafts or stem cuttings. Usually root grafts or stem cuttings are commonly used method. Stem cuttings can be plant either in pit or row system. The cuttings are planted after the first monsoon rainfall. Plants are well watered until they have taken roots and have become strong. Weeding is done manually or mechanically so that mulberry plants can utilise the soil nutrients properly. Harvesting of leaves for feeding larvae is done by leaf picking, branch cutting and top shoot harvesting.

*Bombyx mori*is domesticated specie, this species does not occur in the wild. The optimum rearing conditions are 20-28degree C temperature, 70-85 per cent relative humidity, 16 hour photophase and unpolluted air. These favourable conditions are available in the states of Jammu and Kashmir, W. Bengal, Karnataka, A.P. and T.N. and mulberry sericulture can be easily carried out there.

The number of generations are termed as “crops” which depends on the race or strain of the moth. A moth is univoltine if it produces only one crop a year, bivoltine, If two and multivoltine if more than 2.Multivoltines are usually the locally occurring races at some places e.g., “Mysore” race produces greenish-yellow cocoons in Karnataka and “Nistari” race produces deep yellow cocoons in West Bengal. The cocoon yield of multivoltine are poor in comparison to uni- and bivoltine races. A bivoltine “Nandi” is one such hybrid that is popular in Karnataka.

Silkworms must be reared with utmost care since they are susceptible to diseases. Therefore, to prevent diseases, good sanitation methods and hygienic rearing techniques must be followed. The appliances and the rearing room should be thoroughly cleaned and disinfected with 2-4% formaldehyde solution. Room temperature should be maintained around 25^0 C.

Table : The following required temperature, humidity, spacing should be provided according to Krishnawami, et. al, (1979a)

S. No.	Stage	Temperature C°	Humidity %	Spacing (m^2)	
				At the beginning of each age	At the end
1	1st Instar	26-28	85-90	0.2	0.8
2	2nd Instar	26-28	85-90	1.0	2.0
3	3rd Instar	25-26	80-85	2.0	4.5
4	4th Instar	24-25	70-75	5.0	10.0
5	5th Instar	23-24	70	10.0	20.0

ii) **Rearing house-** The Rearing room or building should be as per conditions suitable for silkworm. The rearing room should have properly ventilation without dampness, stagnation of air, exposure to bright sunlight and strong winds.

iii) **Rearing equipments**- Following are the equipments needed for proper rearing of silkworms :

a) Rearing stands- These are stands of frames on which are placed rearing trays containing silkworms. They could be made of wood or bamboo. To protect from ants, silkworms rearing stand legs are kept in rectangular or circular enamel or concrete bowls containing water mixed with some insecticide.

b) Rearing trays- These are trays, generally circular, made up of locally available cheap material like bamboo. Or may be box type wooden trays are used to rear early instars.

c) Paraffin paper- Thick paper sheets coated with paraffin wax are required to cover the rearing trays to maintain humidity and prevent withering of leaves.

d) Foam rubber strips- Pieces (2.5 x 2.5 cm) of foam rubber soaked in water are kept all around silkworm rearing beds to maintain humidity. Moistened newspaper strips can also be used.

e) Chopsticks- Chopsticks are pointed bamboo rods meant to pick up younger stages of larvae to ensure their hygienic handling and preventing from injuries.

- **f)** Feathers- Feathers are used for brushing together newly hatched worms to prevent injuries.
- **g)** Leaf chamber- Mulberry leaves are stored in chambers made up of 7.5 cm wide wooden strips fixed some distance apart or of some porous board. This is covered with gunny bag cloth, it is kept moist during the summer months and dry days.
- **h)** Chopping boards, knives and mats- As mulberry leaves are presented to the worms in a chopped condition, chopping board, knives and mats are required.
- **i)** Cleaning nets-Cleaning nets are made up of cotton or nylon of the mesh size suitable for different instars are used for changing the rearing beds so that the left over leaf-pieces and litter are filtered out
- **j)** Mountages- Mountages (cocoonages or chandrikas) are contrivances made up of rectangular bamboo mat tied on 4 bamboo sticks and bearing on its surface spirals of bamboo tapes. Matured worms for to spin cocoons are transferred on to them. The larvae suspend themselves to the spirals and spin cocoons. The chandrikes are cheap and easily made, easily stored, excreta of spinning worms dry up soon due to free passages and thus prevent cocoons, can be easily shifted from place to place, easily disinfected.
- **k)** Miscellaneous appliances-Hygrometer to measure humidity, a thermometer to record temperature , a charcoal stove to heat the rooms in winter, disinfection pads of gunny soaked in 2% formaline to disinfect the feet of the workers entering the rearing room, a sprayer to disinfect the rooms themselves, wooden stands of crossed legs to place trays during feeding and bed cleaning, a stand for wash-basin containing 2% formaline to disinfect the hands of the workers handling the worms and leaf-baskets to transport mulberry leaves from the gardens to the rearing, house.

Procurement of quality seeds

Like agriculture yield depends upon the quality of seed choosen same in case of sericulture, the success depends upon the selection of best quality seeds or silkworm eggs. Such seeds can be obtained from grainages which are centres for production of disease-free seeds of pure and hybrid races in large quantities.

These centres are the certified seed cocoon producers. The cocoons are placed in well-ventilated rooms with optimum temperature of 23-25^{o} C and humidity of 70-80 %, and emergence of moth is allowed. Grainage rooms may be kept dark, and light may be supplied suddenly on the expected day of emergence to bring uniform emergence.

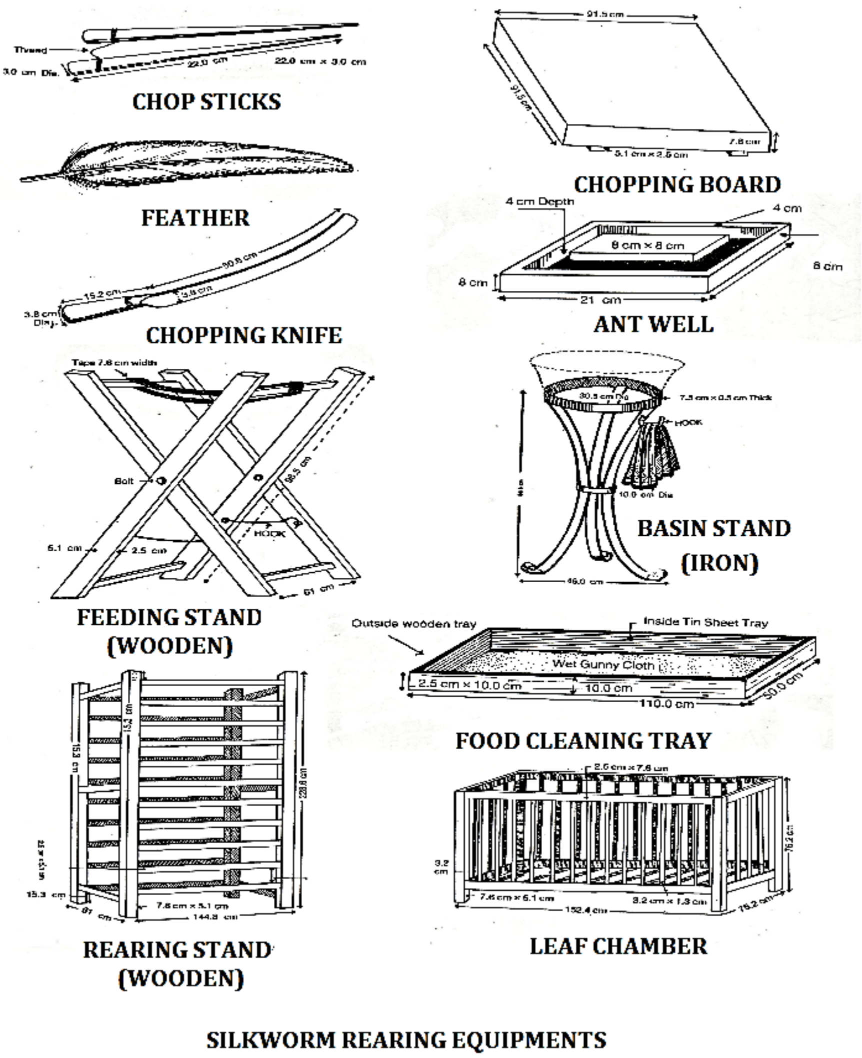


Figure- Silkworm rearing equipments

Male silkworms are kept in the trays of the females and on the beginning of copulation, the pair is transferred to black plastic vessel. Three hours of mating secures maximum fertilised eggs. Male moths are then kept safely at 5 degree C for further second mating while the female moths are kept in cellules for egg laying. Within 12 hours female silkworm lays 400-600 eggs. Proper examination is done to check infection of pebrine disease. In case of any infection, eggs are discarded and destroyed. Generally females are made to lay eggs on paper sheets or cards whose surface has been coated with a gummy substance. The eggs are transported in the form of egg sheet. These sheets are easy to transport. To loosen the eggs, the sheets are soaked in water. The loose eggs are washed in salt solution of 1.06-1.10 specific gravity to separate out unfertilized eggs and dead eggs floating on surface. Prior to the final washing, the eggs are disinfected with 2% formalin solution. Eggs are dried, weighed to the required standard and packed in small flat boxes with muslin covers and dispatched to buyers. The sheets are dried in shade and transferred to incubators for hatching.

For large scale production, 50-100 moths are allowed to lay eggs on paper sheets. The egg-sheets are soaked in water to loosen the eggs. The loose eggs are washed in salt solution to remove unfertilised eggs which float on the surface. The fertilised eggs thus separated are distinfected with 2% formaline, shade dried and packed in egg boxes for supply to buyers.

Quality of food

Mulberry tree variety is the main factor for the growth of silkworms, high yielding mulberry varieties leaves cause good growth of silkworms. Initially early developmental stages like I and II instar larvae are given tender succulent leaves with a high moisture content and the older instars, mature but soft leaves with lesser moisture content.

Shape and size of leaves

Chopped mulberry leaves are given to the larvae for feeding. For chopping, leaves are spread on the chopping board by the handfuls, smoothly gathered flat and in tiers. Chopping should be carried out by a broad-bladed sharp-edged knife. For cutting smaller pieces, smaller quantities of leaves should be taken at a time and the knife should be drawn towards the cutter rather than forwards and backwards like a saw.

Chopped leaves can be spread evenly, the quantity of feed can be regulated and the results assessed, they prevent silkworm beds from getting damp in wet weather, and they do not curl up when the weather is dry. The main problem is that chopping requires labour and expense. Shape of the chopped leaves depends upon the type of climate. Square pieces are best when the air is dry because they prevent rapid withering. Long thin strips or oblong pieces are suitable when the season is wet. Triangular leaves take less labour and so can be given to older instars who consume large quantities of leaves.

Table : Leaf Requirement for rearing of 20,000 eggs of silkworm As per Krishnawami, et. al. (1979a)

S. No.	Silkworm Stage	Quantity of mulberry leaf Required (Kgs)
1	1st Instar	1-2
2	2nd Instar	5-6
3	3rd Instar	20-25
4	4th Instar	80-90
5	5th Instar	450-475
Total		550-600

Brushing

The process of transferring the silkworm to rearing trays is called brushing. Suitable time for brushing is about 10.00 am. Eggs at the blue egg stage are kept in black boxes on the days prior to hatching. The next day they are exposed to diffused light so that the larvae hatch uniformly in response to photic stimuli. About 90% hatching can be obtained in one day by this method.

In case of eggs prepared on egg cards, the cards with the newly hatched worms are placed in the rearing trays or boxes and tender mulberry leaves are chopped into pieces and sprinkled over egg cards. In case of loose eggs a net with small holes is spread over the box containing the hatched larvae and mulberry leaves cut into small pieces are scattered over the net. Worms start crawling over the leaves on the net; the net with worms is transferred to rearing tray.

Figure- Brushing by feathe

Preparation of feed bed

After brushing, the bed is prepared by collecting the worms and the mulberry leaves together by using a feather. The bed is spread uniformly using chopsticks. The first feeding is given after two hours of brushing. Feed bed is a layer of chopped leaves spread on a tray or over a large area. The first and second instar larvae are commonly known as chawki worms. For chawki worms, paraffin paper sheet is spread on the rearing tray. Chopped mulberry leaves are sprinkled on the sheet and hatched larvae are brushed on to the leaves. A second paraffin paper sheet is spread over the first bed. In between two sheets water soaked foam rubber strips are placed to maintain humidity.

The 4th and 5th instars are reared in wooden or bamboo trays by any of the three methods: viz., shelf-rearing, floor-rearing and shoot-rearing. In shelf rearing, the rearing trays are arranged one above the other in tiers on a rearing stand which can accommodate 10 -11 trays. This method provides enough space for rearing, but it is uneconomical as it requires large number of labourers to handle the trays. Chopped leaves are given as feed in this method. In floor rearing, fixed rearing sheets of 5-7x1-1.5m size are constructed out of wooden or bamboo strips in two tiers one meter apart. These sheets are used for rearing. Chopped leaves are given as feed. This method is economical than the first one because it does not involve much labour in handling of trays. Shoot-rearing is most economical of the three methods. The rearing sheet used is one meter wide and any length long in single tier and the larvae are offered fresh shoot or twigs bearing leaves. This method can be practiced both outdoors and indoors depending upon the weather.

Each age of the silk worms could be conveniently divided into seven stages. First feeding stage, sparse eating stage, moderate eating stage, active eating stage, premoulting stage, last feeding stage, moulting stage. The larvae have good appetite at first feeding stage and comparatively little appetite at sparse and moderate eating stages. They eat voraciously during active stage to last feeding stage after which they stop feeding. About the number of feeds to be given to different instars, it was earlier believed that all stages should be fed 10-12 times a day. However, recent finding show that 4 feeds a day are sufficient for each instar. The feeds are normally given at 9 A.M., 3, 5 and 9 P.M.

Bed cleaning

Removal of unused left leaf and silkworm excreta after regular time interval is called as bed cleaning. It is important not only from the hygienic point of view but also for the proper growth of the larvae. Generally four methods are used for bed cleaning- conventional method, husk method, net method and the combined husk and net method.

In the conventional method, the worms I-III instar stages are simply swept together with a feather and transferred from the old to the new bed and the worms in IV and V instar stages are transferred manually. This is the most common practiced method, at least with the sericulture farmers.

In the husk method, paddy husk is sprinkled over the bed in form of thin layer and on the husk is scattered the chopped leaves. The worms quickly crawl through the husk to get at the feed where from they can be removed to the new tray. For the I and II instars, the husk should be just broken into small pieces size, for the III instar is broken husk and for the IV and V instars even chopped straw can be used.

In the net method, a cotton or nylon net of suitable mesh size is spread over the old bed and leaves scattered on it. The larvae as usual migrate to the net in search of fresh leaves and can be collected and transferred to a new bed.

In the combined husk and net method, a thin layer of paddy husk is first sprinkled over the old bed and a net of suitable mesh is superimposed on it. Two successive feedings follow where after the net with the worms on it is transferred to another tray. This method combines the cleaness of husk method with the case of transference of the net method. It also requires less skill and care in manipulation though it is slightly more expensive than the former.

Spacing

Spacing is very important to avoid overcrowding of caterpillars and for vigorous growth of silkworms. As the worms grow in size, the density in the rearing bed increases and conditions of overcrowding are faced. This can be done by increasing the surface area of the feeding trays with the growth of the insects. For optimum results, rearing space may be doubled or trebled for I-III instars, 2-3 times more than this for the IV and 2 times more than this for the instar. It would save time and labour if the spacing is combined with bed cleaning. Spacing could be achieved by marking out the extended feed area and distributing both the leaves and worms evenly over the entire area. If there are still left some crowded spots, worms from those spots could be picked up and transferred to sparser areas. Contrary to the belief in some farmers that crowding saves on leaves, it leads to under-nourishment and so uneven development resulting in a substandard harvest. Besides, crowding increases accumulation of gases, heat, and fermentation of faecal matter, particularly during the early stages when the temperature and humidity in the rearing beds are high. Such unhygienic conditions may lead to infection, death and loss of crop.

Moulting

Moulting is a very critical event in the life of caterpillars. When about to moult, the larvae attain their maximum size for that particular instar. At this stage bed cleaning should be carried out and leaves should be chopped to small size for pre-moult feeding. When the larvae settle down for moulting, feeding stops. It is advisable to sprinkle some lime powder after the last feed which prevents early ecdysing larvae from commencing feeding and thus maintaining uniform growth in all. During moulting, the worms are most susceptible to muscardine infection which could be prevented by dusting them with ceresin and lime.

Mounting

Transferring mature fifth instar larvae to mountages (cocoonages or chandrikes) is called mounting. When larvae are fully mature, they become translucent, their body shrinks, and they stop feeding and start searching for suitable place to attach themselves for cocoon spinning and pupation. They generally move to the periphery of the rearing tray for this purpose. The worms attach themselves to the spirals of the mountages and start spinning the cocoon. By continuous movement of head, silk fluid is secreted around the body which hardens to form a long continuous filament. The silkworm at first lays the foundation for the cocoon structure by weaving a preliminary web providing the necessary foot hold for the larva to spin the compact shell of cocoon. Owing to characteristic movements of the head, the silk filament is deposited in a series of short waves forming the figure of eight. This way layers are built and added to form the compact cocoon shell. After the compact shell of the cocoon is formed, the shrinking larva wraps itself and detaches from the shell and becomes pupa or chrysalis. The spinning completes within 2-3 days in multi-voltine varieties and

3-4 days in uni- and bi-voltine. This is the right time to pick them up and put them on mountages.

Usually in picking up ripe worms, two methods can be applied: branch method and net method. In the branch method, branches of mulberry with green leaves are kept over the rearing bed and when the worms crawl on to them, they are shaken off on a net and transferred to the mountages. In the net method, a net is spread over the bed after feeding. The non-feeding (mature) worms come up and crawl on to the net which is then shaken on a mat and the larvae transferred to the mountages.

Care during cocoon spinning

During cocoon spinning the favourable and optimum conditions should be maintained in rearing chamber for best quality of cocoons. Quality of the cocoons spun by the larvae depends to a great extent on the temperature, humidity and proper ventilation at the time they are being spun. The optimum temperature of the room at this time should be 24 degree C, and the humidity 60-70 percent. Too high a temperature induces the larvae to spin their cocoons in a great hurry and the larvae which are in haste to do so waste a good deal of silk in preliminary processes. Besides, they spin irregular-shaped cocoons of poor reeling quality and of thicker fibres. Too low a temperature, on the other hand, causes delay in spinning, adversely affect the colour and texture of the silk, thread becomes thin, and cocoons flaccid, resulting in reeling trouble and wastage. Abnormally high and low temperatures adversely affect the health of the worms and make the resulting cocoons unfit for seed purposes. Likewise, too much humidity spoils the lustre of the filaments and too dry an air depilates the worms. From the point of view of reeling, a relatively drier air during mounting is good. Similarly, ventilation of the room should be such that humidity is reduced but the worms are not exposed to violent draught of wind or to direct sun.

Harvesting of cocoons

Harvesting should be done at proper time too early and too delay can cause abnormality in cocoons. When the caterpillar has spun its silken cage or cocoon around itself, it casts off its skin to pupate. In early days, pupal skin is tender and ruptures easily. Therefore, early harvest of the cocoons could injure the pupae and result in their blood not only soaking in and staining the former but also inducing fermentation and infection and making the stained portion unreelable. Late harvest, on the other hand, leaves less time for transporting the cocoons to the market and so for their stifling with the result that they will run the risk of being cut by the emerging moths and thus being rendered unfit for reeling, a loss that a sericulturist can ill afford to bear. It is, therefore, very crucial for the sericulturist to harvest the cocoons at the correct time. In tropical climate (as in Karnataka, A.P., W. Bengal), the proper time to harvest cocoons is 5th day after their formation and in temperate climate (as in Kashmir), 7th to 8th day. Cocoons are harvested by hand. After harvesting the cocoons are sorted out. The good cocoons are cleaned by removing silk wool and faecal matter and are then marketed. The cocoons are sold by farmers to filature units through Cooperative or State Govt. Agencies. The cocoons are priced on the basis Rendita and reeling parameters. Rendita may be defined as number of kg of cocoon producing 1 kg of raw silk.

Figure – Cocoon Harvesting

Post-harvest processing of cocoons

Now the process starts in the industrial part of the silk industry. However, since production of silk is all that the sericulture is about, we cannot ignore the events that meet the cocoons after they have been harvested.

These events are

- Stifling
- Boiling
- Brushing
- Reeling

- Re-Reeling
- Finishing
- Testing.

Stifling- This means the killing of cocoons by different methods. The purpose of stifling is to kill the pupae before they metamorphose into moths and emerge, cutting the cocoons and rendering them unreelable. This is achieved by any of these 3 methods: drying cocoons under the sun, hot-air stifling or steam-stifling.

Cocoon boiling - This is also called as cooking. The cocoons are boiled first in hot water at 95-97^{o}C for 10-15 minutes to soften the adhesion of silk threads among themselves, loosening of the threads to separate freely, and to facilitate the unbinding of silk threads.

Brushing - Brushing is done for seeking the free end of the silk filament (brin) in the cocoon. It could be achieved manually or by mechanically operated brushes.

Reeling–Reeling is the process of unwinding the silk thread from the cocoons. Four or five free ends of the threads of cocoon are passed through eyelets and guides to twist into one thread and wound round a large wheel. The twisting is done with the help of **croissure**. The silk is transferred finally to spools, and silk obtained on the spool is called the **Raw Silk** or **Reeled Silk**.

Re-reeling–After the reeling of the raw silk on small reels,after proper drying they are re-reeled on large reels. Direct reeling on large reels leads to insufficient drying which in turn leads to production of hard gum spots on the thread. This is overcome by first reeling the raw silk on small reels which permits better drying.

Finishing–This is the last stage of silkworm rearing, in this process, the different defects of the raw silk threadare removed and the silk is boiled, stretched, purified by acid or by fermentation and repeatedly washed to bring out the glossy look, the characteristic feature of the silk. The threads are then changed into bundles or skeins.

Testing–Before moving to market testing is necessary to know the grade of silk. There are some Indian and International standards to judge the quality of the raw silk and facilitate its marketing. To maintain these standards, raw silk is put to a number of tests to assess its size variations, winding quality, neatness, evenness, cohesion and tenacity.

Diseases of *Bombyx mori*

Mulberry silkworms, the most important of all the silkworms, are susceptible to atleast 4 diseases : pebrine, flacheric, grasserie and muscardine. They are all serious capable of destroying the entire stock (crop).

- **Pebrine**: Pebrine is also known as**pepper disease**or**corpuscle disease**. The diseaseis caused by a sporozoan, *Nosema bombycis* (family Nosematidae). The main source of infection is food contaminated with spores. Infection can be carried from one larva to another by the spores contained in faeces or liberated in other ways by the moths carrying infection. Pebrinized eggs easily get detached from the egg cards. They may be laid in lumps. The eggs may die before hatching. The larva shows black spots. They may become sluggish and dull, and the cuticle gets wrinkled. Pupa may show dark spots. Moths emerging from pebrinized cocoons have deformed wings and distorted antennae. The egg laying capacityof the moth becomes poor.
- **Flacherie:**Flacherie is a common term to denote bacterial and viral diseases. It hasbeen classified into following types:-
    - **Bacterial diseases of digestive organs**: Due to the poor supply of qualitymulberry leaves, the digestive physiology of the silkworm is disturbed, and multiplication of bacteria occurs in the gastric cavity. Bacteria like *Streptococci, Coli,* etc. have been found associated with this disease.Symptoms, like diarrhoea, vomiting, shrinkage of larval body may be seen.
    - **Septicemia**: Penetration and multiplication of certain kinds of bacteria inhaemolymph cause septicemia. The principal pathogenic bacteria are large and small *Bacilli, Streptococci, and Staphylococci* etc. Symptoms like diarrhoea, vomiting, shrinkage of larval body may be seen. Appearance of foul odor is also a common symptom.
    - **Sotto disease**: It is caused by toxin of*Bacillus thuringensis*. The

larvaebecome unconscious, soft, and darkish and rot off.

- **Infectious Flacherie**: It is caused by a virus called*Morator*Virus which doesnot form polyhedra in the body of silkworm larvae. The infection occurs mainly through oral cavity. The virus multiplies in the midgut and is released into the gastric juice and is excreted in faeces.
- **Cytoplasmic polyhedrosis**: It is caused by a virus called*Smithia*which formPolyhedra are formed in the cytoplasm of the cylindrical cells of the midgut. The larva loses appetite. The head may become disproportionately large. Infection occurs through the oral cavity.

- **Grasserie:**The disease is also known as**Jaundice**or**Nuclear Polyhedrosis**It iscaused by a virus called *Borrelina,* which form polyhedra in the nuclei of the cells of fatty tissues , dermal tissues, muscles, tracheal membrane ,basement membrane , epithelial cells of midgut and blood corpuscles. The infected larvae lose appetite,become inactive, membranes become swollen, skin becomes tender and pus leaks out from skin. The larvae finally die.
- **Muscardine or Calcino**: It is of 3 types-
  - **White Muscardine**: It is caused by the fungus,*Beuveria bassiana*. The larvaloses appetite, body loses elasticity and they cease to move and finally die.
  - **Green Muscardine**: It is caused by*Metarrhizium anisopliae*. The larva losesappetite, appears yellowish, becomes feeble and dies.
  - **Yellow Muscardine**: It is caused by*Isaria farinosa*. Many small black specksappear on the skin. Larvae lose appetite and dies.

Enemies of silkworms

1. **Uzi fly (*Tricholyga bombycis* : Diptera) -** These flies are parasites of silkworms. They lay their eggs on them and the maggots on hatching eat away the body of the caterpillars.
   Prevention - Fly-proof doors, windows and ventilators should be used in the silkworm rearing house. All crevices of

the rooms should be closed to prevent maggots pupating in the soil.

2. **Beetles (*Dermestes cadeverinus*: Coleopetra)-** Adults and grubs (larvae) of this and other dermestid beetles are attracked to the smell of cocoons in storage. They eat the cocoons, enclosed pupae and often the eggs (seeds) of the silkworms.

   Prevention - The females of these beetles lay their eggs in crevices, organic matter and wooden boards. Therefore, closure of the crevices, and scrupulous cleaning of the rearing room is the first requirement of prevention. Occasionally, the rooms could be fumigated with CH_3Br (methyl bromide) and stifled cocoons should not be stored for long.

3. **Ants (Hymenoptera) -** Ants attack silkworms in rearing trays.

   Prevention - Legs of rearing stands should be dipped in antwells (filled with water + insecticide). At the time of spinning, ash or kerosene is put at the handles of the chandrikes to keep the ants off.

4. **Lizards, birds, rats and squirrels** - All these animals feed on silkworms. Mammals predate also on the pupae by bitting open the cocoons.

   Prevention - Rearing rooms should be kept free of lizards with the help of insecticides. Birds could be scared away from the vicinity and for rat and squirrel trapping could be carried out in rearing houses.

Non-Mulberry Sericultures

1. **Muga Sericulture**

   Cultivation of food plants - The primary food plants of *A. assama* are Som (*Machilus bombycina*) and Soalu (*Litsaea polyantha*) which are Assammese names. Earlier Som was grown in upper Assam and Soalu in lower Assam. But as som has been found to be more suitable for muga sericulture due to its long life and resistance to stem borers, it is now grown in both the regions. Traditionally, muga silkworm rearing is done on irregularly scattered tall trees. But since the productivity of cocoons is low and their management rather difficult, plants are now cultivated on farms and maintained on scientific lines. Propagation of plants is done through seeds and vegetatively by air layering.

Antheraea (assamenisis) assama

Distribution - In wild form, muga moths, muga is an Assamese word meaning brown or amber) are distributed from Western Himalayas to Nagaland, Cachar districts of Assam of South Tripura. But the sericulture practice is confined to the Brahmaputra valley of Assam and Foothills of East Garo hills of Meghalaya. Ideal temperature for muga silkworm growth is 24-30 degree C and humidity 75-85 per cent.

Appearance - The wings and body of the male moth are copper brown to dark brown and those of the female, yellowish to brown, both pairs of wings bearing eye spots. Besides colouration, the male moth can be distinguished from the female from its slightly smaller size, slender abdomen, bushy antennae and sharply curved forewing tips.

Life-history

The male moth flies actively and mates with the stationary female which seldomly flies. After copulation, the female moth lays eggs preferably on dry twigs called “Kharika”. The moth is non-feeding and dies within 7-12 days. Duration of life-history is greatly variable in summer and winter. The figures in parentheses are those of winter and outside, of summer.

Rearing of muga silkworms. The muga silkworms are polyphagous, semi-domesticated and multivoltine having 5-6 overlapping generations in a year

Muga silkworm rearers commence their rearing work with the procurement of seed cocoons (not layings i.e., eggs) either from commercial rearers or from Govt. grainages (places where disease free (dfl) seed layings or seed cocoons are developed), traditionally from the former, in the months of May-June (Springcrop) or Oct-Nov. (Autumn crop). Foothill areas of Garo, Naga and Cachar hills are the main seed growing areas for muga. Commercial rearers from different localities reach these zones much in advance, survey the rearings of different seed growers and select what they consider the healthiest and the best rearing.

Once selection is made, the customer rearers settle in the nearly area until cocoons are ready. The rears always prefer to collect seed cocoons of the stock of the peak day harvest which they call “Bharpok” stock. The quantity of cocoons purchased depends on the number of food plants a rearer has. If he does not have the plants of his own, he hires them from other rearers or conducts rearing in the Government’s Village Grazing Reserve at a nominal rate.

After collection of seed cocoons, they are loosely packed in bamboo basket containing dry straw and transported to the site of rearing which is near the rearer’s home. Transportation is done either on shoulder (if the distance is short) or on trucks and buses (if the distance is long). But in either case, the timing of transportation is during night or early morning to avoid thermal shock. On reaching home, the cocoons are transferred to bamboo cages and stored in a thatched and mud-plastered house. Emergence of moths is thereafter awaited during which period nobody is allowed to enter the grainage with shoes on. Emergence starts from dusk and continues till morning. The emerging adults are allowed to mate and in the copulated state itself, the pair is laid on 1.5-2 ft long sticks made of dried straw which the locals call “Kharikas”. Two to four copulating pairs occupy one Kharika to which the female is tied with thread around its right forewing shoulder. After over-night mating, the couples separate in the morning and if they do not decouple naturally, they are made to do so by the heat of fire lighted some distance away. Some tribal rearers devour the male moths after decoupling and the female moths after third day of egg laying.

Brushing - Brushing, as we know, refers to transference of the newly hatched larvae on to the food plants. At the site of brushing, the tribals perform a traditional ceremony (Puja) after cleaning the site. This is done to propitiate God and drive out evil moths which they believe are the cause of poor rearing performance. This over, the Kharikas with their moths are hung on the upper branches of the food trees. The larvae that hatch from the eggs crawl up to the foliage and start feeding. Plantain leaves or cloth sheets are spread under the food plants to collect the larvae that may fall to be put back on to the foliage. The basal region of the food plant is rubbed with thin layer of lime powder and ash to prevent crawling insect pests from climbing the tree and also coils of straw rope or banana bark is tied to prevent downwards movement of the straying larvae. The Kharikas are shifted to newer hosts after 2,3 and sometimes 4 days of brushing. If due to shortage of leaves, the larvae descend down the trunk, they are collected in a kind of bamboo umbrella-like structure called Chaloni which is then placed on another tree with the help of a bomboo pole.

Cocoonage of mountage - The cocoonages, unlike the chandrikes of mulberry silkworms are called "Jali" which are made up of partly dried leaves of jackfruit, mango etc. tied into a bundle. Preparation of Jalis commence when the larvae are in their 3rd or 4th stage and are kept ready one day before they are mature for spinning cocoons. Mature or ripe worms are collected during dusk or night and transferred on the Jalis. Prior to doing this, the rearers perform the Puja once again. The Jalis are then hung and left undisturbed in separate rooms or at some shady place till cocoons are formed. After harvesting of the cocoons, seed cocoons are sorted out and the excess cocoons are stifling with smoke by placing them over an oven for the purpose of reeling.

During monsoon (July-September) when the rain may continue for days together, brushing of minute or "chawki worms", as they are called, on to food plants is not advised for the danger of their being washed off. The worms during this period can be easily reared indoors by brushing them on to tender twigs may be immersed in water contained in bottles. This is called 'chawki rearing' which could continue until 3rd instar when the worms are strong enough to cling to the host plants even during the rains.

In every case, keen watch and supervision of the larvae on host plants have to be kept to protect them from enemies (uziflies, braconids, insect predators and birds), the site of rearing has to kept clean of fallen leaves and dead larvae, larvae dropping down to the ground have to be placed back on the leaves, in 'chalonis' and infected larvae have to be identified, collected and burnt.

Grainages, as we have learnt, are centres for producing disease free seeds – of layings (eggs) or cocoons – of pure and hybrid races in large quantities. To accomplish this, certain scientific practices, as listed below, are adopted :

1. Infections of the diseases like pebrine are the worst enemies of sericulture. To avoid it, disinfection of the grainage hall, and equipments that come in use is the first operation that is carried out by washing them with water and then spraying 4% formaldehyde solution. After 48 hours of the spray, fumigation with formaline by boiling 35-40% of it is done.
2. Seeds, Eggs or cocoons are obtained from Govt. certified agencies or reliable sericulturists and the moths emerging from them are crushed and their fluid examined under the microscope for any infection. Only healthy disease free moths are utilised for seed production.
3. The eggs produced are once again disinfected by soaking them in 2-5% formaline solution for 5 minutes, washed in water and dried. This can also be done with high chlorines bleaching powder.
4. Overcrowding, whether at egg stage, cocoon stage, or while brushing the larvae to food plants, is always avoided not only to check damage to the developing embryos or pupae but also to check infections to allow healthy growth of the worms.
5. Rearing sites should not be low lying or shady ; host plants should be of medium size and not infested with pests like ants, wasps, aphid termites etc. It should be kept clean by deweeding.
6. The rest of the practices are similar to those adopted by traditional rearers.

Stifling - Stifling as we already know means killing the pupa inside the cocoons so that the latter are not damaged (cut) by the emerging moths. This is done by first spreading the cocoons on a bamboo mat and then exposing them to the sun. this partly kills the chrysalis. The mat is then kept above an oven where hot air and smoke kill the pupae fully. This process is repeated 2-3 times whereafter the cocoons are shown to the sun once again.

Degumming - Degumming means removal of the serecin protein covering the silk fibres which helps maintain the shape of the cocoons. This is done by boiling the cocoons in alkaline solution of sodium carbonate for 10-30 minutes depending on the amount of soda – 3 or 1 gm per litre – present in the solution. Some traditional sericulturists employ ash of leaves, wood and bark of some trees in place of soda.

Reeling - Muga cocoons are reeled on a primitive machine called "Bhir" in which two persons are needed – one to defloss the cocoons and draw filaments out of 8-10 cocoons and the other to twist these filaments and wound yarn on the spindle. Now-a-days, improved machines that do the job faster are available. Some of them are Choudhury type machine, Central Muga and Eri Research Station-III (CMERS-III) machine etc.

2. **Ericulture**

Cultivation of food plants -Eri silkworms are polyphagous in nature, they feeds on some primary and some secondary food plants. The primary food plants are castor (*Ricinus communis*) and Kasseru (*Heteropanax fragrans*) and some of the secondary ones are tapioca (*Manihot utilissima*) payam (*Evodia flaxinifola*), papaya (*Carica papaya*) etc. Castor is grown by seed sowing. Best season for sowing is September to October and March to April. Land is prepared and manured beforehand.

Kasseru is wild plant or can be cultivated by plantations on embankments around homestead land. It is grown both vegetatively by cuttings and by seed sowing. Seeds sown in nurseries are transplanted at proper spacing. Pruning or pollarding is carried out annually to induce branching. Leaves become suitable for feeding from August to December; in other months, they are too tender. Worms can be easily shifted from kasseruto castor but not vice versa.

Philosamia (Attacus) ricini

Distribution-The natural habitat of *P. ricini* is Assam and bordering districts of W.Bengal coexisting with it is its wild form *P.cynthia* which can easily hybridise with the domesticated *P. ricini*. The right climatic conditions for the growth of these insects are a temperature ranging between 18.3 – 29.4 degree C and humidity of 75-95 per cent.

Appearance–Eri silkworm is brownish chocolate in appearance with black or green coloured wings with white crescent markings, and woolly white abdomen. The male is smaller than the female bearing bushy antennae, and narrower abdomen.

Life-history

Adult moths emerge from morning to mid-day, males emerging earlier than the female. After an hour or two of emergence, mating occurs and continues up to evening. The males are then separated but can be used for 2-3 more matings. For the seed crops, the males are used only once for mating. The moth is multivoltine (its wild counterpart is uni- or bivoltine) producing 5-6 generations. Like muga worms, Eri worms also have a variable duration of life-history – about 44 days in summer and 85 days in winter. The figures in parentheses are those of winter and outside, of summer.

Rearing of Eri silkworms. Disinfected seed cocoons are reared fully indoors. Healthy cocoons are spread on bamboo trays in a cool dark room. On hatching, active males are separated from the passive females and are allowed to mate in a quiet dark room. Fertilised females are then tied to "Kharikas" by passing a thread around the shoulder joint of the right wings as in the case of muga moths. Kharikas are then suspended from a string. The eggs laid within 25 hours are normally selected for rearing. As usual, the eggs are disinfected by washing them in 2% formaline solution and then again in fresh water to remove traces of the chemical. Larvae hatching from the eggs are gently brushed on to trays over which few tender leaves plucked from top regions of the plant are spread. Crowding of trays either with worms or leaves is avoided. If humidity is less than 75 per cent, the trays are covered with moist sheets of sac cloth. As the worms advance in age, older and older leaves can be given. The worms should be given 4-5 feeds at specified timings – at 4 hour intervals starting from 6 A.M. in the case of I-III instars and 5 hour intervals, in the case of IV and V instars. Whereas I-III instars are reared in trays, IV and V instars are given bunch feeding wherein bunches or leaves are tied by their stalks and hung saddle-like on horizontal bamboo supports. A bamboo at spread below these bunches helps collection and replacement of larvae that may drop down. Bunch rearing affords greater cleanness since the excreta falls down leaving the foliage unsoiled. Bed cleaning for earlier instars reared in trays is carried out in the same way as for the mulberry silkworms.

Mounting and harvesting-After maturation the worms empty their gut contents as a result their body becomes plump and shortened and they start looking for a mounting place moving away from their food. Maturation of worms commences from 9 A.M. and continues up to mid-day. Such worms are hand-picked and transferred to 'Chandrikes' like those of the mulberry silkworms or to bamboo baskets filled with dry mango or banana leaves. Cocoons are spun between the folds of leaves. To prevent worms from straying out, the lids of the baskets are closed.

Cocoon spinning takes 3 days in summer and 5 days in winter. But they are normally collected from the chandrikes or bamboo baskets after 5 days in summer and a days in winter. The cocoons may be white or brick-red, 5 cm long in the case of female (4.6 cm for male), tapering at one and flat rounded and open at the other end, flossy and without a peduncle. They are cleaned and spread over bamboo trays and kept protected from ants, lizards, rats etc.

Stifling, degumming and spinning -Stifling is done by sun drying the cocoons for 1-2 days after this for degumming cocoons are tied in a cloth sac and with the help of stone weights sunk in boiling soda solution. When sufficiently boiled, cocoons are taken out, washed in water several times to remove soda, squeezed to wring out water and spread on mats to dry. Being open-mouthed, the thread of the cocoons are discontinuous and so they can only be spun and not reeled. Spinning is done in wet condition on a Takli and in semi-dried condition, on a charkha. However, in these methods both the hands need to be used and so spinning becomes laborious and slow. The colour of the eri worm silk is while or brick red and since the threads have to be spun, the cloth produced with them is coarse and has to be cheaper compared to the silk got out of other worms. Eri silk, therefore, is called a poor man's silk.

3. **Tasar Sericulture**

Cultivation of food plants–Tasar Silkworm is a wild variety and is preferred to be reared outdoors like onAsan (*Terminalia tomentosa*), Arjun (*Terminalia arjuna*), Saal (*Shorea robusta*) and Ber (*Zizyphus jujuba*) plants. However, modern sericulturists prefer to cultivate the food plants on their farms for better supervision and adequate leaf supply. Cultivation of plants is done with seeds. Saplings are raised in nurseries and transplanted in fields, 20-25 feet apart after sufficient rain-fall. Watering, manuring and ploughing around the saplings are carried out regularly and also the plants are protected from cattle, other animals and villagers until they have achieved a good height. Pruning of the branches, 3-5 weeks before starting rearing, is carried out for better foliage growth. Due to continuous rearing on same plants, there is possibility of plant to become weak, therefore it is better to grow food plants in two plots and the rearing should be done only on alternate years in each plot.

Antheraea paphia.

Distribution- Tasar silk is divided into two categories: tropical tasar and temperate tasar. Tropical tasar is produced in humid areas like Bihar, Orissa, M.P. and to a less extent in U.P., A.P., Maharashtra, and Karnataka while temperate tasar, at Jammu and Kashmir, Arunachal Pradesh and Mizoram.

Appearance- Tasar moths are fairly large insects, female being larger and yellowish-brown in colour while males smaller and radish brick in colour but both having prominent eye spots on their wings. The antennae of the male are bushy (branched) and abdomen narrower compared to that of the female.

Life-history

Tasar moths are bivoltine giving two crops a year – one during August to October and the other during October to December.

Rearing of tasar silkworms-The variety of silkworm - tasar silkworms is entirely wild, they have to be fully reared on host plants. Adult moths from the cocoons collected during winter of the previous year emerge only in August of the following year due to diapause. Single male-female pairs are kept in separate palm-leave vessels called "monia" or "mauni". After 24 hours when mating is completed, the lids of the monias are opened and the males allowed to fly away. The fertilised females are then transferred to earthen-pots or cardboard boxes for egg laying. In the next 24 hours when the egg-laying is over, the females are crushed and their body fluid examined under microscope for any diseases. If diseases, the whole lot of the eggs is destroyed by burning. Only the disease free layings (dfls) are kept for rearing.

The eggs are washed in 2% formaline solution to disinfect them, washed in water to remove the chemical, dried and kept in an incubator for hatching which takes 7-8 days. The freshly hatched ½ inch yellowish larvae are transferred (brushed) to the leaves of the food plants that have been kept ready after pruning and growth of new tender shoots. The first three instars stages of larvae are small, possess a weak grip over the foliage and therefore, run the risk of being washed off during rains. To avoid this, these instars could be fed indoors on food plant twigs dipped in earthern vessels containing water to retain freshness for a longer time. The larvae feed, grow in size and moult 4 times to become full-grown. Moults of I-IV instars occur in 3-4, 5-7, 7-8 and 8-10 days respectively while the V instar takes 15 days of voracious feeding to become full-grown when it measures 4-5 inches and weighs 50 gms. It then stops feeding, evacuates its gut by passing out the excreta for the last time and starts looking for a suitable spot to spin cocoon to pupate.

Pupation and cocoon formation- Pupation as in all other silkworms occurs inside the cocoon. For constructing its cocoon, the larva selects a suitable spot on a twig preferably near its origin. It then crawls down, entangles a few leaves in its silk threads to form a cone-shaped tent or hammock, open on top. The larva comes out of this opening and sets about spinning its cocoon which it does in 3 steps: ring formation, peduncle formation and cocoon formation. For ring formation, the larva nibbles the bark all around the chosen site with its powerful mandibles to form a furrowed ring. This is followed by ejection of silk in semicircular loops around half the furrowed circle so that in a short time a strong half-ring of silk is formed. The larva then secretes silk to make the peduncle which brings it near the leaf-tent. It enters the tent and begins to spin the cocoon which takes 4-6 days to complete. The larva by this time is already inside the cocoon to pupate. During cocoon spinning, the tasar larvae have to be kept under close watch to protect them from the predators like birds, bats, lizards and rodents and the cocoons from man (thieves).

Stifling and reeling of cocoons - Tasar silkworm cocoons are hard and are first soaked in 5% Na_2CO_3 (soda) solution for 18 hours and then subjected to steam cooking in pressure chamber for approximately 3 hours. After 24 hours, the cocoons are washed in 0.5% formaline for 15-20 minutes. These steps give silk fibres a greater tensile strength. Cocoons are then squeezed to expel water and reeled on a reeling machine. Threads from 4 cocoons are used for reeling.

Sericulture and its role in economy of India

Silk is the most elegant fabric industry of the world with unparalleled grandeur, natural sheen, and inherent affinity for dyes, high absorbance, light weight, soft touch and high durability and known as the “Queen of Textiles” the world over. On the other hand, it stands for livelihood opportunity for millions owing to high employment oriented, low capital intensive and remunerative nature of its production. The very nature of this industry with its rural based on-farm and off-farm activities and enormous employment generation potential has attracted the attention of the planners and policy makers to recognize the industry among one of the most appropriate avenues for socio-economic development of a largely agrarian economy like India.

Silk has been intermingled with the life and culture of the Indians. India has a rich and complex history in silk production and its silk trade dates back to 15th century. Sericulture industry provides employment to approximately 8 million persons in rural and semi-urban areas in India. Of these, a sizeable number of workers belong to the economically weaker sections of society, including women. India's traditional and culture bound domestic market and an amazing diversity of silk garments that reflect geographic specificity have helped the country to achieve a leading position in silk industry. India has the unique distinction of being the only country producing all the five known commercial silks, namely, mulberry, tropical tasar, oak tasar, eri and muga, of which muga with its golden yellow glitter is unique and prerogative of India.

India is the Second largest producer of silk in the World. Among the four varieties of silk produced, in 2015-16, Mulberry accounts for 71.8% (20,434 MT), Tasar 9.9% (2,818 MT), Eri 17.8% (5,054 MT) and Muga 0.6% (166 MT) of the total raw silk production of 28,472 MT. An analysis of trends in international silk production suggests that sericulture has better prospects for growth in the developing countries rather than in the advanced countries. Silk production in temperate countries like Japan, South Korea, USSR etc., is declining steadily not only because of the high cost of labour and heavy industrialization in these countries, but also due to climatic restrictions imposed on mulberry leaf availability that allows only two cocoon crops per annum. Thus, India has a distinct advantage of practicing sericulture all through the year, yielding a stream of about 4 – 6 crops as a result of its tropical climate.

The bivoltine raw silk production achieved a record production of 4,532 MT during 2015-16 by registering 17% growth over previous year. Similarly, vanya silk, which includes tasar, eri and muga raw silks, has achieved 9.8% growth during 2015-16 over 2014-15. However, the crossbreed silk production has declined during 2015-16 compared to the last year.

Reduction in crossbreed raw silk production is due to severe drought condition and drastic depletion in ground water in sericulture belts in the major silk producing states. Further, the mulberry area expansion was severely affected in many states due to crash in mulberry cocoon prices during planting season for mulberry. The price crash and the drought conditions prevailed during 2015-16 also resulted in uprootment of mulberry leading to decline in mulberry area.

State wise Raw Silk production during 2012-13 to 2015-16(P) (in MT)

#	State	Achievement			
		2012-13	**2013-14**	**2014-15**	**2015-16 (P)**
1	Karnataka	8219	8574	9645	9823
2	Andhra Pradesh	6550	6912	6485	5086
3	Telangana			101	116
3	Tamil Nadu	1185	1120	1602	1898
4	Kerala	6	4	7	9
5	Maharashtra	97	122	221	274
6	Uttar Pradesh	157	188	236	249
7	Madhya Pradesh	190	195	248	214
8	Chhattisgarh	391	391	234	261
9	West Bengal	2070	2079	2500	2391

10	Bihar	22	52	53	67
11	Jharkhand	1090	2003	1946	2284
12	Odisha	104	53	98	117
13	Jammu & Kashmir	145	136	138	127
14	Himachal Pradesh	23	25	30	32
15	Uttarakhand	17	22	29	30
16	Haryana	0.13	0.13	0.3	0.6
17	Punjab	5	4	4	0.8
18	Assam & Bodoland	2068	2766	3222	3325
19	Ar.Pradesh	22	15	12	37
20	Manipur	418	487	516	522
22	Meghalaya	517	644	656	857
23	Mizoram	40	44	50	64
24	Nagaland	324	606	619	631
25	Sikkim	3	0.20	8	6
26	Tripura	15	40	48	52
	Total	**23,679**	**26,480**	**28,708**	**28,472**

(p): Provisional

Production of silkworm seed

The CSB has a chain of Basic Seed Farms supplying basic seeds to the States. Its commercial seed production centers augment efforts of the States in supplying commercial silkworm seed to farmers. The Table below indicates the total quantity of seed production during first 4 years of XII Plan (2012-13, 2013-14, 2014-15 & 2015-16)

(UNIT: LAKH DFLS)

Particulars	XI Plan (2011-12) Achmnt.	2012-13		2013-14		2014-15		2015-16	
		Target	Achmnt.	Target	Achmnt.	Target	Achmnt.	Target	Achmnt.
Mulberry	321.54	325.00	308.48	325.00	338.57	350.00	370.13	375.00	410.50
Tasar	36.44	33.13	39.74	34.51	38.44	44.09	42.46	47.14	51.62
Muga	2.52	5.02	4.87	5.52	5.00	6.07	6.11	7.26	7.45
Eri	3.17	3.39	4.21	3.60	3.61	4.10	5.69	4.52	5.75
Total	**363.57**	**367.21**	**357.30**	**368.63**	**385.62**	**404.26**	**424.39**	**433.92**	**475.32**

In India, sericulture is not only a tradition but also a living culture. It is a farm-based, labour intensive and commercially attractive economic activity falling under the cottage and small-scale sector. It particularly suits rural-based farmers, entrepreneurs and artisans, as it requires low investment but, with potential for relatively higher returns. It provides income and employment to the rural poor especially farmers with small land-holdings and the marginalized and weaker sections of the society. Several socio-economic studies have affirmed that the benefit-cost ratio in sericulture is highest among comparable agricultural crops

Some initiatives like cocoon testing in some select markets, raw silk testing in the silk conditioning and test houses and technical service centres across the county by the Central Silk Technological Research Institute, Central Silk Board, Bangalore has created visible impact to bring awareness about quality among the rearers, reelers and weavers. This is important to achieve quality silk of international standard. Recently, Central Silk Board has started a testing laboratory for Silk and Zari at Kancheepuram to facilitate customers, producers and other stakeholders for spot testing of silk and zari material without any destruction to the products by x-ray analysers. More importantly, 'Silk Mark' Scheme is introduced by Silk Mark Organisation of India (SMOI), a registered society, sponsored by Central Silk Board, Ministry of Textiles, Government of India. The Silk Mark is a quality assurance label for the assurance of pure silk and in addition serves as a brand for generic promotion of Pure Silk. The Silk Mark is under the process of registration as a Trade Mark.

Indian silkworm breeds are multivoltine (*i.e.,* they produce several broods a year) and though, good progress has been achieved in cross breed (multivoltine x bivoltine) silk production, the quality still remains incomparable to that of Chinese breeds which are bivoltine. In spite of abundant natural resources, socio-economic benefit of the sector like generation of employment for the large sections of tribals and marginalized rural men and women, growing export market as well as large domestic demand, a variety of problems have kept Indian sericulture away from achieving its true potential. These may include unhygienic conditions and diseases prevalent during silkworm rearing, mediocre quality of silkworm breeds and sub-optimal processing technology, lack of proper seed organization system and poor quality seed production, low technology adoption by the stakeholders, inadequate/poor extension efforts, age-old practices of post-cocoon operations, absence of quality certification and quality-linked pricing system and poor linkages among the four production sub-systems *viz.,* seed, cocoon, yarn and fabric.

An interest of sericulture in India as a whole is protected by 'Central Silk Board' running under the Union Ministry of Trade and Commerce. A qualitative and quantitative breakthrough has been made due to research conducted on various aspects of the industry by the respective research centres running under this board. The quality control and export of Silk is also looked after by the board.

The important research centres are the following;—

(i)Central Sericulture Research Station, Berhampur, West-Bengal (Mulberry).

(ii) Sericulture Research Institute Channapatna, Mysore (Mulberry).

(iii) Central Munga and Eri Research Station Titabar, Assam.

(iv)Central Tasar Research Station, Ranchi, Bihar.

These research stations have 'sub-stations and extension centres in' different parts of the country for the convenience of the sericulturists there in remote areas.

Silk properties and Its Use

Silk contains 70-75% fibroin and 25-30% sericin protein. The biochemical composition of fibroin can be represented by the formula $C_{15}H_{23}N_5O_6$. It has the characteristic appearance of pure silk with pearly lustre. It is insoluble in water, ether or alcohol, but dissolves in concentrated alkaline solutions, mineral acids, and glacial acetic acid and in ammoniacal solution of oxides of copper. Sericin, a gummy covering of the fiber is a gelatinous body which dissolves readily in warm soapy solutions and in hot water, which on cooling forms a jelly with even as little as 1% of the substance. It is precipitated as a white powder from hot solutions by alcohol. Its chemical formula is $C_{15}H_{25}N_5O_8$. It can be dyed before or after it has been woven into a cloth. The weight in gram of 900m long silk filaments is called a denier which represents size of silk filament.

Silk has following peculiar properties: -

1. Natural colour of Mulberry silk is white , yellow or yellowish green; that of Tasar brown; of Muga, light brown or golden; and of Eri, brick red or creamy white or light brown.
2. Silk has all desirable qualities of textile fibres, viz. strength, elasticity,

softness, coolness, and affinity to dyes. The silk fibre is exceptionally strong having a breaking strength of 65,000-lbs/sq. inch.

3. Silk fibre can elongate 20% of original length before breaking. 4. Density is 1.3-1.37g/cm^3.
4. Natural silk is hygroscopic and gains moisture up to 11%.
5. Silk is poor conductor of heat and electricity. However, under friction, it produces static electricity. Silk is sensitive to light and UV- rays.
6. Silk fibre can be heated to higher temperature without damage. It becomes pale yellow at 110^o C in 15 minutes and disintegrates at 165^o C.
7. On burning it produces a deadly hydrocyanic gas.

Use of silk:

Silk is used in the manufacture of following articles:

- Garments in various weaves like plain, crepe, georgette and velvet.
- Knitted goods such as vests, gloves, socks, stockings.
- Silk is dyed and printed to prepare ornamented fabrics for saries, ghagras, lehengas and dupattas.
- Jackets, shawls and wrappers.
- Caps, handkerchiefs, scarves, dhotis, turbans.
- Quilts, bedcovers, cushions, table-cloths and curtains generally from Eri-silk or spun silk.
- Parachutes and parachute cords.
- Fishing lines.
- Sieve for flour mills.
- Insulation coil for electric and telephone wire.
- Tyres of racing cars.

- Artillery gunpowder.
- Surgical sutures.

10.6 Insect Pollinators

A **pollinator** is the biotic agent that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization or 'syngamy' of the female gametes in the ovule of the flower by the male gametes from the pollen grain. Animals that assist plants in their reproduction as pollinators include many insect species like bees, (honey bees, solitary species, bumblebees); pollen wasps (Masarinae); ants; a variety of flies including bee flies and hoverflies; lepidopterans, both butterflies and moths; and flower beetles as well as other animals like bats, monkeys, lemurs, possums, rodents, reptiles like lizards and snakes, birds like hummingbirds, honeyeaters, sunbirds etc.with long beaks pollinate various plants. Wind and water also play a role in the pollination of many plants. Somewhere between 75% and 95% of all flowering plants on the earth need help with pollination – they need pollinators. Pollinators provide pollination services to over 180,000 different plant species and more than 1200 crops. That means that 1 out of every three bites of food we eat is there because of pollinators. In addition to the food that we eat, pollinators support healthy ecosystems. **Anthecology** is the scientific study of pollination.

Pollination

Pollen is basically a spore of plant that has been produced asexually. It germinates on contact with the stigma of a flower and grows as a pollen tube through the style to the embryo sac where it discharges two nuclei. One nucleus unites with the egg cell of an ovule and results in fertilization. Pollination is the process by which pollen is transferred to the female reproductive organs of a plant, thereby enabling fertilization to take place. The fertilized egg develops into a mature plant. The other nucleus from the pollen tube unites with the polar bodies to form the endosperm nucleus in the same ovule. The seed endosperm, or nutritive tissue like yolk in an animal egg, develops from this union. It then dies early in the development of the young seed or seedling which drains it of nutriment. Sperm cells and egg cells mature by dividing the number of their chromosomes in half. Then when egg and sperm unite, the original number of chromosomes characteristic of the cells in the plant is restored. Inheritable traits of the parents of both the egg and the sperm cells are now combined in the developing embryo.

Pollination is a very important process in both human managed and natural terrestrial ecosystems depending upon the symbiosis between species, the pollinated and the pollinator. It is the result of intricate relationships between plants and insects, and the reduction or loss of either will affect the survival of both. Insect pollinators provide an essential ecosystem service for pollination, clean the air, stabilize soils, protect from severe weather, and support other wildlife.

Insects especially are of enormous importance in the pollinations of many agriculturally important crops. Although gravity, wind, water, molluscs, birds, bats and humans are agents of pollination, it is often possible to manipulate insects in their performance on high value cropping systems.

Insect Orders working as pollinating agents

Insects are classified into 31 major orders and most of the species are pollinators. Some of the important pollinators insect orders are Hymenoptera (ants, wasps, bees, sawflies, Ichneumon flies and chalcid flies), Hemiptera (true bugs, cicadas, leafhoppers, scale insects, aphids), Thysanoptera (thrips), Coleoptera (beetles), Diptera (flies, gnats, mosquitoes), Lepidoptera (moths and butterflies) etc. Here are some important pollinating insect orders

1. **Hymenoptera**

The most familiar pollinating Hymenopterans are the bees, wasps and ants. Hymenoptera characteristically have two pairs of wings, a large fore pair and a smaller hind pair. These wings are held together by a series of hooks (called a frenulum) and may appear like a single pair to the naked eye. Hymenoptera also tend to have prominent antennae, generally with nine or more segments and biting mouthparts.

a) *Honey bees*

The most recognized pollinators are the various species of bees, which are plainly adapted to pollination. Bees typically are fuzzy and carry an electrostatic charge which helps them to adhere pollen grains to their bodies, but they also have specialized pollen-carrying structures; in most bees, this takes the form of a structure known as the scopa, which is on the hind legs of most bees, and the lower abdomen (e.g., megachilidae bees), made up of thick, plumose setae. Honey bees, bumblebees, and their relatives do not have a scopa, but the hind leg is modified into a structure called the corbicula ("pollen basket"). Most bees gather nectar, a concentrated energy source, and pollen, which is high protein food, to nurture their young, and inadvertently transfer some among the flowers as they are working.

Honey bees travel from flower to flower, collecting nectar which is later converted into honey, and pollen grains. The bee collects the pollen by rubbing against the anthers. The pollen collects on the hind legs, in a structure referred to as a "pollen basket". As the bee flies from flower to flower, some of the pollen grains are transferred onto the stigma of other flowers. Nectar provides the energy for bee nutrition; pollen provides the protein.

Good pollination management during the blooming time of the crop, helps the bees to gather pollen, and making them more efficient pollinators. Millions of hives of honey bees are contracted out as pollinators by beekeepers, and honey bees are by far the most important commercial pollinating agents, but many other kinds of pollinators, from blue bottle flies, to bumblebees, orchard mason bees, and leaf cutter bees are cultured and sold for managed pollination.

b) Wasps

Many insects other than bees do pollination by visiting flowers for nectar or pollen, or commonly both. For example, many species of hunting wasps, rely on freely flowering plants as sources of energy in the form of nectar and also predatory wasps (especially Sphecidae, Vespidae, and Pompilidae). They are remarkable among solitary wasps in that they specialise in gathering pollen for feeding their larvae, carried internally and regurgitated into a mud chamber prior to oviposition.

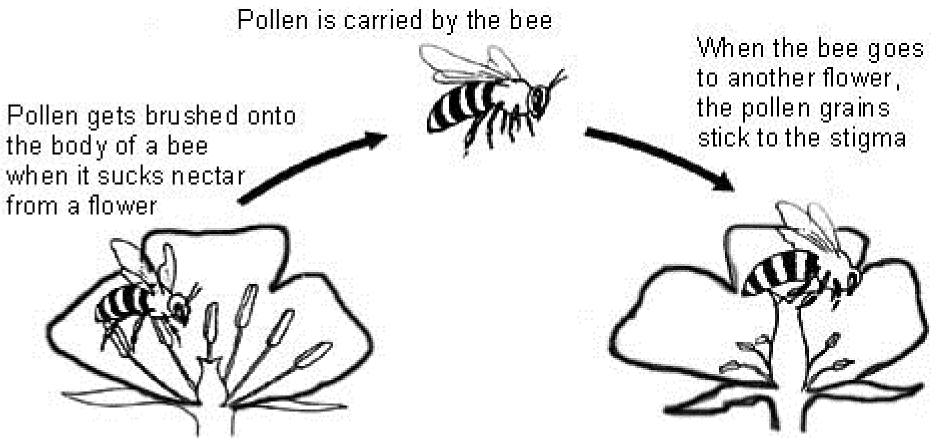


Figure - Bee Pollinations

2. **Diptera**

The several families of Diptera are involved in pollination. Usually adult dipterans feed frequently on nectar or pollen or both, but the larval stage are harmful to plants. Examples are found in the Anthomyidae (hovering house flies), Bombyliidae (bee flies), Calliphoridae (blow flies & bottle flies), Ceratopogonidae (biting midges) Conopidae (thick-headed flies), Cyrtidae (small-headed flies), Empididae (dance flies), Muscidae (house flies), Sarcophagidae (flesh flies), Stratiomyidae (soldier flies), Syrphidae (flower flies, syrphid flies, hover flies), Tabanidae males (horse flies), Tachinidae (tachinid flies), Tephritidae (fruit flies). These families might be considered in the following order of decreasing importance: Syrphidae, Muscidae, Calliphoridae, Sarcophagidae, Bombyliidae, Conopidae, Tachinidae, Empididae, Stratiomyiidae, Tabanidae, Tephritidae, Ceratopogonidae and Cyrtidae. However, this order may differ for any one-plant species.

In Syrphidae most species feed on nectar and pollen or only nectar. Nectar-feeding species have a long, slender proboscis and generally visit the same group of flowers as the long-tongued bees. Bombyliidae adults have a long, slender proboscis and visit flowers. In Muscidae the adults of most species visit flowers and eat pollen and nectar.

3. **Lepidoptera**

Adults of most Lepidoptera feed mainly on nectar from flowers, while their larvae feed on herbage, some roots or stored food products and wool and are therefore pestiferous. The tongue lengths of Lepidoptera vary from 1 to 250 mm. Those with 4-10 mm.Butterflies tend to frequent day-blooming flowers and moths visit constantly open or evening and night-blooming flowers. The entire suborder, Rhopalocera and 5 families of Heterocera that are numerous or specially adapted as pollinators are Arctiidae (tiger moths & wooly bears), Geometridae (loopers), Noctuidae (nun moths, cut worms), Pyralidae (snout moths), Rhopaloceridae (butterflies) and Sphingidae (hawk moths & horn worms).

Butterflies generally visits to flowers in daylight, the value of moths as pollinators is probably underestimated. Butterflies often spend a lot of time on the same flowers and they are regularly less effective than bees in pollination. Hawk moths that fly in the evening or at night are assiduous flower visitors by darting rapidly from plant to plant. Their very long proboscis seems to be especially suited for the most highly developed Lepidoptera flowers that have musky odors, long and narrow corolla tubes or long spurs that contain nectar. Butterflies tend to prefer red flowers while moths prefer white flowers. Many flowers are sometimes referred to as haw moth flowers, and where the corolla tube exceeds 25 mm. the term is deserved.

4. **Hemiptera**

Some Hemipterans are also of pollination importance such as Anthocoridae (minute pirate bugs), Phymatidae (ambush bugs) and Reduviidae (kissing bugs). The Anthocoride prey on thrips in flowers; a few Reduviidae prey on bees in flowers and most Phymatidae prey on bees and flies in flowers. Anthocoridae are found in almost any flowers that are visited by thrips. Phymartids and reduvids are found primarily on Compositae and flowers that are grouped into tight heads.

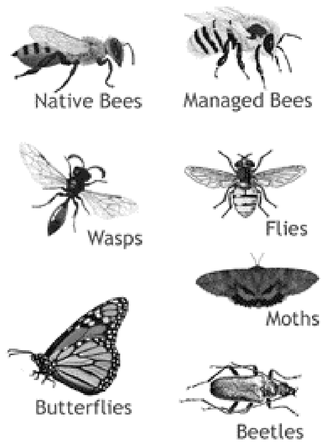
5. **Coleoptera**

The Coleoptera are not as important pollinators as the Diptera, Lepidoptera and Hymenoptera. There are nine families of Coleoptera that are at times involved in the pollination of flowers. Most species of Cantharidae, the leather-winged beetles, that are predaceous as larvae occasionally pollinate.. Polleniferous species are also predaceous as adults. The majority of Meloidae, or blister beetles, occasionally are involved in pollination. The larvae of some species are parasitic in bee nests; others are parasitic on grasshopper egg masses. All adult Meloidae feed on pollen or on both nectar and pollen. The larvae of some species of Cleridae are flower inhabiting. They are mainly parasites in the nests of wasps and bees. The adults are predaceous, but they also feed on pollen. Most Melyridae are predaceous as larvae and both predaceous and polleniferous as adults. One genus of Buprestidae, *Acmaeodera*) (flat-headed borer) is polleniferous. The larvae bore into wood and the adults feed on pollen. Many genera of Cerambycidae, or long-horned beetles and round-headed borers, can be involved as pollinators. The larvae bore into wood but the adults feed on pollen. Several genera of Scarabaeidae, or white grubs, visit flowers. They are primarily root-feeders as larvae, but they also feed on pollen as adults. Elateridae, or click beetles, are mostly root-feeders as larvae, but adults will feed on nectar and pollen. In the Dermestidae, the genus *Anthrenus* feed on decaying animal matter as larvae, but adults may also utilize pollen (especially *Anthrenus*). There are also other small families of Coleoptera, such as the Mordellidae, Oedemeridae, Lycidae and Rhipiphoridae, whose members have been observed to act as pollinators. Some blister beetles will feed on legume petals in order to expose the pollen and nectar. Some very tiny flower-visiting beetles may crawl into the narrowest corollas or tightest keels. Nevertheless, only a few groups of flowers are visited regularly by a variety of beetles. Examples are flowers with abundant pollen, social flowers with concealed nectar, flowers with exposed nectar and flowers with partially concealed nectar.

6. **Thysanoptera (Thrips)**

A small order, Thysanoptera are tiny but individual species also are good pollinators. Adults and larvae feed either mostly on honey and pollen or are predators of other thrips in flowers.

The larvae of many genera of Diptera are destructive. Adults may pose a health hazard and are thus unsuitable for purposeful deployment. Muscidae may be useful in confinement for breeding work and small-scale increase of desirable plant stocks. There are may good pollinators among the Syrphidae, however. They could be increased rapidly and used as predaceous forms in insectaries. Although species may resemble bees and wasps, they are non-biting. Semi-aquatic species could be increased in field crops. The drone fly, e.g., is an efficient fruit pollinator and might be propagated in shallow tanks infused with organic material.



FEW INSECT POLLINATORS

Importance of Pollination to Agriculture

Insects in their pollination activities have a direct impact on the flora and fauna. It is believed that angiosperm plants and the more highly evolved insects evolved together. Primitive flowering plants are all insect pollinated. Therefore, grasses and all other plants are dependent upon insects. Some beetles, most Hymenoptera, many Diptera and almost all Lepidoptera are dependent upon materials provided by flowers. Therefore insect pollination was necessary to the development of angiosperms.

Major Threats to Pollinators

Insect pollinators are affected by the same environmental challenges as other species, including habitat loss, degradation, and fragmentation; non-native species and diseases; pollution, including pesticides; and climate change. Many pollinators are adversely affected by broken up of habitat into smaller, isolated patches by road construction, development, or agriculture. These habitat fragments may not be large enough to meet all pollinator needs by themselves. Pollinator’s habitat has been lost because of modern techniques of agriculture and urban and suburban development. Habitat degradation, the decline in habitat quality, is another serious concern. For example, the loose, friable soil required by ground-nesting bees may be trampled by heavy foot traffic or the use of off-road vehicles. In cities, ground-nesting species may be particularly limited due to the large amount of landscape that has been covered with concrete or other impervious surface.

Plants or animals brought here from other places can decrease the quality of pollinator habitat. When non-native shrubs such as autumn olive and multiflora rose take over open fields, they crowd out the wildflowers needed by certain butterfly and bee species for pollen, nectar, or larval food. For example, Japanese barberry shades out native spring ephemerals like Dutchman's breeches, which provide food for early spring bumble bees. Introduced parasites and diseases are still another threat to pollinators. Thus far, the effects of these parasites have been species-specific, including the mite and virus species that have severely compromised honey bee colonies.

Air pollution is a very real problem for bees and other pollinators that rely on scent trails to find flowers. Light pollution can harm moth pollinators by increasing their susceptibility to predation by bats or birds when they are attracted to artificial lights at night. Excessive use or misuse of pesticide and drift from aerial spraying are a major threat to insect pollinators, especially spraying with so-called persistent chemicals that remain in the environment for a long time before degrading. Systemic insecticides applied to seeds can contaminate the pollen grains that are an essential source of food for bees and their young. Pesticides often kill directly, but sub-lethal amounts can also be detrimental to bees and other pollinators by impeding their ability to navigate or forage.

10.7 Biocontrol agents of weeds

Weeds

A weed is a plant considered undesirable in a particular situation, or in other words it is a plant at the wrong place. These are commonly grown plants that are unwanted in human-controlled settings, such as farm fields, gardens, lawns, and parks. The term also is applied to any plant that grows or reproduces aggressively, or is invasive outside its native habitat.

Weeds are estimated to cause more than $40 billion in annual global losses through degraded agricultural and silvicultural productivity, reduced access to land and water, impaired esthetics, and disruption of human activities and well-being. Manual removal, mechanical cultivation, cultural practices, or chemical herbicides can control weeds. However, use of physical and chemical methods of weed control alone is not feasible, desirable, or sufficient in every situation.

Biological control by insect agents

Biological control of weeds is broadly defined as the use of an agent, a complex of agents, or biological processes to bring about weed suppression. All forms of macrobial and microbial organisms are considered as biological control agents. Examples of biological control agents include, but are not limited to: arthropods (insects and mites), plant pathogens (fungi, bacteria, viruses, and nematodes), fish, birds, and other animals. Biologically based weed management is a much broader category of approaches that may include gene modification, genetic processes, and gene products. Human activities intended to remove weeds directly or indirectly, such as hand-weeding and burning, deliberate uses of plant competition, allelopathy, and cultural and soil management practices that alter the biotic balance of soil are considered important adjuncts to biological control in integrated weed management systems.

If plants are introduced to a new region that does not have these natural enemies, their populations may grow unchecked to the point where they become so prevalent that they are regarded as weeds. It is critical that the biological control agents introduced do not become pests themselves. Considerable testing is done prior to the release of biological control agents to ensure they will not pose a threat to non-target species such as native and agricultural plants.

Although in the long term, biological control can be cost effective and can reduce the need for less desirable management practices, not all weeds are suitable for biological control. Developing a biological control project requires a substantial investment, sometimes costing millions of dollars over many years.

An early success in biological control of weeds in Australia was the use in the 1920s of the *Cactoblastis* Moth (*Cactoblastis cactorum*) to control Prickly Pear (*Opuntia stricta*), which at the time was smothering large tracts of north-east Australia, and spreading rapidly each year. The larvae of the *Cactoblastis* Moth eat the leaves and seed pods of the Prickly Pear. The release and spread of *Cactoblastis* Moth in Australia virtually destroyed Prickly Pear populations.

There have been several other successful biological controlling insects are used all over the world. Insects that attack leaves, fruits or stems have been released, following stringent screening, to control weeds such as Skeleton Weed, Bridal Creeper, and Salvinia. There is also major research being undertaken on biological control for a number of other weed species.

Insects as biological control agent of weeds

There are some well-known examples of biological control insects that have been successfully applied for many weeds. Some of them are as follows-

1. *Agapeta zoegana*

This moth attacks spotted and diffuse knapweed. Larvae feed within the roots is root miner, robbing the plant of nutrients and energy reserves, resulting in decreased plant biomass and density. Larval feeding can cause death in small plants and in plants infested with multiple larvae. *Agapeta zoegana* should be only be released at sites where knapweed infestations are large and immediate eradication of the weed is not the primary objective. Moths can be used with other knapweed insects. Any control methods that directly kill the plant will reduce or eliminate biocontrol populations. A selective herbicide should be used to avoid diminishing the effects of strong grass competition.

2. Agrilus hyperici

*Agrilus*larvae feed within the roots of Klamath weed, goatweed and may completely consume the root. Most plants infested with these larvae die. *A. hyperici* should only be released at sites where weed infestations are large and immediate eradication of the weed is not the primary objective. These beetles can be used with other insects and can be especially effective where goatweed plants grow in the shade. Smaller populations of the weed can either be hand-pulled or sprayed, provided that chemicals will not leach or runoff into water resources.

3. *Aphthona spps.*

The adult and larval stage of this beetles attack leafy spurge. Adults feed on leaves and flowers, and larvae feed on root hairs and young roots. Larvae cause the greatest impact by decreasing the availability of stored energy reserves. Larval feeding damage may also make plants more susceptible to infection and disease caused by soil-dwelling fungi. Some *Aphthona* spp. have been known to feed on a few other plants in the genus *Euphorbia*, including the native Leafy spurge is highly toxic, extremely difficult to control with herbicides, and nearly impossible to control with physical, mechanical or other methods. Roots can grow 3 to 7 m deep, and new plants can sprout from pieces of roots. Thus, successful control of leafy spurge is usually a long-term process, and biological control is an absolutely critical component of effective management. *Aphthona* spp. should be released where large infestations of leafy spurge occur. Some beetle species are susceptible to predation by ants and interference from grasshoppers, so initial releases should be avoided in areas where those insects are abundant. Sheep and goats can feed safely on leafy spurge, and grazing by these animals can help slow spread of the weed. Do not however, allow cattle to feed on leafy spurge. Ingestion of the plant by cattle can cause animal illness or death.

4. *Bangasternus fausti*

This weevil attacks diffuse, spotted**,** and squarrose knapweed**.** Larvae inhibit plant reproduction by feeding on seeds within flower heads. Up to 100% of the seeds in a single flower head may be consumed and the viability of any seeds not attacked is reduced. Several seed head agents have been released for control of knapweed. Because *B. fausti* larvae attack any other insects occupying the flower heads, beetles are best released at sites where other seed head agents are not present. Releases should be made only at sites where knapweed infestations are large and immediate eradication of the weed is not the primary objective.

5. *Brachypterolus pulcarius*

This beetle attacks both yellow and Dalmatian toadflax**,** although it appears to have a far greater impact on yellow toadflax. Larvae feed on reproductive structures within the flowers, including maturing seeds, and can reduce yellow toadflax seed production by up to 90%. Adult feeding on young stems decreases overall plant health by causing increased branching and stunted growth. Because *B. pulicarius* is already found in most yellow toadflax infestations, redistribution may be unnecessary. Agents should only be released at sites where toadflax infestations are large and immediate eradication of the weed is not the primary objective.

6. *Chrysolina* spp.

The larvae and adults of two species of *Chrysolina* feed on the leaves of Klamath weed, goatweed. *C. quadrigemina*, is known to feed on one ornamental and one native St. Johnswort, but no broad-level impacts have yet been reported on the native species.*Chrysolina* spp. have established at many sites across several states, so redistribution may be unnecessary. Releases should only be made at sites where goatweed infestations are large and immediate eradication of the weed is not the primary objective. Smaller weed populations and satellite plants can either be hand-pulled or sprayed.

7. *Cystiphora schmidti*

Its larvae feed on the leaf and stem tissues of rush skeleton weed, reducing the nutrients available for plant growth and maintenance. Plant tissues are either damaged or destroyed, causing yellowing, wilting, or death of those tissues. Infested plants may have reduced biomass, flower production, and seed viability.

8. *Eustenopus villosus*

This weevil attacks yellow starthistle and a few other non-native species of the genus *Centaurea*. Both larvae and adults suppress the spread of new plants by interfering with seed production. Adults feed on and destroy young seed heads; larvae feed inside the flower heads and can reduce seed production by up to 100% in the infested heads.

9. *Larinus curtus*

This beetle attacks yellow starthistle. Larvae feed on developing seeds and can reduce seed production by up to 100%.*L. curtus* should only be released where other seed head beetles have not established. Releases should be made at sites where yellow starthistle infestations are large and immediate eradication of the weed is not the primary goal.

10. *Sphenoptera jugoslavica*

This beetle prefers diffuse knapweed, but will also attack spotted and squarrose knapweed**.** Larvae bore into and tunnel within knapweed roots, reducing the availability of the plant's energy reserves. Releases of *S. jugoslavica* should only be made at sites where knapweed infestations are large and immediate eradication of the weed is not the primary goal. Knapweed seed head insects and/or other root feeders may already be present at a given site and *S. jugoslavica* can be used in combination with all available agents.

11. *Urophora sirunaseva*

This fly attacks yellow star thistle. Larvae are associated with galls formed within seed heads. Galls are abnormal tissue growth that displace seeds and steal vital nutrients and energy away from normal plant growth and reproduction Releases should be made at sites where yellow starthistle infestations are large and immediate eradication of the weed is not the primary goal.

10.8 Soil fertility improving agents

Insects are one of the better groups of invertebrates, in improving soil fertility. The degree of association of insects with the soil is very varied, from living permanently in the soil and completing their whole life-cycle there, to using soil as a temporary refuge. Many insects play a fundamental role in forming soil and maintaining its fertility by digging tunnels in the earth, they aerate and loosen the soil, promoting plant growth. Without scavenger-decomposer insects, the soil would be strewn with waste, corpses and faecal matter, leading to the growth of potentially dangerous bacteria. Decomposers are masters of recycling. Nutrients in excrement and dead plants and animals are made available by them for plants and the entire ecosystem.

Many insects depend on soil for part of their life cycle, e.g., many beetles, moths, and flies, and many of these are economically important pests because of the feeding activities of their larvae. The representatives of most insect orders - Orthoptera (grasshoppers, crickets, weta, mole crickets), Blattodea (cockroaches), Isoptera (termites), Dermaptera (earwigs), Hemiptera (bugs), Homoptera (cicadas, aphids, mealybugs), Coleoptera (beetles), Diptera (mosquitoes, flies), Lepidoptera (moths, butterflies), Hymenoptera (ants, wasps, bees) and a number of smaller orders (Psocoptera, Thysanoptera, Neuroptera) are found in the soil, number of terrestrial stoneflies (order Plecoptera), which live in the damp litter. Some of the insects groups helpful in improving soil fertility are as follows-

Order Orthoptera (crickets, grasshoppers, mole crickets)

Most Orthoptera are large and conspicuous insects and are familiar to everyone. Many can jump, using their strong hind legs. Wings may be present or absent. In most species of grasshopper, females can be easily recognized by their long sabre-like ovipositor, which they use to deposit the eggs into the soil. Crickets are medium-sized, brown or black insects with rounded heads and long antennae. Males are known for their chirping songs. They live in low vegetation and in dry plant detritus, often hiding in burrows or under rocks making soil more fertile. Mole crickets live underground, building tunnels 10-20 cm below the surface in moist soil, and are not encountered very often. The front legs are very strong, broad, flattened, and modified for digging. Mole crickets feed on plant roots and ground invertebrates. These crickets make the ground porous and fertile by their dead and decay matter and decomposition of litter matter.

Order Blattodea (Cockroaches)

The appearance of cockroaches is familiar to everyone. Cockroaches live in litter under debris, under rocks and stones, under bark of dead logs, in rotten wood and in other similar environments. They are omnivorous, and may feed on all sorts of organic materials. They can even eat dead wood, which they digest with the help of symbiotic gut flora.

Order Isoptera (Termites)

Termites are soft-bodied, light-coloured social insects, which live in colonies in dead wood - often in rotting tree stumps or in decaying logs and branches on the ground. The colony is made of numerous workers and solders, usually feed on dead wood, digesting cellulose with the help of symbiotic micro-organisms in their gut.

Order Dermaptera (Earwigs)

Earwigs are elongate, slender, flattened insects with a dark body and prominent forceps-like cerci at the end of the abdomen. Earwigs are nocturnal and omnivorous, feeding on all sorts of dead plant and animal matter, as well as on small invertebrates making the ground fertile.

True bugs - Order Hemiptera

Hemiptera are also known as "true bugs". All true bugs have sucking mouthparts shaped into a long piercing beak, and feed on fluids - plant sap, body fluids of insects and other invertebrates, or even blood. Many true bugs are found in soil and litter, some of these bugs feed on roots by sucking sap increasing the fertility of soil.

Order Homoptera(Cicadas, aphids, mealybugs, scale insects)

Homoptera is a large and diverse group of insects closely related to true bugs. Homoptera vary greatly in shape and size, but all have tube-shaped sucking mouthparts and feed on plant sap. This group is well represented in soil and litter, where they suck the sap from plant roots. Similar to true bugs, the Homoptera plays an important role in making soil fertile.

The cicada nymphs live in the soil, often quite deep underground, sucking sap from roots. The nymphs remain in the soil for many years before their development is complete. For its last moult, the cicada nymph emerges from the soil and climbs onto some vertical object above the ground, holding onto the rough surface with its sharp claws. Moulting into an adult then occurs. The light-brown empty skins of cicada nymphs, still attached to the trees and fences, are a common sight in spring.

The mealy bugs get their name from the white waxy or powdery secretions that cover their bodies. Mealy bugs live in colonies, and are sometimes encountered in the soil and litter, where they feed on root sap.

Aphids are small, delicate soft-bodied insects with globular bodies and piercing, sucking mouthparts. They usually live in colonies and are familiar garden pests, feeding on the sap of many plants. Several species of aphids occur in the soil, where they suck the sap from plant roots.

Order Coleoptera (Beetles)

The order Coleoptera, or beetles, is the largest of all the insect orders, and the largest of all arthropod orders as well. The beetles vary greatly in shape and size, but all can be recognized by their thick, hardened wing covers (elytra).

Chafer beetles and dung beetles adults feed on plant leaves, flowers, fruit, and also on dung and dead animal matter (dung beetles are often found in pitfall traps). The larvae of chafer beetles can be often found in the soil, where they feed mainly on plant roots. The larvae of the grass grub live in the soil and feed on grass roots, causing serious damage to pastures.

The elongate click beetles can be recognised by their peculiar ability to "click": if the click beetle is placed on its back, it will jump and turn itself right side up by using a snapping junction between prothorax and mesothorax, with a clicking sound. The adult click beetles are often found on dead logs. The larvae of click beetles are shiny, hard-bodied "wireworms". The larvae live in soil and in dead logs on the ground, where they feed on plant material or on other insects.

Longhorn beetles are elongate, with narrow bodies and very long antennae. The adult beetles are often found on flowers where they feed on nectar; in other species adults do not feed at all. The larvae live in dead wood. These beetles are not soil animals strictly speaking, but may be found there occasionally.

Tiger beetles are iridescent, very active beetles 1.5-2 cm in length, often found on the bare ground in open sunny situations. These predatory beetles are active surface hunters. The predatory larvae are ambush hunters, and wait for their prey inside vertical burrows they construct in humid soil.

Ground beetles are the most common beetles found in soil litter. Many Carabidae are omnivores (feed on both plant and animal material), scavengers, and some are herbovores.

Weevils can be recognized by the shape of their head, which is drawn out to form a long snout. The small mandibles sit at the tip of the snout. These robust convex beetles are common in soil samples, and are often found on the ground.

Order Diptera(Flies, gnats, and daddy-long legs)

The Diptera are easy to recognise because they have only one pair of wings. The second pair is modified into tiny drumstick-like organs called halteres, which serve as flight stabilizers. The adult Diptera do not feed at all. The larvae of many species are common in soil and litter, where they feed on decaying organic matter, fungi, plant roots, or prey on other small animals.

The crane flies, or daddy-long legs (family Tipulidae) are typically large (there are small craneflies as well) mosquito-like gnats with very long legs, which they loose easily. The larvae of craneflies are large (1-2 cm), grey-brown maggots, which are common in damp soil litter and in dead wood. They feed on decomposing plant material.

Order Lepidoptera (Moths and butterflies)

Adult moths and butterflies are the familiar flying insects, but their larvae (caterpillars) and pupae are often found in soil or on the soil surface. The caterpillars have characteristic long cylindrical body with a well-developed head. In many families caterpillars feed on mosses, liverworts, plant roots, leaf litter, and detritus. In some species caterpillars live in burrows in the soil, but emerge at night to feed on plants aboveground.

Order Hymenoptera, Family Formicidae (Ants)

This is a common and widespread group, familiar to everyone. The colour of ants ranges from yellow, to reddish-brown, to black. Ants often build their colonies in soil, under rocks and decaying logs, and in dead wood. Ants may feed on various invertebrates, plants, nectar and sap, honeydew, and fungi. This all are helpful directly or indirectly in increasing richness.

10.9 Scavanger Insects

A scavenger is an animal that feeds on decaying organic matter and can be either carnivorous or herbivorous. Scavengers play an important role in every ecosystem, they consume the dead animal and plant material so that it does not just rot and spread diseases. When the life of one organism ends, the work of insect decomposers begins. These insects consume excrement or dead plants or animals, and in the process help to recycle nutrients, returning materials to the soil or atmosphere. Some insect decomposers are general omnivores that feed on a variety of decaying organic matter like cockroaches, for example while others feed on decaying and decomposing animals and plants or their by products, such as dung or animal droppings. These scavengers are extremely important to our environment, as their feeding causes the breakdown of complex materials into simpler compounds and nutrients that are returned to the soil and used by other plants - thus, insects are essential to the nutrient cycle. They are important for keeping ecological balance in nature. The food web would break down completely without scavengers.

The insect scavengers are involved in the processes of decomposition of animals and plants remains belong to different orders eg. springtails

(Collembola),wood-boring beetles (e.g., Scarabaeidae, Geotrupidae or Silphidae), Diptera larvae (e.g., Muscidae, Sarcophagidae, Scatophagidae or Calliphoridae),woodlice (Isopoda)and termites, etc. All these groups are responsible for the fragmentation of plant or animal remains, contributing to the destruction phase. They contribute both to the redistribution of the organic remains and formation of soil elements. These insect decomposers are present in nearly all terrestrial habitats, and generally in very high numbers. In some cases, millions of individuals belonging to hundreds of species have been identified in just one square meter. Especially in temperate areas, insects are the major decomposers, playing a very important role in degradation of waste.

Recyclers of plant remains

Insects play an important role in degradation processes of plant remains. Insects lacks the ability to develop enzymatic processes for degrading the fundamental components of any plant: lignin and cellulose. Degradation of cellulose requires the presence of the enzyme cellulase, which most insect lack. Many insects have solved this problem by means of mutualistic relations with micro-organisms, having bacteria or symbiotic protozoa in the intestinal tract.

The well-known insect decomposers of plant remains are termites (Isoptera) and cockroaches (Blattodea). The termites possess symbiotic bacteria and protozoa, and in their absence wood cannot be assimilated by these insects. Another important group in the degradation of plant remains is woodlice (Isopoda), which also possess symbiotic microorganisms in their intestine that allows them to degrade cellulose. Included in this group are some species of springtails such as *Tomocerus* (Collembola), *Ambrosia* beetles (Coleoptera: Scolitydae), ants of the genera *Atta* (Hymenoptera: Formicidae) and termites (Isoptera) that cultivate fungi.

Fruits are extensively exploited by some insects, such as flies (*Drosophila*) and wasps (Hymenoptera: Vespidae) to feed into the product resulting from the fermentation. Micro-organisms like bacteria, fungi and protozoa and plant are very closely related and therefore, in most cases it is expected that the insects consume both resources simultaneously. In some cases, the ingested biomass of micro-organisms is more important nutritionally than the ingested plant remains.

Recyclers of excrement and corpses

The process of decomposition of carrion and dung, is also important, these decaying matter causes attraction to insects, as they are very rich resources of organic components and have very special microclimatic conditions. Dung and carrion are rich sources of energy and a very specialized habitat that is exploited specifically by entomological fauna. This fauna obtains food either directly, such as in the case of the coprophages and carrion-eating insects.

Decomposers of corpses

Insect species attracted to corpses change according to the ecosystem and environmental conditions. The importance of necrophagous insects is not only the ingestion of carrion, but also in making the carrion available to microorganisms. Many insects, principally fly larvae, secret enzymes directly into the carrion, producing liquefaction of the tissues. Likewise, adult and larval beetles, and fly larvae, make tunnels through the carrion, increasing aeration and microbial activity. The dominant groups, both in number of individuals and diversity, are dipterous and coleopterous species. Also, in geographic areas where ants are abundant, the corpses are removed rapidly by these insects, specially the corpses of invertebrates. The number of insects living in carrion diminishes with depth of burial.

The insects colonizing corpses form a sequential succession of groups and species that depends on the size of the carrion, and on the climatic and edaphic conditions of the area where they live. Very few species are widespread throughout the world, and each geographical area and ecosystem has its specialist species feeding on carrion.

The colonization of a corpse is a sequence of insects arriving as successive waves at the carrion. The form, nature and timing of the succession depend on the geographic area, the surrounding non-biological environment, and the size of the carrion. The first waves involve blow flies (Diptera: Calliphoridae) and house flies (Diptera: Muscidae) arriving for a few hours to oviposit or drop live larvae. Later, there is a second wave of sarcophagid flies (Diptera: Sarcophagidae) that together with species of calliphorid and muscid flies, deposit their eggs or live larvae on the corpse. The larvae of these flies are, in turn, consumed by larvae and adults of predatory beetles living in corpses.

Staphylinids (Coleoptera: Staphylinidae), histerids (Coleoptera: Histeridae) and silphids (Coleoptera: Silphidae), all are predators of flies, though they also feed on carrion. When the viscera decompose and the fat of the corpse turns rancid, a third wave of insects starts, with some species of phorids (Diptera: Phoridae), drosophilids (Diptera: Drosophilidae) and hover fliesof the subfamily Eristalinae (Diptera: Syrphidae) arriving. The fourth wave consists of cheese skipper species (Diptera: Piophilidae) and related families of flies. Finally, a fifth wave occurs, the larvae and adults from some groups of beetles such as dermestids (Coleoptera: Dermestidae), trogids (Coleoptera: Scarabaeoidea: Trogidae) and clerids (Coleoptera: Cleridae) and tineid caterpillars (Lepidoptera: Tineidae) that eat keratin and feed on the remaining hair and feathers.

Diptera are among the most important decomposers, especially some of the Calliphoridae (e.g., *Lucilia*, *Calliphora*, *Chrysomyia*, etc.), followedby some Muscidae (e.g., *Fannia*), and Sarcophagidae (e.g., *Sarcophaga*).Though the adults feed on the fluids of the corpse, the larvae are the true decomposer organisms, secreting enzymes directly into the carrion and helping with the liquefaction of the corpse tissues while assisting the increase of microbial activity. These families of Diptera are more abundant from early summer to mid-autumn in temperate regions, and also in the rainy season in tropical areas.

Among Coleoptera, a principal group in many temperate ecosystems is Silphidae (e.g., *Nicrophorus*, *Silpha*). It is a group specifically adapted to living in carrion and its action is comparable to that of the Diptera.

Applications of Forensic entomology

Forensic entomology is an important instrument in criminal investigation; however, we must take into account that each succession will consist of different species in different geographical regions. Knowledge of the succession of species taking place in a corpse following death has been used in studies of forensic entomology. This rather consistent succession has been used for medical legal analyses to estimate the time elapsed since death of an animal. The study of insect species from a cadaver gives us information about the location, time, and conditions to which the corpse was exposed before being found. The generalized sequence of fly colonization is most frequently used.

The first colonizing species are the bigger flies belonging to the blow fly family (Calliphoridae) followed by sarcophagids (Sarcophagidae) and house flies (Muscidae). The adults of the lesser-sized families such as Psychodidae, Scatopsidae, Sciaridae, Phoridae, Sepsidae and Sphaeroceridae come to the corpse in the last phase of decomposition, after the corpse has been abandoned by the larvae of the first colonizing flies. Their larvae leave the corpse to pupate away from the larval site, normally in the ground or substrate below carrion. The development of larvae is temperature dependent, and knowledge of the larval cycle and its relationships at different temperatures, can be used to estimate of age a cadaver.

Decomposers of excrement

The excrement of vertebrates generally is a rich source of nutrients, and insects play an important role in the rapid recycling processes of feces. However, carnivorous excrement contains little material useable by insects because of their efficient digestive process. In contrast, the digestive system of herbivores is less efficient, and the dung produced is quite similar to the original leaf material. More than half the food consumed by herbivorous animals is returned to the ground in the form of unassimilated material, i.e., dung. Because it is abundant in organic matter and moist, herbivore dung is an ideal medium for establishment of a specific, rich entomofauna involved in the process of decomposition and elimination of feces. Quantitatively, large herbivore dung pats are the most important resource for dung beetles in most regions, and this fauna is especially abundant in historic grazing areas.

Excrement is a very special habitat for coprophagous species, and the spatial distribution of dung increases the tendency of these insects to concentrate in a limited space. The process of colonization of excrement typically consists of three waves of insects. The first wave of colonizers involves certain flies arriving within hours to lay eggs or larviposit on the dung before a crust is formed on the pat. The second wave is several families of beetles. Lastly, mites become abundant.

The main groups of flies are Muscidae and Scatophagidae, followed by Fanniidae and Calliphoridae. Most adults and larvae of flies are coprophagous, but feeding also on the micro-organisms present in the dung. Others are facultative or obligate predator species. Many species are attracted to any decaying matter, but others only feed and breed in dung. Throughout the world, muscid coprophages such as *Musca domestica*, *Musca vetustissima* and *Haematobia irritans* are pests of cattle. But somemuscids are facultative predators (*Muscina* spp.) and obligate predatory larvae (*Mydaeae* spp.). The best-known species of Scatophagidae is probably *Scatophaga stercoraria*, a species frequently found visiting dung.

Among beetles that use dung resources, the dung beetles belonging to the Scarabaeidae (Scarabaeinae, Geotrupinae and Aphodiinae) are the most important and numerous. Not all scarab larvae are strictly coprophagous, and some ingest soil organic matter or feed on roots of plants. However, many are coprophages, and often exceedingly abundant. Thousands of individuals from many species may be found colonizing single dung pats in temperate and tropical grazing ecosystems. Most Aphodiinae are saprophagous and within the Geotrupinae coprophagy is the rule for the Geotrupini. Only Scarabaeinae has coprophagy as a characteristic of most of its species. In this case, most of the nutrients eaten by the adults are derived from eating microbes or colloids suspended in dung. The larvae feed on the dung supplied by their parents in a nest chamber.

Various other groups of beetles visit dung but they are primarily predators. Coleoptera of the families Hydrophilidae, Staphylinidae and Histeridae are associated with carrion as predators of larvae of flies and dung-beetles. However, the two former families also include coprophagous species. In the temperate region, the hydrophilids *Cercyon* and *Sphaeridium* (Coleoptera Hydrophilidae) are coprophagous, arriving within the early hours after deposition of dung.

The behavior of dung beetles (Coleoptera: Scarabaeidae) is specialized and diversified in response to exploitation of excrement by adults and larvae. The Scarabaeidae consist of approximately 7,000 species (5,000 Scarabaeinae, 1,900 Aphodiinae and 150 Geotrupinae). Many species of Scarabaeinae and Geotrupinae have developed special feeding and breeding strategies that allow them to remove dung rapidly the soil surfaces by digging burrows below the dung pad to store fragments of dung in tunnels. The also may form dung into balls and roll them away from the pad for burial far from the food source. The importance of these habits is the protection of food for adult or larvae, avoiding competitors, predators and unfavourable climatic conditions. Only Aphodiidae do not make a nest. Aphodiidae eat directly into the dung and many species deposit theirs eggs directly in dung pads without nest chamber or in the surrounding soil. Geotrupinae and many tribes of Scarabaeinae are tunnelers. These species dig a tunnel below the dung pat and accumulate dung in the bottom of the burrow; this food can be used either for adult or for larval feeding. Finally, some species of Scarabaeinae are rollers, making a ball of dung that is rolled away from the pat for a variable distance before burying.

Other groups of dung beetles make nests containing several or many brood masses such as those observed in some species of Dichotomini, Onitini, Onthophagini and Oniticellini. The brood masses are constructed in series, in the same tunnel or separated in individual side branches. In this type of nesting, bisexual cooperation may exist, but the role of the male is restricted to introducing food into the tunnel. These species have relatively high fecundity, and there is no maternal care.

10.10 Use of Insects and Insect Products in Medicines

Insects have been used medicinally in cultures around the world, often according to the Doctrine of Signatures. Thus, the femurs of grasshoppers, which were said to resemble the human liver, were used to treat liver ailments by the indigenous peoples of Mexico. The doctrine was applied in both Traditional Chinese Medicine and in Ayurveda. The Chinese Black Mountain Ant, *Polyrhachis Vicina*, is used as an anti-cancer agent. Ayurveda uses insects such as Termite for conditions such as ulcers, rheumatic diseases, anaemia, and pain. The Jatropha leaf miner's larvae are used boiled to induce lactation, reduce fever, and soothe the gastrointestinal tract. The indigenous peoples of Central America used a wide variety of insects medicinally. Mayans used Army ant soldiers as living sutures. The venom of the Red harvester ant was used to cure rheumatism, arthritis, and polimyelitis via the immunological reaction produced by its sting. Boiled *silkworm* pupae were taken to treat apoplexy, aphasy, bronchitis, pneumonia, convulsions, hemorrhages, and frequent urination.

The rise of antibiotic resistant infections has sparked pharmaceutical research for new resources, including into arthropods. Maggot therapy uses blowfly larvae to perform wound-cleaning debridement. They secrete allantoin, which is used to treat the infectious bone disease, Osteomyelitis.

Modern Scientific Use of Insects in Medicine

Although insects were widely used from long time for medical treatment on nearly every continent, relatively little medical entomological research has been conducted since the revolutionary advent of antibiotics. Heavy reliance on antibiotics, coupled with discomfort with insects in Western culture limited the field of insect pharmacology until the rise of antibiotic resistant infections sparked pharmaceutical research to explore new resources. Arthropods represent a rich and largely unexplored source of new medicinal compounds.

Maggot Therapy

Maggot Therapy is most commonly used in medical field, this is done with the help of the blow fly larvae. Firstly it was used by Military surgeons during World War II. Military surgeons noticed that wounds which were left untreated for several days and which became infested with maggots, healed better than wounds not infested with the blow fly larvae. It was later discovered that the larvae secreted a chemical called allantoin, which had a curative effect. Allantoin is now being used to treat the infectious bone disease, Osteomyelitis. Maggot Debridement therapy is the intentional introduction of live, disinfected fly larvae into non-healing or dead skin and soft tissue wounds of a human or other animal for the purpose of selectively cleaning out only the necrotic tissue within a wound in order to promote wound healing. It is also used to prevent infection and to speed the healing process.

Apitherapy

Apitherapy is the medical use of honeybee products such as honey, pollen, bee bread, propolis, royal jelly and bee venom. One of the major peptides in bee venom, called Melittin, has the potential to treat inflammation in sufferers of Rheumatoid arthritis and Multiple sclerosis. Melittin blocks the expression of inflammatory genes, thus reducing swelling and pain. It is administered by direct insect sting, or intramuscular injections. Bee products demonstrate a wide array of antimicrobial factors and in laboratory studies and have been shown to kill antibiotic resistant bacteria, pancreatic cancer cells, and many other infectious microbes.

Honey bee products are used medicinally in apitherapy across Asia, Europe, Africa, Australia, and the Americas. The most frequently use is honey. It can be applied to skin to treat excessive scar tissue, rashes, and burns, and as an eye dressing to treat infection. Honey is taken for digestive problems and as a general health restorative. It is taken hot to treat head colds, cough, throat infections, laryngitis, tuberculosis, and lung diseases. Apitoxin (honey bee venom) is applied via direct stings to relieve arthritis, rheumatism, polyneuritis, and asthma. Propolis, a resinous, waxy mixture collected by honeybees and used as a hive insulator and sealant, is often consumed by menopausal women because of its high hormone content, and it is said to have antibiotic, anaesthetic, and anti-inflammatory properties. Royal jelly is used to treat anaemia, gastrointestinal ulcers, arteriosclerosis, hypo- and hypertension, and inhibition of sexual libido. Finally Bee bread, or bee pollen, is eaten as a generally health restorative, and is said to help treat both internal and external infections. One of the major peptides in bee venom, Melittin, has the potential to treat inflammation in sufferers of Rheumatoid arthritis and Multiple sclerosis.

Blister Beetle (*Lytta vesicatoria)* or Spanish fly

It is an emerald-green beetle in the family Meloidae of order coleopteran. Cantharidin is an odourless, colourless terpene secreted by many species of blister beetles. Cantharidin, the blister-causing oil found in several families of beetles, was accepted by the FDA in 2004 as treatment for warts and other skin problems. Historically used by the Greeks and Romans and is used as an aphrodisiac in some societies. Recent studies in cell culture and animal models have demonstrated powerful tumor fighting properties of Cantharidin. Commonly called as Spanish fly, is used in treatment for warts and other skin problems. It was in Ancient Greece and Rome, and has been used as an aphrodisiac in some societies. Recent studies in cell culture and animal models have demonstrated its powerful tumour-fighting properties.

Blood-Feeding Insects

Many blood-feeding insects like horseflies, and mosquitoes inject multiple bioactive compounds into their prey. These insects have been used by practitioners of Eastern Medicine for hundreds of years to prevent blood clot formation or thrombosis. Different components of the saliva of blood feeding insects are capable of increasing the ease of blood feeding by preventing coagulation of platelets around the wound and provide protection against the host's immune response. The diverse range of compounds in the saliva of blood feeding organisms, includes inhibitors of platelet aggregation, ADP, arachidonic acid, thrombin, and PAF, anticoagulants, vasodilators, vasoconstrictors, antihistamines, sodium channel blockers, complement inhibitors, pore formers, inhibitors of angiogenesis, anaesthetics, AMPs and microbial pattern recognition molecules, and parasite enhancers/activators. Despite the strong potential of these compounds for use as anticoagulants or immunomodulating drugs no modern medicines, developed from the saliva of blood-sucking insects, are currently on the market.

Silkworm Supplements

Silkworm extracts are the traditional Asian equivalents of Tylenol, the universal pain reliever and all-purpose remedy of first resort. Asian healers use silkworm extracts to treat everything from turgidity to seizure disorders, and they often mix silkworm extracts with ginseng, Ma Huang, and saw palmetto to promote male potency. Emerging science suggests that silkworm extracts may have special benefits as dietary supplements for patients with heart disease and circulatory disorders, because preliminary studies indicate they reduce serum cholesterol and dissolve vascular plaque. A few optimistic pharmacists speculate that silkworm extracts may prove effective as the most popular anti-cholesterol medications without harmful side effects for users' livers and kidneys.

Grasshoppers Potential

For more than 50 years, grasshoppers have numbered among bio-medical researchers' very best friends. By some strange, unaccountable evolutionary quirk, grasshoppers' central nervous systems very closely resemble humans' so that, before human trials, researchers test many psycho-active drugs on the hoppy green creatures, looking for cardio-pulmonary and behavioural side effects. Just as importantly, grasshoppers have ranked first on cytologists' lists because their relatively simple DNA and their processes of cell reproduction show extremely well under classroom microscopes. Methods for isolating and tracking grasshoppers' meiosis have been sophisticated for use with cancer cells, and many scientists believe these processes will reveal how carcinogens trigger human cell mutation.

Several African cultures use dressings made from ground grasshoppers as pain relievers, especially for migraines. Neurologists hypothesize that grasshopper toxins stimulate the human central nervous system and subsequently dilate blood vessels increasing circulation. Used for blood vessel constriction triggers migraines, grasshoppers' therapeutic benefits seem perfectly logical.

Usefulness of insects in scientific investigations

(For this refer to Unit -11)

10.11 Insects as Food (Entomophagy)

Entomophagy is the human consumption of insects as food. The eggs, larvae, pupae, and adults of certain insect species have been eaten by humans from prehistoric times to the present day. Insects as food and feed emerge as an especially relevant issue in the twenty-first century due to the rising cost of animal protein, food and feed insecurity, environmental pressures, population growth and increasing demand for protein among the middle classes. Thus, alternative solutions to conventional livestock and feed sources urgently need to be found. The consumption of insects therefore contributes positively to the environment and to health and livelihoods.

Entomophagy is heavily influenced by cultural and religious practices, and human insect-eating is common to cultures in most parts of the world, including North, Central, and South America; and Africa, Asia, Australia, and New Zealand. Over 1,000 species of insects are known to be eaten in 80% of the world's nations. The total number of ethnic groups recorded to practice entomophagy is around 3,000. Today insect eating is rare in the developed world, but insects remain a popular food in many developing regions of Latin America, Africa, Asia, and Oceania. There are some companies that are trying to introduce insects into Western diets. FAO has registered some 1900 edible insect species and estimates there were in 2005 some 2 billion insect consumers world-wide. They also suggest entomophagy should be considered as a solution to environmental pollution. Entomophagy is a potential alternative protein source to animal livestock, citing possible benefits including greater efficiency, lower resource use, increased food security, and environmental and economic sustainability.

Insects are a highly nutritious and healthy food source with high fat, protein, vitamin, fibre and mineral content. The nutritional value of edible insects is highly variable because of the wide range of edible insect species. Even within the same group of species, nutritional value may differ depending on the metamorphic stage of the insect, the habitat in which it lives, and its diet. For example, the composition of unsaturated omega-3 and six fatty acids in mealworms is comparable with that in fish even higher than in cattle and pigs), and the protein, vitamin and mineral content of mealworms is similar to that in fish and meat.

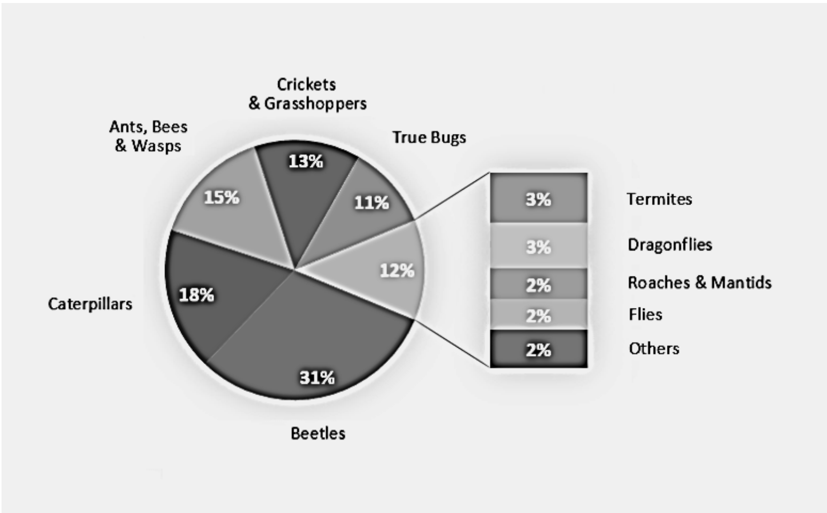


Figure - Entomophagous Insects orders worldwide statistics

Globally, the most commonly consumed insects are beetles (Coleoptera) (31 percent), caterpillars (Lepidoptera) (18 percent) and bees, wasps and ants (Hymenoptera) (15 percent). Following these are grasshoppers, locustsand crickets (Orthoptera) (13 percent), cicadas, leafhoppers, plant hoppers, scale insects and true bugs (Hemiptera) (11 percent), termites (Isoptera) (3 percent), dragonflies (Odonata)(3 percent), flies (Diptera) (2 percent) and other orders (4 percent).

Some of the edible insects are as follows-

1. ***Agave Weevils***

   Ii is also known as an Agave Worm, the Agave Snout Weevil (*Scyphophorus acupunctatus*) is a type of beetle, but is often confused with caterpillars of a butterfly (*Aegiale hesperiaris*) and a moth (*Hypopta agavis*). All species feed on agave plants and are eaten fried and are even sold canned in many places of the world.

2. ***Ants***

   Ants are eaten all over the world, from honeypot ants (*Camponotus inflatus*) in Australia to green tree ants (*Oecophylla smaragdina*) in China, India and Thailand, carpenter ants (*Camponotus* spp.) in Indonesia and the Philippines, and weaver ants (*Oecophylla longinoda*) in the Congo. Leafcutter ants (*Atta* spp.) in Colombia and Brazil taste like a bacon-pistachio fusion and the lemon ants (*Myrmelachista schumanni*) of the Amazon are named after their citrus taste.

3. ***Aphids***

   Aphids (*Aphididae*) are more of a source of liquid than food since all they really eat is plant sap, sucked up directly from the plant's phloem with their syphons. They leave behind a sugary honeydew which is exploited by people in Mexico and the Middle East, clearly taking after ants, some of which are famous for herding and protecting their collections of aphids. Aphid honeydew can taste either bitter or sweet depending on the plants on which they feed.

4. ***Bagworms***

   Bagworms are pretty strange creatures. They are actually caterpillars of the bagworm moth (*Psychidae*gen.) and they build protective casings around themselves from twigs and leaves. Their larvae are eaten in Mexico and Equatorial Africa, and their pupae, called *fangalabola* in Madagascar, are eaten as a delicious food.

5. ***Bamboo Worms***

   Bamboo worms, or bamboo borers, are grass moth larvae (*Omphisa fuscidentalis*) that feed on bamboo pulp in Thailand, Myanmar, Laos and parts of China. It's called *rot duan*, or *express train,* in Thai due to its shape and can be found at almost every street food vendor in the country. It's sometimes confused with larvae of the wood-boring beetle (*Dinoderus minutus*), another bamboo pest, but these are not as popular as food.

6. Bees

Honey bee drones (*Apis* spp.) are eaten in China and are also used as traditional medicine, but by far the most popular way to eat them throughout the world is in their larval form. Bee larvae, either from honey bees, bumblebees (*Bombus* spp.), carpenter bees (*Xylocopa*spp.) or stingless bees (*Trigona* spp.), are eaten in many countries throughout Asia, central and southern Africa, South America, and the West Indies.

7. Cactus Weevils

Eaten as both larvae and adults in Ecuador, Mexico and Venezuela, cactus weevils (*Metamasius* spp.) are from the same family as agave weevils and feed on cacti throughout their life cycle.

8. Christmas Beetles

Commonly eaten by the Aboriginal people of Australia, Christmas beetle (*Anoplognathus viridiaeneus*) larvae.

9. Cicadas

One of the few insects eaten in the US, cicadas (*Magicicada* spp.) are said to be most tender and tasty just after they molt. They are pretty nutty so folks from Nashville have them as sweet treats cooked with buttermilk. They are also eaten in China, Japan, Thailand, Malaysia, Mexico and India.

10. Cochineals

Cochineals are scale bugs from the Superfamily Coccoidea that suck the sap from prickly pear cacti. Although variants are eaten in China and the Canary Islands, Cochineals are more famous for being the source of red carmine dye. This dye has supposedly been used in the Americas since the 10th century and used in a lots of foods products, from jams and cakes to sausages and marinades.

11. Cockroaches

These may be the epitome of filth as far as the Western mind is concerned, but when they are fed only on salad and fruit, they can actually taste pretty good and are quite healthy. They are consumed by Australian, Chinese, Indian, Thai, Malay, Mexican or Brazilian entomophagists.

12. Crickets

Crickets are eaten throughout the world in too many countries. They are probably the most commonly used edible insect. They can be fried, boiled, and when roasted, taste like roast nuts.

13. Diving Beetles

Diving beetles (Dytiscidae) are eaten throughout East and Southeast Asia. In China, they are thought to have an anti-diuretic effect and are eaten not out of nutritional necessity.

14. Dragonflies & Damselflies

Dragonflies and their close relatives, damselflies, make up the Order Odonata and are eaten throughout the world, from Central Africa and South America to Asia and Papua New Guinea. They are eaten either in adult or larval form.

15. Emperor Moths

Emperor moth caterpillars (Saturniidae) are actually quite a common edible insect in food throughout the African continent. They have a number of genera and can be found in most African markets. They are also eaten in Mexico.

16. Flies

Rich in fatty acids to the same extent as in some fish oils, pupae of the common house fly (*Musca* spp.) are said to taste like black pudding. Another fly of interest is the black soldier fly (*Hermetia illucens*). Fly larvae is used as processed organic food waste for livestock feed, insect oils and fertilisers.

17. Giant Water Bugs

Giant Water Bugs are eaten in Mexico, Venezuela, China, Japan, Congo, Thailand, are probably most famous with tourists there as they are among the most fearsome looking of street food options. Some say they are like clam-flavoured potatoes and others like a salty, fruity taste. Thai locals like them best pregnant and full of creamy eggs.

18. Grasshoppers

Like crickets, grasshoppers are eaten almost everywhere on the map. Not all grasshoppers are edible since there are thousands of species, but perhaps the most thoroughly exploited are *Sphenarium* spp. They are most often toasted on a clay stove with lime, garlic, salt and agave worm extract to add in more complex flavours.

19. Hornets

Essentially wasps on steroids, hornets are from the same family (Vespidae) as their smaller counterparts. They are eaten in either larval or pupal form in China, Japan, and across Southeast Asia.

20. Hornworms

Hornworms are the larvae of hummingbird moths and are a prominent pest species for the commercial plants they eat. The tobacco hornworm (*Manduca sexta*) is found throughout North America, is eaten due to its ability to bioaccumulate and secrete nicotine in body.

21. Jewel Beetles

The Buprestidae family, or the jewel beetles, are a massive group of around 15,000 species. Their larvae bore through wood, and some even through living trees, making them a serious pest problem. They are eaten throughout Africa, Southeast Asia and China, either as larvae or as adult beetles.

22. June Beetles

June beetles (*Phyllophaga* spp.) were traditionally roasted over coals by Native Americans, either as adults or larvae, and are said to taste like buttery walnuts.

23. Katydids

Katydids are better known as *bush crickets* (Tettigoniidae), but are actually closer relatives of grasshoppers than crickets. Much like these other hopping relatives of theirs, they are eaten pretty much everywhere they're found throughout Africa, South America, East and Southeast Asia, India and Papua New Guinea. They taste like somewhere between chicken, shrimp and croutons.

24. Locusts

This insect is eaten almost everywhere on our map, locusts, along with grasshoppers, crickets and katydids. They are said to taste somewhere between shrimp and sunflower seeds, and are especially delicious when fed on sesame leaves.

25. Longhorn Beetles

A large family of beetles with over 20,000 species, longhorn beetles (Cerambycidae) are named after their antennae, which are sometimes longer than their bodies. One of the most popular edible insect families, longhorns are eaten in almost as many of the same countries that katydids are.

26. Mayflies

Much like dragonflies and damselflies, adult mayflies have short lifespans, even shorter in fact than the former two groups; the Order Ephemeroptera to which they belong is from the Greek for short-lived. Collected during their day-long swarms as mating adults, they are eaten in Kenya, Malawi, China and Japan.

27. Mealworms

Mealworms are probably one of the first edible insects people ever try, mainly because they are super easy to raise, they have a great nutrition profile, and they taste really good. They're not actually worms at all, but are larvae of the darkling beetle (*Tenebrio* spp.), a small, black, non-biting, flightless beetle about a centimetre long that doesn't mind crowded spaces and loves the dark perfect for farming.

28. Midges & Mosquitos

Both from the fly Order Diptera, midges (Chaoboridae) and mosquitos (Culicidae) are the insects most people would probably describe as the biggest nuisance. East Africans harvest midges by the net-full as they swarm over their many lakes, and Mexicans serve up mosquito eggs in tortillas with lime.

29. Mopane Worms

It is a caterpillar of a particular species of emperor moth (*Gonimbrasia belina*). They have huge popularity throughout Southern Africa.

30. Palm Weevils

Packed with nutrition and essential fats, palm weevil larvae (*Rhynchophorus*spp.) are a staple insect throughout the world. They are eaten in China, Central and Western Africa, Southeast Asia, South America and Papua New Guinea.

31. Rhinoceros Beetles

The larvae of this beetle are more palatable than the hard exoskeletons of the adults so this is what's most commonly eaten. Widespread throughout the world and extremely nutritious, they are being touted as a significant protein source for impoverished regions in the future.

32. Silkworms

Silkworms come from a range of families, but are all from the butterfly and moth Order Lepidoptera. Most commonly eaten in pupal form, they are a by-product of the silk industry and can be found in street markets in any silk-producing country. In South Korea, China and Japan, the *Bombyx mori* species is eaten and tastes a bit bland, much like tofu, but many people eat them marinated in chili and garlic sauce.

33. Stag Beetles

Stag beetles (Lucanidae) get their name from mandibles that the males use for fighting other males around mating time. They are the largest terrestrial insect in Europe. They are, however, common food in

Mexico, Ecuador, India, Malaysia, Japan, Papua New Guinea and Madagascar.

34. Stick Insects

The members of the Phasmatodea family are *true bugs*. They are not a popular edible insect and they are only eaten to a significant extent in Malaysia and Papua New Guinea, probably because they are said to taste a bit like tree.

35. Stink Bugs

Stink bugs are a large group of insects and are eaten throughout Southeast Asia, India, South America and Southern Africa. Their flavour varies from bitter to slightly sweet and tangy, and they are often eaten raw.

36. Termites

Termites are rich in protein and full of essential amino acids.They are eaten throughout the African continent and Southeast Asia. They are harvested straight from the ground or collected when they get their wings and swarm to find mates. Their taste depends on the species some are nutty and others taste of mint.

37. Wasps

Wasps are most commonly eaten in China, Thailand, Myanmar, Indonesia, Australia and the Congo, more often than not in their larval form. They are said to taste earthy and buttery, they are cooked with sugar and soya sauce, served with boiled rice.

38. Water Boatmen

These look like beetles, but are *true bugs*, eaten mostly in Mexico. Water boatmen (Corixidae), as their name suggests, are aquatic insects that live in ponds and slow streams. Most are vegetarian, which is quite unusual for aquatic bugs.

39. Water Scorpions

Water scorpions (Nepidae) are not the true scorpions but are *true bugs.* They are ferocious ambush predators that will eat anything from insect larvae to tadpoles. They are common food eaten in Laos, Thailand, Indonesia, Japan, Madagascar and the Congo.

40. Waxworms

Waxworms (Pyralidae) are caterpillars of the wax moth, sometimes called *bee moths* because they live in beehives and eat pretty much everything in there, other than the adult bees. They're the common food in China, Japan, Mexico and Brazil.

Disadvantages

Spoilage

Spore forming bacteria are a potential spoilage and safety risk for both raw and cooked insect protein. During processing of edible insects, they must be processed with care, simple methods are available to prevent spoilage. Boiling before refrigeration is recommended, with drying, acidification, or use in fermented foods also seeming promising.

Toxicity

In general, many insects are herbivorous and less problematic than omnivores. Cooking is advisable before consumption since parasites of concern may be present. Pesticides use can make insects unsuitable for human consumption. Herbicides can accumulate in insects through bioaccumulation. The moths of the Zygaenidae family are known to produce hydrogen cyanide precursors in both larvae and adults. Cases of lead poisoning after consumption and adverse allergic reactions are also a possible hazard

10.12 Summary

Lac is Nature's gift to mankind and the only known commercial resin of animal origin. It is the hardened resin secreted by tiny lac insects belonging to a bug family. The lac insects yields resin, lac dye and lac wax. Lac resin, dye etc. still find extensive use in Ayurveda and Siddha systems of medicine. Lac culture is a source of livelihood of tribal and poor inhabiting forest and sub-forest areas. With increasing universal environment awareness, the importance of lac has assumed special relevance in the present age, being an eco-friendly, biodegradable and self-sustaining natural material. Since lac insects are cultured on host trees which are growing primarily in wasteland areas,

promotion of lac and its culture can help in eco-system development as well as reasonably high economic returns.

Apiculture is the rearing of the honeybees. Bees and beekeepers are found throughout the world. Honey industry involves honeybee, flowering plants that provide food to the bees and to the beekeepers who manipulate bees according to the climate and vegetation for their own benefit. Beekeeping creates employment, income and a measure of economic security and well-being. Bees have been reared by man originally for harvesting honey. Today, apiculture industry is not restricted to honey alone. It also involves production and harvest of all hive products, like beeswax, bee collected pollen, royal jelly, bee venom and propolis. Honeybees are also involved in pollination to increase the yield of agricultural and horticultural crops.

Silk is Nature's gift to mankind and has been under use by human beings for various purposes since ancient times. Silk is one of the finest and most beautiful natural fibres of the world. Being an eco-friendly, biodegradable and self-sustaining material; silk has assumed special relevance in present age. Promotion of sericulture can help in ecosystem development as well as high economic returns. Different rearing techniques are applied in different parts of the world for large scale production of silk threads of fine quality. This is known as sericulture.

A pollinator is the biotic agent that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization or 'syngamy' of the female gametes in the ovule of the flower by the male gametes from the pollen grain. Animals that assist plants in their reproduction as pollinators include many insect species like honey bees, solitary species, bumblebees, pollen wasps, ants, a variety of flies including bee flies and hoverflies; lepidopterans, both butterflies and moths; and flower beetles as well as other animals like bats, monkeys, lemurs, possums, rodents, reptiles like lizards and snakes, birds like hummingbirds, honeyeaters, sunbirds etc. with long beaks pollinate various plants. Wind and water also play a role in the pollination of many plants.

Insects are one of the better groups of invertebrates, in improving soil fertility. The degree of association of insects with the soil is very varied, from living permanently in the soil and completing their whole life-cycle there, to using soil as a temporary refuge. Many insects play a fundamental role in forming soil and maintaining its fertility by digging tunnels in the earth, they aerate and loosen the soil, promoting plant growth. Without scavenger-decomposer insects, the soil would be strewn with waste, corpses and faecal matter, leading to the growth of potentially dangerous bacteria. Decomposers are masters of recycling.

Forensic entomology is an important instrument in criminal investigation; however, we must take into account that each succession will consist of different species in different geographical regions. Knowledge of the succession of species taking place in a corpse following death has been used in studies of forensic entomology. This rather consistent succession has been used for medical legal analyses to estimate the time elapsed since death of an animal.

The insect scavengers are involved in the processes of decomposition of animals and plants remains belong to different orders examples- Springtails, wood-boring beetles, Diptera larvae, woodlice and termites, etc.

Insects have been used medicinally in cultures around the world. Insects were widely used from long time for medical treatment on nearly every continent, relatively little medical entomological research has been conducted. The Chinese Black Mountain Ant, *Polyrhachis Vicina*, is used as an anti-cancer agent. Ayurveda uses insects such as Termite for conditions such as ulcers, rheumatic diseases, anaemia, and pain. The Jatropha leaf miner's larvae are used boiled to induce lactation, reduce fever, and soothe the gastrointestinal tract.

Entomophagy is the human consumption of insects as food. The eggs, larvae, pupae, and adults of certain insect species have been eaten by humans from prehistoric times to the present day. Insects as food and feed emerge as an especially relevant issue in the twenty-first century due to the rising cost of animal protein, food and feed insecurity, environmental pressures, population growth and increasing demand for protein among the middle classes. Thus, alternative solutions to conventional livestock and feed sources urgently need to be found. The consumption of insects therefore contributes positively to the environment and to health and livelihoods.

10.13 Self Assessment Questions

1. Describe some beneficial insects.
2. Describe the Biology, host trees of Lac Insect.
3. What do you mean by enemies of lac insect?
4. Explain the Lac culture management in details.
5. Describe the different *Apis* species found in India.
6. Write an essay on Social organization of bees.
7. Write a short note on different fields of forensic entomology.
8. Describe the different steps of beekeeping.
9. Explain the different bee enemies with their control methods.
10. Discuss the economic importance of apiculture.
11. Write an essay on Sericulture and its management.
12. Explain the lifecycle of *Bombyx mori.*
13. Compare the different characteristic features of Muga, Eri and Tassar Silkworms.
14. Write a short note on role of sericulture in Indian Economy.
15. Write a short note on the different enemies and diseases of silkworms.
16. Briefly describe the different characteristic features of *Megachile* spp.
17. What do you mean by Bee pasturage?
18. Describe the structure of artificial bee hive with a well labelled diagram.
19. Describe the importance of pollinator insects.
20. Write an essay on medicinal importance of insects.
21. What do you mean by entomophagy? Describe in details with examples

10.14 References

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Unit – 11

Pests of Forestry and Forensic Entomology

Structure of the Unit:

11.1 Objectives

By the end of the chapter, the student would acquaint himself with-Pests Of Forestry- Bionomics, main host plants,Insect Biology,Life Cycle,Nature Of Damage, Control of *Sinoxylon, Dinoderus, Hoplocerambyx spinicornis*.

The history, fields and applications of forensic entomology, methods employed in the estimation of Post-Mortem Interval (PMI), the biology, identification, collection and preservation of insects that are of use in this branch of science.

11.2 Introduction

11.2.1 Pests of Forestry

Forests and biodiversity is key to all life forms. The richer the diversity of life, the greater the opportunity for medical discoveries, economic development and adaptive responses to such new challenges as climate change. India is quite rich in forest wealth. About one-fifth of its land is under forests. India's forests cover about 23% of total geographical area of the country. Our forests are mostly in the hilly area or over the plateau.

Forests play a vital role in the economy of the country. Forests are precious & valuable ecosystems that provide a variety of useful products, such as timber, fuelwood, fibre and non-wood forest products, and contribute to the livelihoods of rural communities. They also provide vital ecosystem services, such as combating desertification, protecting watersheds, maintaining biodiversity, and enhancing carbon sequestration, and play an important role in preserving social and cultural values. It is critically important to protect these valuable resources from disturbances such as fire, pollution, invasive species, insects and diseases.

Insects plays an essential ecological role in forests by consuming trees and other plant material, forest insects and micro-organisms contribute to healthy change and regeneration in forest ecosystems. They help renew forests by removing old or otherwise susceptible trees by recycling nutrients and providing new habitat and food for wildlife. However, there are not always ecological benefits of forest insects but when there are severe infestations they destroy or damage large areas of commercially valuable forest, or infest forest products bound for export, then insects and diseases whether native or exotic insect species becomes "pests."

Insect pests, diseases and other biotic agents have significant impacts on forests and the forest sector. They can badly affect tree growth, vigour and survival, the yield and quality of wood and non-wood products, wildlife habitat, recreation, aesthetics and cultural values. Damage caused by forest pests can directly and indirectly reduce wildlife habitat thereby reducing local biodiversity and species richness.

There is need for forests management so that the risks and impacts of unwanted disturbances are minimized. Under sustainable forest management, various measures are applied to protect forests from insect pests and diseases. Effective pest management requires reliable information on the pests themselves, their biology, ecology, and distribution, their impacts on forest ecosystems and possible methods of control.

Pests of Forestry

Sinoxylon (Auger Beetles, Powder Post Beetle)

Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Superfamily: Bostrichoidea

Family: Bostrichidae

Subfamily: Bostrichinae

Tribe: Sinoxylini

Genus: ***Sinoxylon*** Duftschmid, 1825

Distribution

Auger beetles, also known as false powderpost beetles, are serious pests of trees, forest products, agricultural crops, and stored vegetable products in most regions of the world. There are approximately 570 species in 89 genera worldwide, including approximately 73 native species found in North America. Most woodboring bostrichids obtain nutrition from starch, enabling many species to utilize almost any dry wood material from an enormous host range. The frequency of non-native bostrichid interceptions at ports of entry and storage facilities around the world has increased during the last few years. Bostrichids, along with many other woodboring insects, are often accidentally introduced inside solid wood packing material in containerized cargo. The bostrichid genus *Sinoxylon* Duftschmid contains 52 species, all of which are native to Asia, Africa, and Southern Europe and are typically not considered primary pests. Widely distributed in the Oriental Region and introduced in India from Australia and New Zealand.

Sinoxylon damage is typically caused by the boring of adults and larvae in the stems, branches, or twigs of dead, damaged, or stressed hosts. One species has even been known to damage lead cables.

Main Host Plants

Sinoxylon species utilize a wide variety of hosts, including numerous trees, shrubs, herbaceous plants, and bamboos. Some of the host plants of *Sinoxylon* are *Acacia arabica, Acacia catechu, Acacia gageana, Acacia modesta, Acrocarpus fraxinifolius, Adina cordifolia, Albizzia amara, Albizzia lebbek, Albizzia odoratissima, Albizzia procera, Albizzia stipulate, Anogeissus acuminate, A. latifolia, Bamboo species, Buted frondosa, Caesalpinia sepiaria, Calycopteris floribunda, Cassia fistula, Cassia siamea, Castanea vesca, Castanopsis argyrophylla, Casuarian equisetifolia, Cedrela toona, Combretum ovalifolium, Cordia myxa, Dalbergia latifolia, Dalbergia sissoo, Dendrocalamus strictus; Derris elliptica, Dipterocarpus tuberculatus, Eucalyplus citriodora, Eugenia jambolana, Ficus glomerata, Ficus religiosa, Flugged microcarpa, Gmelina arborea, Grevillea robusta, Grewia tiliaefolia, Indigofera tinctoria, Lagerstroemia, lanceolata, Lannea grandis, Mallotus philipinensis, Mallotus roxburghianus, Mangifera indica, Melia azedarach, Millettia brandisiana, Morus indica, Ougeinia dalbergioides, Parashorea stellata, Pongamia glabra, Prosopis juliflora, Prosopis spicigera, Pterocarpus indicus, Pterocarpus marsupium, Quercus sp., Shorea robusta, Sterculia ornata, Tectona grandis, Terminalia arjuna, Terminalia belerica, Terminalia bialata, Terminalia tomentosa, Xylia dolabriformis, Zizyphus jujuba, Zizyphus rugosa, Zizyphus xylopyra etc*.

Insect Biology

The genus *Sinoxylon* is characterised by wide and very short mandibles, ends truncate and not capable of crossing each other, body length is approximately 3.5-8.5mm, Elytral apical declivity with a pair of juxtasutural processes situated on, next to or away from the suture, second antennal club segment strongly transverse and third antennal club segment always strongly transverse. There are approx 52 known valid species in this genus.

Sinoxylon anale

- Body length 3.5-6mm
- Marginal groove of each elytron either stopped near the outer turning point or sometimes joining the posterior margin of the apical declivity.
- Elytrons bases are with a sharp ridge between the shoulders and scutellum
- Sutural margins on apical declivity crenelate laterally below the juxtasutural processes
- Pronotum front armed with a transverse row of four teeth.

Life Cycle

The life-cycle varies with different *Sinoxylon* species. Life cycle can be minimum for about 3 months and the maximum over 4 years.

Sinoxylon anale

S. anale emerges as adult beetle throughout the year, and there is no regular sequence of generations and no regular correlation between the length of the life-cycle and the season of the year.

The adults bore tunnels into the sapwood and eggs are laid inside. A generation of *S. anale* may start with oviposition on any date in the year (except in cold) and the life-cycle of individuals hatching from eggs of the same date may be completed in as little as two and half months or may require over a year. On hatching, larvae excavate sapwood by making more or less straight, often intersecting lines, which are circular in section and tightly packed with fine wood dust. The larvae are white, curved with short legs and measuring upto 6mm. The larvae bore circular galleries in the sap-wood, the galleries being packed with fine wood-dust. Larvae pupate in a cell at the extreme end of the larval tunnel and beetles bore out directly to the surface. The life cycle get completed in 3-4 months. The population is more in August to October months. Life cycle varies between wide limits, minimum and maximum being about 3 months and over four years respectively. The beetles are on wing from March to October.

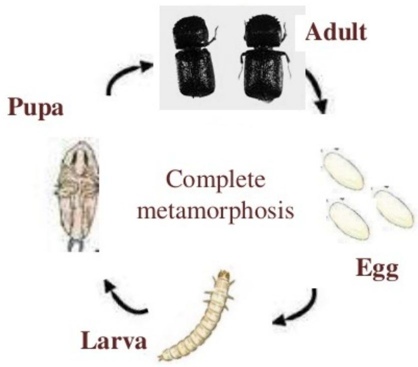


Figure – Generalized life-cycle of *Sinoxylon*

Nature of Damage

Sinoxylon anale specie is the commonest bostrychid in India and is found as frequently within the forest as in timber depots, sawmills and factories. Sinoxylon species are known to tunnel into freshly or recently felled wood or sickly or dying standing green trees, and rarely dry timber. Attacked trees and wood can be identified by the presence of circular shot holes measuring 2.5-3.0 mm, with wood powder at or near their entrances. Small white grubs or pupae can be found in the sapwood behind the bark. Severely affected logs look completely riddled and a network of tunnels can be seen in the interior. Sometimes complete death of a tree can happen due to attack. It is primarily a borer of the sapwood of logs particularly of Leguminosae but its range of food-plants is wide and varied. In timbers with well-defined line of separation between sapwood and heartwood the larval galleries do not penetrate the true heart; the sapwood may be entirely reduced to dust. It is recorded as injurious to the sapwood of timbers used in building construction and in boxes and packing cases of planks but not of plywood.

The adult beetles sometimes bore into green shoots and twigs for the purpose of feeding or hibernation making axial tunnel as a result the leaders of seedlings or young saplings may be girdled or killed. Beetles bore into the stems of sickly or dying poles with more or less success. Horizontal tunnels are made just within the circumference of the cambium layer and these fill with a black gum that exudes from the entrance-hole and runs down the bark.

The gallery-system of S. anale in a log starts with a short entrance tunnel bored radially through the bark in to the inner sapwood, and then turns and runs in the same plane in a curve parallel to the outer sapwood circumstance. It is used as an oviposition tunnel and is cleaned of all the wood-dust produced by the parent beetles during its excavation ; both male and female occupy it while the eggs are laid from time to time in niches in the walls and they remain long hatching is complete, guarding the tunnel against entry of predators and parasites. The larvae bore ever-widening larval galleries which run upwards and downwards in the sapwood for several inches, more or less straight but sometimes they are circular in cross-section and tightly packed with fine wood-dust. Pupation takes place at the extreme end of the larval tunnel in a cell and the beetle bores out by a direct route to the surface.

Control

Cultural Control

Field sanitation measures such as immediate removal of fresh cut wood from forests and plantations, and removal and burning of infested standing trees can minimize borer attack. Primary or epidemic attacks on relatively healthy trees may develop in the vicinity of an unhealthy crop if local infestation is allowed to continue unchecked. Standing sick trees may also be used as traps for egg laying and later can be destroyed.

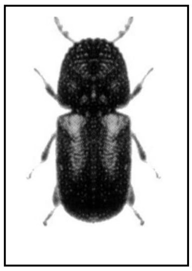
Physical Control

Seasoning to practically air dryness is a very effective way of minimizing or preventing borer incidence. Rapid drying to reduce the exposure time during seasoning by barking, storage in the sun in open rows and kiln seasoning will considerably reduce borer attack. Water seasoning or ponding in which there is submersion of woods in water for up to 10 days is also helpful. Immersion in water for 6-12 months can give protection for 6-32 months and subsequent infestation is also not severe. Logs which are already infested can be sterilized by immersion in cold or hot water.

Chemical Control

The synthetic pyrethroids Sherpa [cypermethrin] and Ripcord [cypermethrin] at 0.1, 0.2 and 0.5%, and Cyperkill [cypermethrin], Sunmerin and Bulldock [beta-cyfluthrin] at 0.5% proved the most effective against powder post beetles (*Sinoxylon anale* and *S. crassum*) attacking stacks of fuelwood. A single spray of Sherpa afforded 88, 92 and 95% protection at 0.1, 0.2 and 0.5% concentrations, while Ripcord protected 82, 90 and 95% billets at the same concentrations for the same period. Cyperkill, Sunmerin and Bulldock at 0.5% concentration gave 82, 95 and 91% protection of billets, respectively. Some 41% of billets remained safe from beetle infestation in the control.

Dinoderus (Bamboo Post-Powder Beetle)



Systematic Position

Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Superfamily: Bostrichoidea

Family: Bostrichidae

Genus: *Dinoderus minutus* (Fabricius, 1775)

Distribution

Dinoderus minutus, the bamboo borer or bamboo powderpost beetle, belongs to Bostrichidae family of Coleoptera. Dinoderinae, an important subfamily including many post-harvest insects, consists of 16 species in four genera. *D. minutus* was first named by Fabricius in 1775, according to records in the Bishop Museum, USA.

D. minutus has a worldwide distribution. It is native to Asia and has been reported in Israel, West Africa, South Africa, North America, Central America, South America, Germany and other European countries. It occurs in almost all the South Asia countries.

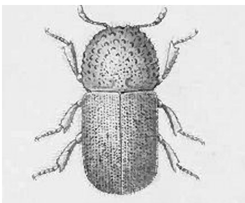
Main Host Plants

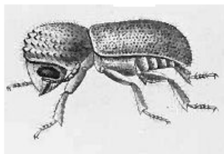
Dinoderus minutus is an important borer that attacks felled culms and bamboo timber products. It also damages rice, cassava and sugarcane. In China and most south Asian countries, the main host plants of *Dinoderus minutus* are *Bambusa bambos* (thorny bamboo), *Bambusa breviflora, Bambusa pervariabilis, Bambusa polymorpha, Bambusa textilis, Bambusa vulgaris* (common bamboo), *Dendrocalamus giganteus* (giant bamboo), *Dendrocalamus hamiltonii, Dendrocalamus strictus* (male bamboo), *Manihot esculenta* (cassava), *Oryza sativa* (rice), *Phyllostachys heteroclada*, *Phyllostachys heterocycla*, *Phyllostachys pubescens*, *Pinus* (pines), *Saccharum officinarum* (sugarcane)

Insect Biology

Life Cycle

Dinoderus minutus is polyvoltine. The life cycle is almost uniform irrespective of distribution. The adults and larvae can be found at any given time of the year and overwintering is not distinct, although they are less active in cold winters. The first peak of adult emergence is in February, the second is in June, and the third is in October.





Eggs

The females begin to deposit eggs individually, in tunnels mined by the adults in mid-April, and oviposition can last 4 months. The peak time for oviposition is in May and June. Temperature and humidity affect ovipositon. A female can lay approximately 20 eggs. The eggs are spindle-shaped or elongate-oval, very small, milky-white, and nearly transparent. The eggs are individually laid in tunnels made by the adults.

Larvae

The eggs hatch in 5 to 8 days. The larvae bore longitudinally in the culm, which can make a tunnel approximately 15 to 20 mm long and take about 40 days to develop. The larvae are approximately 3 to 4 mm long and milky-white. The body is 'C'-shaped. The head is round and the length is equal to the width. The mouthparts are black. The thorax is expanded and bears three legs, which decrease along its length. The spiracles are oval-round, which is longer than those in the sternum. Dense hair covers the tibia.

Pupae

Pupation occurs in cocoons made at the terminal end of the larval tunnels. The pupa is almost spindle-shaped, approximately 2.5 to 4 mm long, and milky-white. The compound eye and mandibles are black, and there is a pair of finger-like projections on the end of the sternum.

Adults

After approximately 4 days, the newly developed adult beetles may fly away or may explore other parts of the same bamboo. Some beetle holes are left on the bamboo and a great quantity of tunnels may be present at high densities of *D. minutus*. The adult is elongate-columnar, approximately 2.5 to 3 mm long and 0.9 to 1.5 mm wide, reddish or dark-brown and covered with dense puncta and hair, which is more obvious at the posterior of the wings. There are many tiny punctures on the head, which is small and black. The head is covered by the prothorax, so that it cannot be seen when viewed dorsally. The compound eyes are back and round. The antennae are ten-segmented and lamellate. The first segment is oval and twice as long as it is wide, the second is the same width as the first, and the three distal segments are swollen. The elytra are covered with dense and small punctures and bristles, which are more obvious at the posterior of the wings. The legs are reddish-brown. The tarsus consists of five segments; the first is no longer than the third or the fourth. The first abdominal segment is equal to the second in length.

Starch, soluble carbohydrates and proteins are nutritionally essential to *D. minutus*. The incidence of borer attacks has a strong correlation to the richness of nutrients in felled culms, and vary significantly with bamboo species, growing sites, timing and culm age at felling, and the method of transportation and storage.

D. minutus has a strong ability for starvation tolerance. The adults have a strong ability for pesticide resistance and have no phototactic reaction toward light

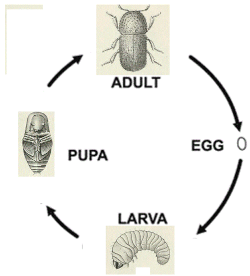


Figure – Generalized life-cycle of *Dinoderus*

Nature of Damage

Ghoon borers (*Dinoderus* spp.), found in most Asian countries, cause the most damage to felled culm and finished products. These are probably the most common and serious pests in the Asian bamboo industry. Damages usually result in the loss of large amounts of raw materials or in the destruction of finished bamboo products. Large quantities of culms are destroyed each year by these insect borers, in storage yards, stacks with immature culms are the starting points for attack and the bamboo is often converted to dust. Approximately 40% of a bamboo stack may be lost within a period of 8 to10 months due to ghoon borer attack.

The adult beetles burrow into felled culms through wounds, cracks and cut ends, and make horizontal tunnels along the fibrovascular tissues of the culms; the larvae make longitudinal tunnels. The damaged part of the culm becomes powdery, and the powder is sifted from the beetle hole. Large populations of borers will leave numerous tunnels in the culm, making it useless. Numerous beetle holes will be left on the surface of the culms.

D. minutus adults have a risk of dispersal because the larvae, pupae and adults may stay inside the tunnels of the bamboo culms, which by transport meanscan be dispersed to new areas which is long distance dispersal.

Control

There are several options for the control of *D. minutus*, such as phytosanitary methods, biological control, physical methods and chemical control. Selecting the best option depends on a number of factors, such as the severity of infestation, the location of infestation, potential for reinfestation, and cost of treatment.

Phytosanitary Measures

D. minutus is a phytosanitary pest in many countries because it can be easily transported between countries in the international trade of bamboo wood and products. Therefore in many open ports, *D. minutus* is a dangerous pest that should be treated seriously and warrants careful inspections. All imported wood, containers and products are treated by government pest control operators using fumigation and heating, for example, if some symptoms of defoliation are detected.

Biological Control

There are a few predators reported that can be used to control *D. minutus.* A clerid preys on the borer in boring tunnels, *Spathius bisignatus* [*Platyspathius dinoderi*] and *Spathius vulnificus* parasitize the eggs of *D. minutus*. *Tillus notatus* preys on the larvae, pupae and adults. These natural enemies cannot be relied upon as an effective control method, although they can cause high mortality of the borers.

Physical Control

After felling, the physical or chemical treatment of culms can significantly improve their resistance to borers as well as to fungi. The traditional and simplest method is to immerse felled culms in water. This method may only be effective in preventing damage from bostrychid beetles. It is also only suitable for those bamboos with a low starch content. This method takes a long time and culms treated in this way tend to blacken. The heating of culms using fire, boiling water or exposure to direct sunlight in hot summers, can kill borers of *D. minutus* including the eggs, larvae, pupae and adults. Some advanced microwave and infrared techniques have recently been developed for killing the borers in bamboo culms.

Chemical Control

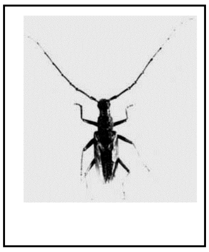
Chemical treatment using various insecticides and preservatives has been the most widely used method in controlling post-harvest pests of bamboos, including *D. minutus*. Various preservatives have been recommended: 5% water solution of copper-chrome-arsenic composition (CCA); 5-6% water solution of copper-potassium dichromate-borax (CCB); 5-6% water solution of boric acid-borax-sodium pentachlorophenate in 0.8:1:1 or 1:1:5 ratios (BBP); 2-3% water solution of borax: boric acid in a 5:1 ratio; and 10% or 20-25% water solution of copper sulphate. These are mostly applied by soaking under normal temperatures, cold or heated conditions, or under high pressure.

Soaking in an aqueous solution of 2% boric acid, 0.5% pentachlorophenate and 5% alcohol can treat bamboo rind and similar semi-finished products. Treating dried bamboo splits by immersing them in diesel oil as a simple and cheap method of bamboo preservation. The two low-toxicity organophosphorus insecticides prothiophos and phoxim, were more effective than organochlorine ones for the preservation of bamboo materials against fungi and boring pests. Treating culm splits by immersing them in 0.2% phoxim for 3 minutes can result in total mortality of *D. minutus* in the culm in 2 to 3 days, and can protect the treated split from attack for over 1 year.

Affected bamboo material can also be treated by fumigating in closed chambers or storehouses with sulphuryl fluoride at a rate of 30 to 50 g/m^3 of timber for 24 hours.

Hoplocerambyx Spinicornis (Sal Heartwood Borer, Longicorn Beetle)

Systematic Position



Phylum:	Arthropoda
Subphylum:	Hexapoda
Class:	Insecta
Order:	Coleoptera
Suborder:	Polyphaga
Superfamily:	Chrysomeloidea
Family:	Cerambycidae
Genus:	Hoplocerambyx
Species:	*Hoplocerambyx spinicornis*

Sal (*Shorea robusta*) is a dominant tree species in the Indian forests. Sal is a deciduous species and attains height up to 45 m. It is the main source building timber and also used as fuelwood and fodder. Sal covers over 11 million ha in

India, Nepal and Bangladesh. Sal forests regenerates very well but are heavily damaged by pests like sal borers, by excessive grazing and frequent forest fires.

Sal heartwood borer, *Hoplocerambyx spinicornis*, is one of the major devastating insect pest in Sal forest. Outbreak of this insect occur periodically in various parts of the India and may destroy thousand of trees. The trees of all sizes and ages are attacked in the epidemic caused by the longicorn beetle, though, the preference was for trees of 60-120 cm. girth class. The sap can attract insects from a distance of 2 km. These insects are always present in the Sal forest in low densities. The infestation of Sal borer is considered to be epidemic when the trees affected are more than 1.0 percent of the total growing stock of the trees.

Distribution

The range of *Hoplocerambyx spinicornis* is from the Philippines and Borneo to the extreme western and southern limits of forests of *Shorea robusta* in India. It does not extend into dipterocarp forests in south India. It appears to be absent from intensively worked sal forests in the Gangetic plain like Gorakhpur, United Provinces owing to the shortage of breeding-material.

Main Host Plants

The main host plants of *Hoplocerambyx spinicornis* are *Shorea assamica, S. obtuse, S. robusta, Duabanga sonneratioides, Hevea braziliensis, Parashorea robusta, Pentacme suavis etc.*

Insect Biology

Hoplocerambyx spinicornis beetles are active by daylight and particularly during the warmest part of the day, usually they avoid direct sunshine by sheltering in shady places, but when the sky is overcast and if a heavy rain is falling they readily take flight and may cover long distance in the open.

In forest the flight is low as well as slow and frequently interrupted by halts on trees or bushes accidentally encountered but the general direction is well controlled. They run actively over the bark of trees and often assemble in large numbers on a particular tree for mating. Ordinarily at sunset they retire to sheltered spots such as the undersurface of logs, crevices and flakes of bark, large leaves, etc., where they rest with the underside of the body pressed close to the surface of the shelter. But they are readily active after dark if stimulated, and have been attracted to trees late night.

Life Cycle

A heartwood borer, *Hoplocerambyx spinicornis*, often emerges soon after a few showers of monsoon rains from the third week of June to the end of August. They attract to the odour of freshly cut bast and sapwood of sal.

For mating there is a tough competition between males, leads to fights in which antennae and legs are bitten off. The bite of the large pointed mandibles is powerful and can draw blood from the human finger. In captivity large males have been observed to monopolise several females driving off smaller males in much the same way as a stag or boar does. When courting a female the male sometimes halts and raises his body to the full extent of his legs and stridulates by vibrating the inner posterior edge of the pronotum against the scutellum. Both male and female sexes can stridulate when alarmed or defensive. Sexes of very unequal size may pair successfully. Pairing is frequently repeated and during the period a female is laying eggs, it usually alternates with the deposition of a few eggs.

Eggs

Male and female beetles pairs at once and soon after mating female start laying eggs on the bark of sal trees. Each female beetle lays about 400 eggs in cracks on the bark of the dead or dying trees 7-9 days after the emergence. The eggs are white-creamed color, about 4 mm long. The preferred site of oviposition are the underside of logs on the ground and the shady side of the trunk and branches of standing trees. The viability of eggs varies from 75 to 100 per cent depending on weather conditions. The egg laying is correlated with humidity. At 55% relative humidity, there is no oviposition. Oviposition is only above 55% r. h. In dry conditions, the eggs are killed due to desiccation and very high humidity invites attack of some fungal hyphae.

Larvae / Grubs

After 3-7 days of egg period, the hatching takes place. The freshly hatched grubs bore the bark and reach to the sapwood, where they form tunnels. The white grubs feed under the bark. They soon enter the sapwood and finally the heartwood by the end of November. The sapwood exudes a sap (resin) sometimes kills larvae. Weak and diseased trees and broken or fallen trees are more attacked. The larvae feeds on sapwood throughout their life. The full grown grub is about 7.5 cm in length. It excretes a lot of wood dust that accumulates into heap near the base of the tree. It ultimately leads the tree to girdle and dry up. One can tell the progress of attack by examining the dust thrown out of holes in the bark, which falls to the ground at the base of the tree and accumulates in a heap often 2 or 3 feet deep. If there is a good deal of heartwood dust it means that the grubs are nearly full grown.

After feeding the sapwood during the winter and ensuring hot weather, the grub move to heartwood where they form a wider pupal chamber, the grubs start pupation from December onwards, develop to immature beetles between April to May and emerge out from middle June onwards during monsoon.It then develops a pupae chamber, In the final stage the larvae shuts itself in by a partition of calcium carbonate and long wood fibers loosely packed.

Pupae

Pupation occurs in pupal chamber. It begins from February and continues till April. After 2-3 weeks of pupal period, immature beetles of Sal borer develop and wait inside the pupal chamber for the emergence till the monsoon arrives.

Adult

The insect turns into a beetle in May-June and waits until the monsoon arrives. Dark brown beetle in color, elyfra varying in colour from piceous black to reddish-brown, body is about 2 - 6.5 cm in size. It has long antennae. The antennas of male are relatively longer than the body while the female is shorter than her body. Antennal segments are with spines at corners.

It appears annually with the start of Monsoon. The emergence is largely complete when the cumulative rainfall is about 900 mm during early monsoon.

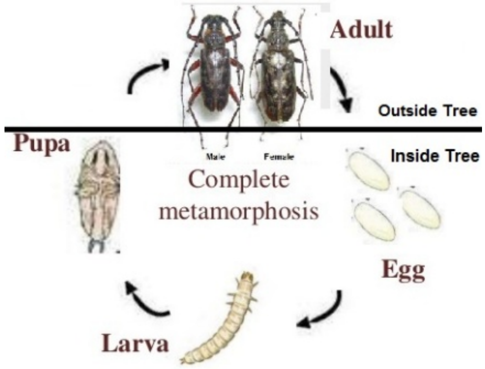


Figure : Lifecycle of *Hoplocerambyx spinicornis*

Nature of Damage

Nowadays *Hoplocerambyx spinicornis* ranks as the potentially most injurious forest insect in India. This is partly due to a series of bad epidermics in the United Provinces and in Central India, and partly to a better realisation of the financial importance of such catastrophes as well as of its more diffuse endemic activities.

For food *H. spinicornis* gnaw the bark of sal, particularly the inner and living bark, when it is exposed by some accident to the free. Fresh sap from the bast and sapwood of *Shorea robusta* is highly attractive and is absorbed with eagerness until the alimentary canal is fully distended. A beetle that is gorged on sap appears intoxicated and often is unable to stand or fly. Fresh sap can be detected by the beetle from considerable distances, beetles have been attracted to newly exposed sap over a measured distance of a quarter of a mile, within 5 minutes, flying upwind. Fermented sap a week or more old is much less acceptable and its range of attractiveness is much diminished. Water is also a necessity to the beetle and without it life is reduced by ten days or more. The beetle drinks from a droplet of water by scooping movements of the palpi and the hypopharynx.

Control

Sal borer is highly destructive insect pest to the Sal. The tree vigorosity should be maintained as the pest attracts to the inferior trees at the beginning. Leaving logs or parts of dead trees on the ground should be avoided. Controlled forest fire maintains its population by killing the eggs in the bark. Insect trap and killing method is most effective remedial method to check its population.

Preventive measures

- Maintain the stand density
- Control burning
- Avoiding the tree damage: Grazing and other biotic interference in sal forests should be minimized as far as possible.
- Burning of debris and stumps after harvesting of trees.
- Sal timber depots should be away from the Sal forests.

Remedial measures

- **Trap tree operation:** few medium sized trees should be felled every year during the monsoon (especially June- July) and their bark should be smashed. The fresh smell attracts the insects from the distance of up to 2 kms.
- **Cutting affected trees:** Felling and removal of affected trees away from the sal forests (identified by the large amount of yellow resin oozing out of the bark and heap of wood dust at the base of the trunk).
- **Stacking** of infested timber in depots 5 km away from Sal forests
- Diseased or dying sal trees, wind-fallen trees, insect (borer) attacked, felling refuse, etc. should be **disposed off** during winter-summer before onset of monsoon every year.

Besides existing preventive and remedial control measures, the authors have advocated spraying of 0.05% endosulfan 3.5 ml insecticide per litre of water of 0.05 per cent chlorpyriphos (10 ml insecticide/litre) on stored borer attacked sal stacks and then covering them with polythene sheets before monsoon in June to kill the beetles emerging from sal logs.

11.3 Forensic Entomology

11.3.1 Introduction

Forensic Entomology is the use of the insects, and their arthropod relatives that inhabit decomposing remains to aid legal investigations. Forensic entomology is the branch of forensic science in which information about insects is used to draw conclusions when investigating legal cases relating to both humans and wildlife, although on occasion the term may be expanded to include other arthropods. Insects can be used in the investigation of a crime scene both on land and in water. It is of immense use in the investigation of crimes of even civil disputes. Forensic entomology is not only a useful tool of decide how long human remains have been undetected, but it can also be used to find out whether the corpse has been moved after death, the cause of death, and also to solve cases of contraband trafficking.

11.3.2 History of Forensic Entomology

Insects are known to have been used in the detection of crimes for a long time and a number of researchers have written about the history of forensic entomology. The Chinese used the presence of flies and other insects as part of their investigative armoury for crime scene investigation and instances of their use are recorded as early as the mid-tenth century.

Indeed, such was the importance of insects in crime scene investigation that in 1235, a training manual on investigating death, *Washing Away of Wrongs*, was written by Sung Tz'u. In this medico-legal book it is recorded that the landing of a number of blowflies on a particular sickle caused a murderer to confess to murdering a fellow Chinese farm worker with that sickle. Between the thirteenth and the nineteenth century, a number of developments in biology laid the foundation for forensic entomology to become a branch of scientific study.

The two most notable were, perhaps, experiments in Italy by Redi (1668) using the flesh of a number of different animal species, in which he demonstrated that larvae developed from eggs laid by flies, and the work by Linnaeus (1775) in developing a system of classification. In so doing, Linnaeus provided a means of insect identification, including identifying such forensically important flies as *Calliphora vomitoria* (Linnaeus). These developments formed foundations from which determination of the length of the stages in the insect's life cycle could be worked out and indicators of time since death could be developed.

The credit for the first modern forensic entomology case goes to **French doctor Bergeret.** A particularly significant legal case, which helped establish forensic entomology as a recognized tool for investigating crime scenes, was that of a murdered newborn baby. The baby's mummified body, encased in a chimney, was revealed behind a mantelpiece in a boarding house when renovation work was being undertaken in 1850. Dr Marcel Bergeret carried out an autopsy on the body and discovered larvae of a fleshfly, *Sarcophaga carnaria* (Linnaeus), and some moths. He concluded that the baby's body had been sealed up in 1848 and that the moths had gained access in 1849. As a result of this estimation of post mortem interval, occupiers of the house previous to 1848 were accused and the current occupiers exonerated.

The next significant point in the history of forensic entomology resulted from observations and conclusions made by Mégnin (1894). He related eight stages of human decomposition to the succession of insects colonizing the body after death. He published his findings in *La Faune des Cadavres: Application de l'Entomologie à la Médicine Légale*. These stages of decomposition were subsequently shown to vary in speed and to be dependent upon environmental conditions, including temperature and, for example, whether or not the corpse was clothed. However, the similarity in overall decomposition sequence and the value of the association of insects has been demonstrated for decomposition of the bodies of a number of animal species. This knowledge about insect succession on a corpse became the basis for forensic entomologists' estimations of the time since death of the corpse.

In the twentieth century insects were shown to be of value in court cases involving insect colonization of body parts recovered from water and not just whole corpses found on land. On 29 September 1935, several body parts, later identified as originating from two females, were recovered from a Scottish river near Edinburgh. The identities of the deceased were determined and the women were named as Mrs Ruxton and Mary Rogerson, 'nanny' for the family. The presence of larvae of the blowfly *Calliphora vicina* Robineau-Desvoidy, in their third larval instar, indicated that the eggs had been laid prior to the bodies being dumped in the river. This information, combined with other evidence, resulted in the husband, Dr Ruxton, being convicted of the murder of his wife and Mary Rogerson.

The importance of ants and cockroaches in causing post-mortem artifacts was shown by German doctors Klingelhöffer and Maschka and the forensic pathologist from Poland (then Austria) Stefan von Horoskiewicz. Both

Horoskiewicz and Maschka have reported cases in which there were bites by ants or cockroaches that resembled ante-mortem abrasions or bruises. In all those cases, but for the findings and testimony of these renowned scientists, innocent people would have been punished. During this time (the beginning of twentieth century) France and Germany were the main centers for the work on entomology. This is evident from the following two books of that time Thierleben (Life of The Animals) by Alfred Brehm and Souvenirs entomologiques (Souvenirs of Insect Life) by Jean Henri Fabre. These books specifically dealt with carrion beetles and blowflies and went a long way in popularizing entomology among the people.

During the next few decades a lot of scientists worked on the subject and the database on the properties of Insects increased. Although the amount of research increased in the field, there was no great increase in the popularity of the subject. Only a few scientists across the globe worked on insects. The main aim of this research was to prepare a database for their own geographic area and environmental conditions. All this changed in the mid 1960s. When Watson and Crick discovered DNA in 1953, even they would not have thought about its potential in forensic sciences especially forensic entomology. The use of DNA brought in a new era in the identification of the invertebrates.

Soon DNA was being used to identify the insects at the scene of crime. This method was billed as more advanced and scientific than morphological features. The late 1970s saw the emergence of entomotoxicology as a new branch of forensic entomology. In this the presence of toxins in the invertebrate decomposers was detected and was used as a method of finding the cause of death. So now the use of forensic entomology was graduating from finding only PMI to finding the cause of death.

According to the latest worldwide directory of forensic entomology approximately only 62 scientists are involved in this field of study in the world. However, forensic entomology in our country is still in its infancy. Currently, there are only two researchers who are active in this field in India: Pankaj Kulshrestha of Medico Legal Institute, Bhopal, and Devinder Singh of Punjab University, Patiala. Kulshrestha pioneered the application of forensic entomology in India Considering the vastness of our country, we are yet to go a long way to generate basic data on the taxonomy, geographic distribution, biology and ecology of the insects involved in the decomposition of dead animal.

Indian courts of justice allow any scientific evidence to prove a case, under article 138 of the Evidence Act. But forensic entomology is yet to find an undisputed place in the legal proceedings in our country due to the absence of sufficient background data on the insects involved in the decomposition of dead animals and also the dearth of professional forensic entomologists.

11.3.3 Fields of Forensic Entomology

Forensic entomology can be divided in three sub fields:

1. **Urban**

   The urban aspect deals with the insects that affect man and his immediate environment. It includes both criminal and civil components as urban pests may feed on both the living and the dead. The damage caused by their mandibles or mouthparts can produce markings and wounds on the skin that may be misinterpreted as prior abuse. Urban pests are of great economic importance and the forensic entomologist may become involved in civil proceedings over monetary damages.

2. **Stored-Product**

   Stored product insects are commonly found in foodstuffs and help in both, criminal and civil proceedings involving food contamination.

3. **Medicolegal (Medicocriminal Entomology)**

   The medicolegal (or medicocriminal) entomology focuses on the criminal component of the legal system and deals with the necrophagous (or carrion feeding) insects that typically infest human remains. Medicolegal forensic entomology includes arthropod involvement: in events such as murder, suicide and rape, and also physical abuse and contraband trafficking.

Applications of Forensic Entomology

1. **Indicators of time of death**

In the first 72 hours after death, the pathologist is usually considered to be able to provide a reasonably accurate determination of the time of death. Historically, this has been based upon the condition of the body itself and such features as the fall in body temperature. Beyond this time, there is less medical information with which to correlate post mortem interval (PMI). So another area of expertise is required to clarify time of death. The forensic entomologist can provide a measure of the possible post mortem interval, based upon the life cycle stages of particular fly species recovered from the corpse, or from the succession of insects present on the body. This estimate can be given over a period of hours, weeks or years. The start of the post mortem interval is considered to coincide with the point when the fly first laid its eggs on the body, and its end to be the discovery of the body and the recognition of life stage of the oldest colonizing species infesting it. The duration of this stage, in relation to the particular stage of decay, gives an accurate measure of the probable length of time the person has been dead and may be the best estimate that is available.

2. Estimating PMI (Post-Mortem Interval):

Forensically significant conclusions often can be drawn by noting the state of successive colonization of a corpse by local arthropod fauna, or by identifying the developmental stage of necrophagous (dead-flesh eating) insects collected in, on, or near the body. The most common use of forensic entomology is to determine the minimum time since death (minimum post-mortem interval, or PMI) in suspicious death investigations. The PMI is estimated by identifying the age of the insects present on a human corpse, which can provide a relatively precise estimate in circumstances where pathologists may only be able to give a broad approximation. The fundamental assumption is that the body has not been dead for longer than it took the insects to arrive at the corpse and develop. Thus, the age of the oldest insects on the body determines the minimum PMI.

Arthropods are important carrion feeders. The first groups of insects that arrive on a dead vertebrate is usually blowflies (Diptera : Calliphoridae). Usually the female oviposits within two days after death of the vertebrate. The maggot undergoes three instars; forms prepupae, pupae within puparium, and then the imago. If we know how long it takes to reach the different stadia in an insect's life, we can calculate the time since the egg was laid. This calculation of the age of the insects can be considered as an estimate of the time of death. But even if the estimate of the insect age is correct, the death of the victim (usually) must have occurred before the eggs were laid. This period is quite variable and depends on temperature, time of day the death occurred, time in year the death occurred, whether the corpse is exposed or immersed in soil or water, etc. As a general rule insects lay eggs on a corpse within two days after the corpse is available for insects.

3. Corpse relocation :

Insects can also be of help in establishing whether the corpse has been moved after death, by comparing the local fauna around the body, and the fauna on the body. In some instances, movement of suspects, goods, victims or suspect vehicles can be traced with the help of insects. Parts of the insects, or whole insects can, for example, be captured in different car parts, such as in radiators or tire threads. Many arthropods live in close relation to carrion. By identifying the insects found, and plotting the distribution of each insect, as well as the biology of each species one can find the greatest degree of overlap, and describe the areas where the suspect has been. For example, certain species of blowflies tend to be found primarily within large urban centers. Identification of such species in association with a corpse found along a rural roadside suggests that the victim was killed in town and subsequently dumped in the remote rural environment.

4. Finding the cause of death :

During crime investigation, the main target is to find out when a victim died but also how the victim died, as this can help identifying the criminal. In some instances the insects themselves may be the killers, and in others the insects occurring on the carrion can shed a light on what happened when the victim died.

Under normal conditions, insects invade the corpse through body orifices such as nose, mouth, eyes, ears, anus, etc. Wounds inflicted due to a knife or a bullet injury attract flies for feeding and egg laying. The aggregation of flies and their life stages help experts to trace the spot and predict how the murder was committed.

Poison can be traced in blood, urine, stomach contents, hair and nails. Maggots occurring on a corpse may also possess traces of poison. After a while when the body is totally decomposed or dried, it is impossible to sample stomach contents, urine and blood from the dead body, but it still is possible to sample the poison from maggots, empty puparia or larval skin cast.

5. Investigating physical abuse :

Insects are of value as forensic indicators in cases of neglect or abuse. One of the applications of forensic entomology includes the detection of abuse in children and neglect of the elderly. Entomological evidence has been used to prove neglect and lack of proper care for wounds existing on the elderly under both private and institutional care.

Some insects, for example the greenbottle *Lucilia sericata* (Meigen), are attracted to odours, such as ammonia, resulting from urine or faecal contamination. Adult flies of this species tend to be attracted to an incontinent individual; a baby that has not had its nappy changed sufficiently often, or incontinent old people who have not been assisted in maintaining their bodily hygiene. Flies may lay their eggs in clothing or on skin. These eggs, if undiscovered, will hatch into maggots (larvae) which start feeding upon flesh, or on wounds, ulcers or natural entry points of the body. Over time the flesh will be eaten away and the region may be further infected by bacteria as well as being invaded by other insects.

In some cases wasps and bees have been used as murder weapons, as in a case some parents had shut their infant in a room full of wasps, in order to get rid of it. Wasps and bees inject venom to which some people may be sensitive and allergic to and can die if not treated in time.

Another important aspect of wasps and bees is their effect on drivers. Many car accidents are probably caused by some wasp, bee or bumble-bee coming through the window, causing hysteria, or a distraction from the road leading to a collision or other accidents. The stings (or mere presence) of bees and wasps may be responsible for a large number of single occupant car accidents that seem to lack a definitive cause. Some accident studies have shown insects to be within the top 20 causes of automobile accidents. Forensic entomologists examine the fragmented remains of insects that have impacted and lodged on the front fascia, windshield, and radiator of automobiles. Analysis of such remains can yield evidence to the probable path of an automobile through particular areas when pinpointing the location and areas of travel are of unique importance.

6. Detecting or investigating drug consumption

Insects could serve as a resource for detecting toxic substances when other typical sources, such as urine, blood, or tissue, are not present. While some evidence supports the hypothesis that insects can be used for detecting these substances, insects sampled from human remains may not be a suitable substrate for quantifying certain compounds e.g., narcotics.

Insect evidence collected from human remains can be used to detect the presence of drugs. In some cases when the primary resources used for toxicological analysis are not present, insects collected from the corpse may serve as an alternative material for examination. Insects also provide valuable clues in cases of deaths related to narcotics or toxins, particularly more so when the corpse itself is too putrefied to be analyzed.

The insect life cycle stage that feeds on the cadaver is a potential reservoir of undigested flesh from the corpse. Because, in some circumstances, the flesh from the corpse can retain some types of drugs that had been consumed by the victim before he/she died and which may even have been the cause of death, these drugs may be recovered by analysing the insects and may include opiates, the barbiturate phenobarbital, benzodiazepines or their metabolites, such as oxazepam, triazolam, antihistamines, alimemazine and chlorimipramine, a tricyclic antidepressant. To date there is not a great deal of information available that indicates the role of drugs, which are present in decomposing body tissue, on necrophagous larvae.

In 2001 Musvaska and his colleagues examined the effects of consuming liver containing either a barbiturate - sodium methohexital or a steroid - hydrocortisone on the development of a fleshfly, *Sarcophaga tibialis* Macquart. They concluded that, compared with controls, the length of the larval stage was increased, whilst pupariation was more rapid. In 2005 Arnaldos and his co workers by various laboratory experiments investigate the effects of heroin, also showed that the length of time taken to complete individual larval stages in *Sarcophaga tibialis* was considerably longer, in contrast to those larvae which were not fed heroin. However, heroin has been shown to increase the rate at which other species of maggots Cocaine and one of its breakdown products has been found in small amounts in the puparium of Calliphoridae, so this drug is clearly sequesteredin the larval body and retained in the next life stage.

Suicide cases can also be investigated using forensic entomology by analysing the maggots which had fed on the corpse and demonstrating the presence in the body of malathion, an organophosphate insecticide,

The following chemicals have been traced in maggots – Triazolam, Oxazepam, Alimemazine,Chloripriamine,Phenobarbitol,Malathion,Mercury,Amritriptyline, Nortriptyline, Cocaine , Phenycyclidine, Heroin, etc.

7. Wildlife investigations :

The illegal killing of animals is a very serious problem. Killing an animal for trophy parts such as the head, antlers or hide is most common by the poachers. In such cases, determining time of death can assist in narrowing the focus of the investigation. Though the use of forensic entomology in wildlife crime is less well known, it is equally valuable.

8. Insect contamination of food

Many parts of world consume insects as part of their diet. For example, aquatic insects such as the giant water bug, *Lethocerus indicus* Lepeletier Serville, are eaten as a delicacy across south-eastern Asia. Chocolate-coated bees are eaten in the UK, and in North America some shops sell canned, fried grasshoppers, whilst Thai cooked crickets in tins are available via the world-wide web. However, the presence in food of insects that are eaten unintentionally, or could be eaten along with the food, is considered unacceptable to the consumer and a source of contamination. For example, the saw-toothed grain beetle, a stored product pest, may be found in cereal packages; wire worms may be sold along with freshly cut lettuces, or may be processed into lettuce and tomato sandwiches; whilst in many countries, fish and meat which is left in the open to dry can become infested with beetles or flies, either in the drying process or later on a market stall. These are then eaten and have the potential to cause illness. Forensic entomologists can be asked for an expert opinion in civil cases relating to the food industry, where food has been contaminated by insects living in close association with man.

11.3.4 Insects of Forensic Importance

The insects that can play very important role in forensic entomological investigations. A deep knowledge of the insect species association with difference habitats may provide information regarding the history of the remains. Several species of insects belonging to the orders Diptera, Coleoptera, Lepidoptera and Hymenoptera are associated with decaying matter, including corpses. Some of the main insects of forensic importance includes blowflies, flesh flies, cheese skippers, hide and skin beetles, rove beetles and clown beetles. In some of these families only the juvenile stages are carrion feeders and consume a dead body. In others both the juvenile stages and the adults will eat the body (are necrophagous). While some other families of insects are attracted to the body solely because they feed on the necrophagous insects that are present.

The Dipterans are predominantly the largest group both in terms of species diversity and density followed by the beetles (Coleoptera). Decomposing bodies undergo biological, chemical and physical changes and at each stage of decomposition, they are invaded by a specific species of insect often in a predictable sequence. These changes are dependent on interrelated factors such as climate, situation and insect access. For instance, blow flies are the first colonizers of the carrion and include several important genera, viz. *Calliphora, Lucilia, Cochliomyia* and *Phormia*. The sarcophagids arrive a few days later. A characteristic pattern of the maggots of these species is their movement in large numbers which presumably facilitates their combined ammonical excretory products to condition the tissues and counter the acidic effects of rigor mortis. As these species develop and the process of decay sets in, the odour of the corpse changes, becoming more ammonical and putrescent.This results in attraction of other dipteran species, particularly the phorids and later, the stratiomyids and species succession begins. Beetles colonize corpses later than the flies. Histerid and staphylinid beetles are the first to arrive followed by beetles belonging to Dermestidae, Rhizhophagidae, Ptinidae and Tenebrionidae.

Wasps and ants are predaceous, preying upon insects that invade the carrion. The diversity of these insect species has been found to vary in different ecosystems depending on the habitat of the carrion as well as that of buried and unburied cadavers. Such difference in diversity paves way for possible suspicion/prediction about any crime. Several species of Lepidoptera may be associated with the corpse at different stages of decomposition, being attracted by the gases excreted from the body (methane, ammonia, carbon dioxide, nitrogen), but since they tend to arrive very late, are less useful in establishing a PMI.

11.3.5 Entomological Evidence Collection During Death Investigations

Death Scene Procedures

The most important step of forensic entomological investigation is to observe a crime scene carefully with all necessary requirements for collecting entomological specimens. With the police investigation there is a need for collection of entomological evidence. It is important to note that the collection of insects and other arthropods from a death scene may disturb the remains. Therefore, the forensic entomologist should contact the primary investigator and make plans for the Once a course of action as been determined, extreme care should be taken during insect collection so that the remains are disturbed as little as possible. Before collections are made proper notes and details should be taken as to the general habitat, ambient weather conditions, the microhabitat immediately surrounding the body and location of the body.

Scene Observations and Weather Data

Entomological investigation of the death scene can be done into the following steps:

1. **General habitat and location of the body :**

   - Carefully observations of the scene should be made and note the general habitat and location of the body in reference to vegetation, sun or shade conditions, and its proximity to any open doors or windows. Sites of insect infestations on the body should be documented as well as different developmental stages of insects are observed such as eggs, larvae, pupae, or adults.
   - The type of habitat shows about the possibility of different types of insects on the body. If insects are typical of other habitats are found than the crime scene may suggest that the body has been dumped. It is also useful to document evidence of scavenging from vertebrate animals and predation of eggs and larvae by other insects such as fire ants. These type of observations should be noted on the Death Scene Form.

2. Collection of meteorological data at the scene :

When estimating the PMI, meteorological data about the crime scene is absolutely critical. The insect development is affected by various abiotic factors like temperature and relative humidity in the environment development takes place.

a) Temperature determination is extremely important to get information about insects growing on the body before it was discovered.
b) The body temperature should be determined by placing a thermometer on the body surface.
c) Ambient air temperature at the scene taken approximately at chest height with the thermometer in the shade. Ambient temperature can be evaluated by taking readings at 0.3 to 1.3 m heights in close proximity to the body.
d) Ground surface temperature is obtained by placing the thermometer on the ground, immediately above any surface ground cover.
e) To take the temperature of the soil, it is better to use a soil thermometer so that there is little chance of the thermometer breaking as it is forced into the ground.
f) Temperature of the soil directly under the body. Soil temperatures should be taken immediately after body removal at a ground point which was under the body before removal. Also take soil temperatures at a second point 1-2 m away from the body. These temperatures should be taken at 3 levels: Directly under any ground cover (grass, leaves, etc.), at 4 cm soil depth and at 20 cm soil depth.
g) Weather data that includes the maximum and minimum daily temperature and rainfall for a period spanning 1-2 weeks before the victims disappearance to 3-5 days after the body was discovered.
h) Weather data for the scene should be collected from the nearest meteorological station. Minimum requirements should be maximum and minimum temperature and amount of precipitation. The climatological data should extend back to the time the victim was last seen.
i) Maggot mass temperatures can be obtained by inserting the thermometer into the center of the maggot mass.

3. Collection of insects from the body at the scene:

- The first insects that should be collected are the adult flies and beetles. These insects are fast moving and can leave the crime scene rapidly once disturbed. The adult flies can be trapped with an insect net. Once the adult flies have been netted, they are placed in the mouth of a "killing jar". The jar is then capped and the insects will be immobilized within a few minutes. Once they are immobile they can be easily transferred to a vial of 75% ethyl alcohol. Beetles can be collected with forceps or gloved fingers and placed directly into 75% ethyl alcohol.
- Another important point is that the collected specimens should be properly labeled. Labels should be made with a **dark graphite pencil**, **NOT IN INK**. The label should be placed in the alcohol along with the specimens, and alcohol and should be used for labelling purposes. The collection label should following format :
    - Geographical Location
    - Date and hour of collection
    - Location on the body where removed
    - Name of collector
- First the investigator should search for the presence of eggs, which are easily overlooked. After this step, the larvae should be readily apparent on the body. The largest larvae should be actively searched for and collected. A sample of 50-60 larvae of same species should be collected from the maggot mass. These insects can be placed directly into a killing solution or ethyl alcohol. If the larvae are boiled with about 48 hours of initial preservation, a good specimen should result. The investigator should discuss preservation techniques with their cooperating entomologist. In any case the exact preservation techniques should be documented and forwarded to the forensic entomologist.
- Living specimens from the crime scene can be placed in specimen containers. Tiny air holes should be made in the lid. This container should be enclosed in an appropriate shipping container and shipped immediately to a forensic entomologist.

4. Estimate the number and kinds of flying and crawling insects.

- Locations of major infestations associated with the body and surrounding area should be note down. These infestations may be egg, larval, pupal or adult stages, alone or in any combinations of the above.
- Immature stages include eggs, larvae, pupae, empty pupal cases, cast larval skins, fecal material, and exit holes or feeding marks on the remains of particular adult insects must be observed.
- Presence of ny insect predation such as beetles, ants and wasps or insect parasites should be carefully observed.
- The various data like the exact position of the body: compass direction of the main axis, position of the extremities, position of head and face, noting of which body parts are in contact with substrate, noting where it would be sunlight and shade during a normal daylight should be note down.
- Different insect activities like flying, resting or crawling insect adults or larvae or pupae within the proximity to the body should be observed.
- Other unusual naturally occurrings, man-made, or scavenger-caused phenomenon which could alter the environmental effects on the body like trauma or mutilation of the body, burning, covering, burial, movement, or dismemberment must be also keenly observed.
- Close-up photos of the different stages of insect found on the different sites of body should be taken before collecting.

5. **Collection of insects from scene after body removal:**

- After the removal of body preserved and living samples of many of the insects that inhabit a corpse will remain on, or buried, in the ground should be taken. Soil and litter samples should also be taken both immediately under where the body was positioned, and from the immediately under where the body was positioned, and from the immediate surroundings. To collect the leaf litter and debris, sample collector first down the exposed upper surface of the soil, and then make a separate collection from about the first two or three inches of topsoil. Each soil collection area should be about 10-15 cm^2, and be taken from underneath the head, torso and extremities. All soil samples should be kept in a cardboard container for immediate delivery to a forensic entomologist. These collections should be labeled and given to the forensic entomologist along with the insects collected from the body.

6. A passive technique for collecting adult insects at the crime scene is by using sticky traps with a slow drying adhesive substance. These traps are made from waxed cardboards. This type of trap will collect many insects in a few minutes. An insect collection net can be used to collect flying insects. Eggs, larvae, pupae and adults of insects on the surface of the human remains should be collected and preserved to show the state of the entomological data at the time of discovery. Insects within the body should not be collected before the autopsy. If there is enough insects, samples of egg, larvae and pupae should be collected alive and placed on a rearing medium such as raw beef liver. Rearing to the adult stage makes identification easier, and may give vital clues to the PMI estimation. It is important that the temperature in the rearing container is as constant as possible, in the range of 20-27^{D} C.
7. **Laboratory findings:**
    - Next step of forensic entomological investigation is processing of samples in laboratory. All samples, both live and dead specimens should now be processed as fast as possible. Live specimens are multiplied in incubators with known temperature and humidity levels. Several times each day these containers should be watched, and changes such as hatching of eggs or larvae, pupariation or eclosion of adult insect should be noted. The exact time should be noted. Pictures could be taken for demonstration to a jury or other investigating officials. Taxonomic status of collected larvae and adult should be determined if possible. For recreation of the environmental conditions for the larvae to estimate PMI it is necessary to do experiments outdoors near the crime scene.
8. **Data analysis :**

After collection and processing of the data, data analysis should be done:

- During the PMI the remains have been disturbed or disarticulated or not.
- Presence of any antemortem administered drugs such as alcohol, cocaine or heroine was proved or not.
- Analysis of the age of all specimens as possible, based on presence of drugs, temperature and humidity conditions.
- After death whether the insect activity was delayed or not.

9. Interpretation of blood splash pattern:

- Insects can also confuse the understanding of blood spatter pattern analysis. Roaches simply walking through pooled and splattered blood produce tracking that may not be readily recognizable to an untrained observer. On other side the Spots of blood in unique and unusual areas such as on ceiling may misinform crime scene experts unless they are aware of the appearance of blood contaminated roach tracks. In the similarl way, flies and fleas may also track through pooled and spattered blood. Sangivorous flies will feed on the blood and then pass the partially digested blood in its feces, termed as “flypecks”. Flies also regurgitate and possibly drop a blood droplet on a remote surface, which may serve to confuse bloodstain analysis. Fleas feeding on the living can excrete out a large amount of undigested blood on many household surfaces. If a crime occurs in a heavily infected apartment, fecal drops already present would serve to confuse analysts as those droplets would test positive for human blood. So it is important to recognize and properly note about all the insects that feed on living, decomposing, or dried vegetable material.
- Entomological evidence can also help determine the circumstances of abuse and rape. Victims that are helpless often have associated fecal and urine soaked clothes or bed dressings. These materials will attract certain species of flies that otherwise would not be recovered. Their presence can yield many clues to both antemortem and post-mortem circumstances of the crime.

11.3.6 Entomological Collection Equipments

Proper equipments are essential for the proper collection of entomological evidence. The entomological equipments includes plastic or polycarbonate screw-top sampling jars for both preserved specimens and live cultures, forceps, stepping plates to preserve the scene from contamination, a killing jar containing ethyl acetate, labels, indelible markers with fine points, fine forceps, artists' paint brushes, an entomological net and killing agents for larvae, such as boiling water, and an insect preservative. A number of preservatives could be used, including 70–80% alcohol, KAAD and Kahle's solution; each has its benefits. Kahle's solution contains both a fungal control and a preservative.

It is possible to configure a collection kit, and most of the necessary items can be purchased locally. A summarized list of necessary item has been compiled.

- Insect Collection Nets
- Screw capped vials of 10 ml
- For long term storage, a neoprene cone inserted lid, which reduces evaporation and periodic maintenance is not required as often.
- Insect killing jars filled with 1.5 cm of plaster of paris with wide-mouth.
- Soft-touch or "Feather-touch" forceps for the collection of entomological specimens without damage
- Collection container for collection of living
- Aluminum foil for constructing a pouch that will hold the live larvae and their food source during shipment.
- Vermiculite or sand or dirt from the death scene should be filled to the bottom of the larval containers to allow for migration, and to absorb excess fluids during shipment.
- Plastic specimen containers (150-250 ml size).
- Paper labels (non-adhesive, heavy bond paper) for labeling and placement inside of the collection containers
- Paper labels (adhesive), for labelling and placement on the exterior of collection containers.

- Graphite pencil (HB or #2) for making labels. **INK SHOULD NOT BE USED** since the preservative fluids will cause the ink to smear and not adhere to the paper.
- Small hand trowel or garden spade for soil sampling and digging for migrating larvae or pupae in outdoor death scenes.
- Digital Thermometers (other traditional types can also be used)
- 35 mm SLR camera, lens, and flash for on-scene macrophotography of insects.
- Ruler or other measuring devices.
- Preservation and collection chemicals (In particular ethyl alcohol, ethyl acetate, and KAA).
- Paper towels, for use in kill jars and for cleaning utensils.
- Disposable gloves.
- Shifting screens for processing soil samples for insects and insect artifacts.
- Styrofoam containers with insulated lids Shipping containers. (Cardboard boxes can also be used)

11.3.7 Collection and Preservation of Insects

- Collect adult flies with sweep-net around corpse and preserve in ethyl alcohol.
- The hairy maggots of Chrysomya are heavily predacious on both other fly species and their own at highly populated densities. So it is important to remember when collecting both hairy maggots (*Chrysomya* spp) and smooth maggots (*Calliphora* and *Lucilia* spp) from the same corpse – if they are placed together in a vial, the smooth maggots will soon be consumed by the hairy maggots, and will not be represented in the entomological evidence gathered.
- Collect all size maggots (1^{st}, 2^{nd} and 3^{rd} instars) and preserve half in ethyl alcohol, and keep the rest alive in ventilated container and refrigerated (4-5 ^{D}C; record time of refrigeration).
- The largest larval stage pupates, forming a dark brown casing, so dry soil is required adjacent to their food source.dry soil for pupation.

- Pupae: some of these pupae need to be collected and placed in a ventilated container and some into ethyl alcohol. Empty pupal cases also need to be collected and placed into a container.
- Beetles grubs are also helpful when determining post-mortem time interval.
- Adult beetles can be collected from or around the corpse or with a sweepnet and preserved in ethyl alcohol.

11.3.8 Forensic Entomological Decomposition

Process after Death

- The body undergoes several changes after the death. These changes can be divided into various stages, which are important to know, in order to fix the time of death.

Stages of dead body processes :

Dead body passes through a series of stages. Since there are many variables, only broad generalizations can be made:

1. **Algormortis** - the change in body temperature after death. This is the most useful indicator of the time of death during the first 24 h.
2. **Livormortis** - the settling of blood in the body, which imparts a bluish purple colour.
3. **Rigor mortis** - the stiffening of the muscles after death. It is a well known phenomenon, and is due to a complex chemical reaction in the body. In the living body muscles can function both aerobic and anaerobic. In the dead body muscle cells can only function anaerobically. When muscle cells work anaerobically, the end product is lactic acid. In the living body, lactic acid can be converted back, by means of excessive oxygen uptake. In the dead body this cannot happen, and the breakdown of glycogen in the muscles leads irreversibly to high levels of lactic acid in the muscles. This leads to a complex reaction where actin and myosin fuse to form a gel. This gel is responsible for the stiffness felt in the body. This stiffness continues till the decomposition begins. However, Rigor mortis is never considered the only basis for estimating time of death.

4. **Autolysis** - the breakdown of the tissues by the body's own internal chemicals and enzymes. Body starts decomposing at different times after death, and may also be used in estimating time of death, however it should be noted that the duration of each stage might vary considerably.

Decomposition :

The decomposition of a body can be divided into several stages:

- **Initial decay**: The body appears fresh but continues decomposing internally due to the activities of bacteria, protozoa and nematodes present in the body before death.
- **Putrefaction:** This results from the breakdown of tissues by bacteria. The body swells or bloating stage due to the gases produced internally that are the chief source of the characteristic decaying flesh.
- **Black putrefaction**: Flesh of creamy consistence with exposed parts black. Odour of decay is very strong.
- **Butyric fermentation**: Corpse starts drying. Some flesh remains at first, and cheesy odour develops. Ventral surface becomes mouldy from fermentation.
- **Dry decay**: Cadaver becomes almost dry and the rate of decay is slowed down.
- **Mummification**: This occurs due to dehydration or desiccation of tissues.

Factors Affecting Body Decomposition :

The rate of decomposition is affected directly or indirectly by a number of factors

- Temperature
- Access by insects
- Burial, and depth of burial
- Access by carnivores or rodents
- Trauma, including wounds and crushing blows
- Humidity, or dryness
- Rainfall

- Body size and weight
- Prior embalming
- Clothing
- The surface on which the body rests

11.3.9 Preliminary Idea about Post Mortem Interval (PMI)/ Estimating Time of Death

Post-mortem interval (PMI) is the time that has elapsed since a person has died. If the time in question is not known, a number of medical/scientific/forensic entomology techniques are used to determine it. This also can refer to the stage of decomposition of the body.

After identification of the specimens from the body, the next stage is to connect this information to the temperature at the crime scene. Temperature data, covering the period since the person was last seen alive, are obtained from the local meteorological station. These data are 'corrected', using a *correction factor* calculated from the meteorological office data and half-hourly temperature readings, which have been recorded at the crime scene for 3–5 days after the body was discovered. These corrected data provide an estimate of the temperatures at the crime scene before the corpse was found. From this information, we can determine the length of time the flies took to grow from an egg to the developmental stage recovered from the body. By implication, this is the best estimate of the post mortem interval (PMI) that is available.

In temperate regions, the time of death can be estimated from the degree of stiffness and temperature of the body up to about 36 hours. These parameters have to be used cautiously as several other factors may play a role.

Initially when the body begins decaying, it starts to smell, different types of insects are attracted to the dead body. The insects that usually arrive first are the dipterans, in particular the blow flies (Calliphoridae) and the flesh flies (Sarcophagidae). The females lay their eggs on the body, especially around the natural orifices such as the nose, eyes, ears, mouth, anus, penis and vagina. If the body has wounds, the eggs are also laid in such wounds. Flesh flies do not lay eggs instead deposit larvae.

After few hours, depending on species, the egg hatches into small maggots. These maggots live on the dead tissue and grow fast. When the larva is fully grown it becomes restless and begins to wander. It is now in its prepupal stage. The prepupa then molts into a pupa, inside puparium. Typically it takes between one to two weeks from the egg to the pupae stage. The exact time depends on the species and the temperature in the surroundings.

The theory behind estimating time of death, or the post mortem interval (PMI) with the help of insects is very simple: since insects arrive on the body soon after death, determining the age of the insects leads to an estimation of the time of death. The PMI can also be estimated by the pattern of colonization of insects. These procedures can be categorized into two methods:

Method I involves determination of the age of the insects from the appearance of various stages, or by application of temperature dependant development of insects usually flies.

Method II uses a generally predictable succession of arthropods that often facilitates decomposition of organic matter.

Method 1: Age and stage of an insect :

In this method age of dipteran insects especially that of blowfly eggs, larvae, pupae and adults is estimated for PMI calculation.

- **Eggs**

  During the first eight hours or so the eggs show little signs of development, after which changes can be noticed. At the end of the egg stage the larvae can be see through the chorion. The egg stage typically lasts a day or so.

- **Larvae :**

  The maggot passes through three instars stages during its development. The first instar is approximately 5 mm long after 1.8 days, the second instar is approximately 10 mm long after 2.5 days, and the third instar is approximately 17 mm long after 4-5 days. Exact stage of instar is identified on the basis of size of larva, length of the crop, size of the larva’s mouth parts and morphology of the posterior spiracles. The duration of different instars depends very much on temperature and humidity.

- **Pupa :**

  After 8-24 days of oviposition the pupal size is about 9 mm in length. The presence of empty puparia indicates death to have occurred more than approximately 20 days ago. Identification can be confirmed based on the remaining mouth parts of the third instar larvae. A more precise way to determine age of larvae and eggs is the use of rearing.

Calculation

- **Time A** - The body is found with masses of eggs on it, none have hatched. The time of the discovery, and the time when the first 1^{st} instar larvae occur is noted. The first occurrence time is substracted from the discovery time.
- **Time B -** The blow flies are reared to adults. They are allowed to mate and lay eggs on raw beef liver under conditions similar to the crime scene. Time from oviposition to the first appearance of 1^{st} instar larvae is recorded. Call this time B.
- **B – A = C** (the time since oviposition to discovery). Similar calculations can be done for other instars as well.

Accumulated degree hours:

- Insects are cold blooded animals, their development is dependent upon temperature. The rate of development is more or less dependent on ambient temperature. The rate of development of all insects is directly dependent on the ambient conditions, particularly temperature. Between upper and lower thresholds, which vary between species, the higher the temperature, the faster the insects develop; the lower the temperature, the slower they develop.
- For each species there is a threshold temperature below which no development occurs. As the temperature rises above this threshold, a certain amount of time is required for the insect to pass through each life stage. Because this heat is accumulated as "thermal units," it can be calibrated and described as "degreedays" or "degreehours". This can be calculated by multiplying the temperature (^{F}) with the number of hours spent during that particular stage. If the ambient temperatures during the

period of development are known, then, in theory, the minimum PMI can be determined.

Factors affecting rate of development of maggots on a body:

- Temperature (which can depend on geographical location, indoor or outdoor exposure, sun or shade, time of day and season).
- Heat generated by the maggot mass
- Food source (tissue type, e.g. liver, heart, lungs)
- Contaminants and toxins (external and internal)
- Burial or other obstructions (e.g. plastic sheets, water) that hinder access and egg laying by adult insects.

The entomologist may attend the crime scene personally to collect the insect specimens from the body or its surroundings. This is ideal, because he or she can use knowledge of Insect Biology and behaviour to make sure that as many specimens as possible are collected which helps interpret the results. Alternatively, the entomologist may collect insect specimens during the post-mortem examination as well as viewing photos of the crime scene or visiting the scene after the body has been removed.

The life-cycle of the maggot is also influenced by many chemicals like – high dosages of cocaine accelerate the development of some sarcophagids. Malathion, an insecticide, is commonly used in suicide, and is usually taken orally. Presence of malathion in the mouth may lead to a delay in the colonization of the mouth. Presence of amitriptyline, an antidepressant, can prolong the developmental time with up to 77 hours, at least in one species of Sarcophagidae. Knowledge of drug use in the victim is therefore important not only in finding the death cause, but also in estimating the time of death.

Another method to estimate the PMI is to use the morphological characters of the maggot. For example the length of the crop of *Calliphora vicina* and length of the maggot at different time periods is given below :

Method 2 : Faunal Succession :

The sequence in which the insects feed on the dead body is called the faunal succession. Another important biological phenomenon that occurs on corpse is a succession of organisms that increase on the different parts, e.g. Files are often first on the scene. They prefer a moist corpse for the maggots to feed on. Predatory rove beetles or parasites that feed on maggots wait until the blow flies arribe to lay their eggs. Beetles that feed on bone, have to wait until bone is exposed. The succession on cadavers happens in a fairly predictable sequence and can be used in estimating time of death if the body has been lying around for some time. Estimation of time since death requires knowledge of sequence and can be used in estimating time of death if the body has been lying around for some time. Estimation of time since death requires knowledge of sequence, pattern, and duration of insect activity, ability to identify each species in all stages of their life cycles and knowledge of the time occupied by each life stage under various conditions. This system of estimation offers great accuracy initially, but is less accurate with increasing time.

Blow flies -> staphylinids -> Adult green bottle fly decrease -> Dermestidae, Silphidae, Histeridae and certain mites -> Large predator/scavenger activity-> Beetles

The first groups to arrive on a body is blow flies, followed shortly by staphylinids. As putrefaction develops, more groups arrive at the scene, with most groups present just before the body dries out due to seepage of liquids. After the body dries out, dermestids, tineids and certain mites dominate the animal groups on the body, and blow flies gradually vanish. The fauna in the soil also change. This can also be used to estimate time since death. A typical sequence of succession at a carcass as an example is given below :

- Ambient temperatures (^{C}):
- Mean 20.8; Min. 9.03; Max. 34.9
- Maggot mass temperature (^{C}):
- Mean 30.9; Max. 50.7 (128 hrs. PMI)
- Mean RH: 50%
- Precipitation : none

Fresh Stage

- 10 minutes PMI – Calliphoridae, species *Lucilia illustris* (Meigen)
- Six hours PMI – Egg clusters.

Bloated Stage

- 8 hours – Bloating
- 12 hours, bald-faced hornets (*Dolichovespula maculate*) (Linnaeus)
- 33 hours PMI: the green bottle fly eggs hatched
- 48 hrs : Staphylinidae appear

Active Decay Stage

- 72 hour PMI – flesh fly (*Sarcophaga haemorrhoidalis*)
- Terrestrial isopods
- Adult green bottle fly decrease
- Dermestidae, Silphidae, Histeridae appear

Advanced Decay Stage

- 120 hours : carcass began to desiccate
- 132 hours : third instar/post feeding maggots
- 147 hours : maggot mass exit carcass
- Large predator/scavenger activity

Body Desiccated, No odour

- 288 hrs. PMI – Beetle Activity
- 25 days: scavengers

Decomposition Summary

- Green bottle fly appear within 10 min
- Ovipositing/ egg cluster 6 hrs.
- 33 hrs: first hatch
- 12 hrs: predators (hornet)
- 72 hrs: predators (beetles)
- 168hrs: green bottle maggots leave carcass

Some insects are specific in living in very decayed dead bodies. For example the cheese skipper, *Piophila casei* (Piophilidae), larvae usually appear 3-6 months after death. The cheese skipper is a well known pest of cheese and bacon worldwide, and has a cosmopolitan distribution. Adult cheese skippers may appear early after death, but larvae occur later. The earliest appearance on human remains is when the body is two months old, and this was under excellent summer conditions. In graves of three to ten years old and three to six feet deep *Piophila casei* was observed.

Finding the transfer of body after death:

Various species of fungi, bacteria and animals inhabits on the dead body after death. The base on which the body is lying also changes over time. Fluids are leaked out from the deadbody can cause the disappearance of certain insects, and other insects increase as the time goes. A forensic entomologist then looks for how long the body has been there by looking at the fauna at the body, and also estimate the time the body has been lying there by sampling soil insects underneath the dead body.

If the dead bodies are found in such an environment where blowflies entry can not possible. If there are blowflies, it means that the body has been moved there. Insects like Calliphorids are heliophilic means that they lay their eggs on warm surfaces only, which means that they usually occur where the bodies lie in sunny places. While some blowflies species prefer shade. For example, *Lucilia* species prefer sunlight, and *Calliphora* prefer shady conditions. Some synanthropic species (which are strongly associated with human activity) occur in urban areas e.g. *Drosophila, Musca, Muscina, Ophyra, Stomoxys*, etc., but are not encountered frequently in investigations. Other species are not synanthropic and occurs in rural areas.

11.3.10 Some Forensic Important Insects – Flies and Beetles

Flies:

- Flies are often seen first on the scene. They prefer a moist corpse for the maggots to feed on, as such a corpse is easier for them to chew. Many dipteran flies have been recorded in the vicinity of carrion. These include: Blow flies (Calliphoridae), flesh flies (Sarcophagidae), muscid flies (Muscidae), skipper flies (Piophilidae), dung flies (Scathophagidae), scavenger flies (Sepsidae and Sphaeroceridae), soldier flies (Stratiomyidae), mushroom flies (Phoridae), sand flies (Psychodidae) etc. However, only some of these are useful in estimating the PMI. Some of the important dipterans are as following:

1. **Blow flies (Calliphoridae) :**

- The blow flies have a bright shining blue or green metallic appearance are known as blue-bottles or green bottles. They are small to medium, some being smaller and other larger than the common housefly. Members of the family Calliphoridae namely *Lucilia, Chrysomya, Calliphora*, and *Phaenicia* include the largest number of flies that feed on carrion. *Calliphora vicina, Lucilia cuprina, L. sericata*, and *Chrysomya bezziana* may be considered the type species, being also very common in various parts of India. All these species are widely distributed in various parts of the world.
- The blowflies (family Calliphoridae) are of greatest value to forensic entomology because they are usually the first insects to colonize a body after death, often within hours. Adult blowflies are well adapted to sensing and locating the sources of odours of decay, so can quickly find the corpses. The age of the oldest blowflies gives the most accurate evidence of the PMI. Blowfly plays a very important role in the environment as primary decomposers, and the larval infestations of a dead body are a vital component of the natural recycling of organic matter. Eggs are usually laid in the natural orifices of the body like eyes, nose, mouth, ears or other dark and moist places, such as the folds of clothes or just under the body. Maggots undergo three instars. Depending on the species, they pupate on the body or move away to find a suitable site. They may move many metres before burrowing into the soil or under objects such as rocks and logs or, if indoors, under carpets and furniture. The larva then forms the barrel-shaped puparium, within which the pupa metamorphoses into an adult fly. When the fly emerges, the empty puparial case is left behind as long-lasting evidence of the insect development.
- The sites of blowfly infestation on the corpse are important in determining the cause of death or reconstruction of events prior to death. For example: if there have been trauma or damage of the body prior to death, this may lead to heavy infestation of other body parts than the usual sites when the victim is not mutilated. After death, blowfly may oviposit in the wounds, rather than the usual body orifices. The usual

sites of oviposition on dead humans are natural openings. Even here there is preference. Blowflies most often lay their eggs in the facial region, and more seldom in the genitoanal region. If there is a sexual assault prior to death, leading to bleeding in the genitoanal region, blowflies are more likely to oviposit in these regions. Therefore, if there blowfly activity is observed in the genitoanal region, one can suspect a sexual crime. This must of course be corroborated with other evidence as well. The interpretation of maggots in the anogenital region becomes very fuzzy after a few (4-5) days, as eggs are laid in this region during the course of decay in the natural course of decomposition.

2. **Flesh flies (Sarcophagidae)**

- Flies of the family Sarcophagidae are commonly known as flesh flies. Flesh flies are stripey backed or chequered flies usually black in colour with grey longitudinal stripes on thorax, with bright red eyes. They are very close to the Blowfly family but none of them are in metallic colour. Ovo-larvipary is a typical trait of the family. The majority of Sarcophagus flies are scavengers of small carrion like dead insects and snails as well as smaller vertebrates, and only few species are breeding in larger vertebrate carcasses and faeces.
- Flesh flies frequently give birth to live young on corpses of human and other animals, at any stage of decomposition from newly dead through to bloated or decaying. They arrive at corpses slightly later than the pioneer blowflies, but the eggs hatch in the uterus of the female, before she lays them, with the result that the larvae are deposited directly on the body. This allows them to catch up on the blowflies, whose eggs take around 24 hours to hatch. Flesh fly pupae can remain dormant for long periods. The sarcophagid larvae are characterized by having a barrel-like shape with their posterior spiracles sunk into a hollow. The edge of the posterior segment has a large number of tubercles. This makes this family easy to distinguish as a larval stage. Maggots of some Sarcophaga species hibernate as pupae in autumn and do not emerge as adult flies until late spring. Flesh flies are often seen in houses.

3. **Soldier flies (Stratiomyidae):**

- Soldier fly, *Hermitia illucens* larvae are scavengers and grow well on many kinds of decaying organic matter, including carrion, manure, plant refuse and the waste products of beehives. Adults commonly frequent flowers of the daisy and carrot families. The fly commonly breeds in outdoor toilets, poorly managed compost and in poultry manure. Larvae occur in greatest densities in moist rather than wet or dry media. It has been shown to be a ubiquitous inhabitant of both surface and buried human remains.
- The adult is a dusky winged, nonbiting fly is 15 to 20mm long. The fly often resembles a black wasp in its appearance and behaviour. When at rest, its wings are folded on top of each other on abdomen. Their long and slightly elbowed antenna also makes them look like a wasp. Their legs are black with white tip. Primarily shiny black, the female's abdomen is reddish at the apex and has two translucent spots on the second abdominal segment. The male's abdomen is somewhat bronze in color.
- Egg is about 1mm long, the elongate-oval egg is pale yellow or cream colored when newly laid but darkens with time. Each egg mass contains about 500 eggs. Maggot is fat, slightly flattened, with a tiny, yellowish to black head. The skin is tough and leathery. Creamy white and about 1.8 mm long when newly hatched. The larva develops through six instars, the last of which is reddish-brown. The mature larva is about 18mm long and 6mm wide, although some individuals may be as long as 27mm.
- The motile pupa develops within the darkened skin of the last larval instar (puparium). The pupa is about one-third the length of the puparium. Adults of the black soldier fly appear to initiate egg laying 20 to 30 days. Even at warm temperatures, subsequent completion of the life cycle can require an additional 55 days. Black soldier fly larvae are preyed upon by sphaecid wasps, histerid beetles, and many species of birds and are parasitized by small wasps.

4. Coffin flies (Phoridae) :

- Adult phorids are slightly smaller aprroximately 2-3mm but more robust flies than sciarids. They are darker in colour with a hump-backed appearance with no obvious differences between male and female flies. Adult flies tend to remain on the compost surface or in close proximity to the cropping area. They are very active in the presence of light and have a characteristic rapid, jerky movement.

- Each female can lay up to 50 eggs in close proximity to developing mycelia. Phorid larvae are off white, legless maggots are without'a distinct head capsule. The anterior region narrows to a point while the posterior is blunt with small protuberances. The duration of phorid development is temperature dependent and may vary between 15 days (24-27^{D}C) to 50 days (16-21^{D}C). Larval development accounts for approximately 1/3 of the development time and the remainder is spent in pupation.

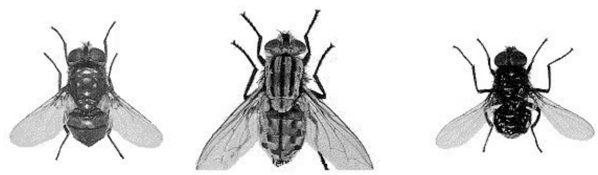


Figure –Flies of Forensic significance

Beetles Beetles are generally found on the corpse when it is more decomposed. **Suborder Polyphaga** contains the majority of families of beetles of forensic importance. The following features characterize this suborder. The hind coxa is rarely fused to the metasternum, it is movable and so does not divide the first visible abdominal sternite. The thorax in this suborder does not have lines or sutures across its dorsal surface. Polyphaga larvae are of many different shapes. They have legs with four segments which end in a claw. Some larvae in the suborder Polyphaga have legs which are reduced, others have vestigial legs, or the legs may even be absent altogether. Polyphaga adults eat a variety of food. Some beetles are predaceous, but in the suborder as a whole many are phytophagous. Only beetles which are predators are of immediate importance to the forensic entomologist. A number of beetles visit a dead body, either because the body itself forms food and a habitat, e.g. the Dermestidae, or to feed on the insects already present, e.g. the Staphylinidae. The families of insects from this suborder that are important in forensic entomology includes hister beetles (Histeridae), rove beetles (Staphilinidae), carrion beetles (Silphidae), carcass beetles (Trogidae), hide beetles or carpet beetles (Dermestidae), checkered beetles (Cleridae), scavenger beetles (Scarabeidae), sap beetles (Nitidulidae) etc. have been recorded to be associated with the dead bodies. Important groups useful in forensic entomology are given below:

1. **Hister beetles (Histeridae)**

- Hister beetles are shiny and glabrous, black or metallic coloured, rarely brownish, and ranging from 0.5 to 20mm long. The body is normally ovate to oblong and strongly convex, sometimes it is elongate and cylindrical or dorsoventrally flattened. The head is usually tucked deeply into the prothorax. The form of the antennae is striking short, elbowed, 3 segmented club. The underside of the prothorax is expanded and excavated to receive the front legs and often the antennae. The front tibiae are broad and often spiny. The elytra are striate, shortened and truncate, usually exposing two or three apical segments of the abdomen.
- Adults and larvae are predators of other insects, especially the soft bodied larvae and eggs of flies. Most are associated with decaying organic matter such as dung, carrion, rotting plants and fungi, where fly maggots abound. Others live in mammal burrows, ant nests, under bark and in bark beetle galleries. Some appear in stored products, where they feed on other insects. The carrion feeding species only become active at night when they enter the maggot infested part of the corpse to capture and devour their maggot prey. During daylight they hide under the corpse unless it is sufficiently decayed to enable them to hide inside it. They have fast larval development with only two larval stages. Among the first beetles to arrive at a corpse are Histeridae of the genus *Saprinus*. *Saprinus* adults feed on both the larvae and pupae of blowflies, although some have a preference for fresh pupae. The adults lay their eggs in the corpse, inhabiting it in the later stages of decay. *Saprinus lugens* Erichson is common and widespread on carrion. *M.umbrosus* (Casey) is common in carrion, sometimes in dung.

2. **Rove beetles (Staphylinidae)**

- Rove beetles live in many different habitats, but are most abundant in leaf litter, decomposing matter and moist soil. Many live in fungi, carrion, dung, vertebrate nests, ant and termite nests, under bark, on vegetation and flowers, and in tidal debris; some are active on beaches. They are 0.5 to 50mm long, brown to black and glabrous to setose. The antennae are usually 10 or 11 segmented, threadlike, sometimes clubbed, and the first segment is usually elongate. The elytra are usually short and truncate, exposing 5 to 6 abdominal segments; hindwings are normally functional. The abdomen in most taxa is flexible dorsoventrally, often held upward, showing 6 to 7 abdominal sternites. These beetles can run quickly and fly well.

3. **Carrion beetle (Silphidae)**

- Carrion beetles or burying beetles, are associated with dead animals. Most species are attracted to carrion, which they feed themselves and sometimes also their developing young ones. Some species are associated with dung or fungi. These are slightly flattened beetles of approximately 20 mm long body. The antennae are club-shaped. Their overall brown or black bodies are marked with yellow, orange or red. The elytra may not cover the entire abdomen, as in the Nicrophorus species.
- These strong insects can move the body of a small animal to a suitable burying place, remove soil from under the animal, and gradually bury it. The beetles lay egg on the body, and the larvae feed on it. Recent evidence suggests that the adult beetles feed on maggots associated with the body, rather than on the dead animal itself.
- The burying beetle (Necrophorus sp.) is black and orange, stout-bodied, and measures ½ to 1 inch in length. This beetle is often covered with very small, tan colored mites, which may be parasites or merely scavengers. Little is known about why these mites are found on the beetle.

4. **Carcass beetles (Trogidae) :**

- Carcass beetles are large in size with very thick exoskeletons and uniform dark colouration. They are among the last beetles to inhabit a carcass and, they feed on dried remains such as skin and ligaments. Adults and larvae both feeds on the carcass and the larvae live in vertical burrows underneath it when they are not foraging. Carcass Beetle, *Omorgus candidus* is typical of carcass beetles found at vertebrate carvasses.

5. **Hide beetles (Dermestidae) :**

- Dermestids are compact, oval, usually strongly convex beetles 1 to 12mm long. The base colour is black; some species have patterns of white, yellow, brown or red setae or scales. The head may be retracted into the prothorax up to the eyes. There is a median ocellus. The antennae are inserted in front of the eyes – they are threadlike or comblike, have 5 to 11 segments, and usually bear a 3-segmented club. The antennae fit in grooves below the pronotum. The legs are mostly retractile; the hind coxae are excavated to hold the folded demora.
- The larvae, densely covered with mostly spiny setae, are scavengers, feeding on dried carcasses, fur, feathers, wool, silk, leather, cereals and many other organic materials. With these habits, many are damaging pests in human habitations; elsewhere they are valuable recyclers. Many live in bee and wasp nests feeding on old pollen stores or insect remains, or in bird and mammal nests eating feathers and hair and other organic matter. Some Trogoderma species are predators of wasps, bee larvae and spider eggs. Adults are usually found on flowers where they eat pollen and nectar.

6. **Darkling Beetles (Tenebrionidae) :**

- Darkling beetles are flightless and hard bodied, brown or black beetles ranging in length from 1 to 80 mm. The 11 segmented antennae are thread like, bead like, or sometimes clubbed; they arise beneath a lateral expansion of the frons, which often notches or divides the eyes into upper and lower parts.
- Darkling beetles are habitants of arid and regions, where they are associated with soil and sand; in forests, many species live under bark, in rotten wood, leaf litter and fungi and in the nests of mammals, birds and insects. Larvae and adults eat fungi, decaying plant matter, roots, seeds and cereal products. The larvae of some groups are predatory; for

example, *Corticeus* species hunt bark beetles in their galleries. *Tenebrio, Tribolium* and other genera are cosmopolitan pests of stored food products. Tenebrionid larvae are typically long and cylindrical to somewhat flattened, often heavily sclerotized.

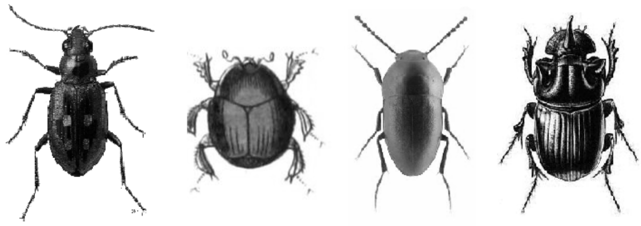


Figure –Beetles of Forensic significance

Moths associated with carrion :

Clothes-moths (Tineidae):

- Larvae feed on mammalian hair during their larval stages and may forage on any hair that remains. They are amongst the final animals contributing to the decomposition of a corpse.

Wasps, ants, and bees associated with carrion :

- These hymenopteran insects are not necessarily necrophagous. Some feed on the body, some are also predatory, while some eat the insects feeding on the body. Bees and wasps have been seen feeding on the body during the early immature developmental stages. These insects may cause problems for murder cases in which larval flies are used to estimate the post mortem interval since eggs and larvae on the body may have been consumed prior to the arrival on scene of investigators.

11.5 Summary

Forests play a vital role in the economy of the country. Forests are precious & valuable ecosystems that provide a variety of useful products, such as timber, fuelwood, fibre and non-wood forest products, and contribute to the livelihoods of rural communities. Insect pests have hazardous impact on forests and the forest sector. They can badly affect tree growth, vigour and survival, the yield and quality of wood and non-wood products, wildlife habitat, recreation, aesthetics and cultural values

Forensic insects are important agents in the biological breakdown of corpses and often provide valuable evidences in criminal incestigations. These insects feed, live, or breed in and on the corpse, depending on their biological preferences and on the state of decomposition. Among all these, insects are considered the most impotant tools in forensic science. Numerous insect species especially the flies (Diptera), beetles (Coleoptera), and their larvae are attracted by corpses. The investigation of insects recovered from crime scenes and corpses opens a wide range of applications for forensic entomology.

Forensic entomology is the application of Insect Biology in criminal investigations. Entomological evidence is particularly useful in estimating the time of death in cases where the post-mortem interval (PMI). Besides this, forensic entomology is also useful in corpse relocation, finding the cause of death, detecting physical abuse, detecting drugs or other poisonous substances and in wildlife investigations. Knowledge of the insect species associated with different habitats may provide information regarding the history of the remains. Several species of insects belonging to the orders Diptera, Coleoptera, Lepidoptera and Hymenoptera are associated with decaying matter, including corpses.

11.6 Self Assessment Questions

1. Describe the Biology, nature, extent of damage and control of *Sinoxylon.*
2. Describe the Biology, nature, extent of damage and control of *Dinoderus,*
3. What do you mean by pests of forests? Explain the details of *Hoplocerambyx spinicornis*?
4. Explain the history of forensic entomology.
5. Describe the different applications of forensic entomology.
6. Write an essay on Social organization of bees.
7. Write a short note on different fields of forensic entomology.
8. Describe the different insects of forensic importance.

9. Suppose you are forensic entomologist, now you have to investigate one dead body, now explain how will you collect the different evidences during your investigations?
10. What is the format for collection label for different entomological samples?
11. Explain the different stages of dead body processes.
12. List out the important families of flies and beetles that appear on a cadaver.
13. List out the important collection equipments used at the death scene.
14. "Forensic entomology is useful in various fields besides the estimation of PMI" discuss.
15. How the time of death is estimated using information about the appearance of various insect species appearing on a death body?

11.7 References

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- Forensic Entomology: An Introduction, Dorothy Gennard (Author), Publisher: Wiley-Blackwell; 2 edition (April 23, 2012), ISBN-13: 978-0470689035.

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Unit - 12

Social insects: Termites, Honeybees, Ants; social organization and caste differentiation

Structure of the Unit:

12.1 Objectives

After completing the unit, you will be able to understand about-

- Social Insects
- Eusocial, Presocial, Subsocial, Parasocial species
- Termites
- Social organization and caste differentiation
- Fertile castes and sterile castes
- Importance of Pheromones in termites life
- Structure and composition of nest of termite
- Different types of termite
- Bees
- Social organization and caste differentiation
- Queen, Drone and workers
- Nuptial Flight

- Structure of Bee hive
- Different types of bees
- Bees communication
- Ants
- Social organization and caste differentiation
- Queens, Workers and Mates
- Importance of Pheromones in ants life
- Nest structure of ants
- Different types of ants

12.2 Introduction

Social insectmeans insects that live in colonies and manifest three characteristics: group integration, division of labour, and overlap of generations, feeding aggregations, parental care of the young and communal nest sites.

Many insects exhibit "social" behaviour. In a broad sense, any insect that interacts with another member of its own species could be called a social insect. Truly social (**eusocial**) means a species must exhibit all four of the following characteristics:

1. Share a common nest site
2. Individuals of the same species cooperate in caring for the young
3. Reproductive division of labor -- sterile (or less fecund) individuals work for the benefit of a few reproductive individuals
4. Overlap of generations -- offspring contribute to colony labor while their parents are still alive

Species that lack one or more of these characteristics are classified as **presocial**. Within this category are **subsocial** species (in which the parents care for their offspring) and **parasocial** species (which have a common nest site but lack one or more of the other eusocial characteristics).

Living in social groups has both advantages and disadvantages. Inlarge colonies there is risk of spread of contagious pathogens, nest sites may be attacked by "social parasites" who steal food or attack the brood, and member individuals must compete with each other for space and resources. On the other hand, cooperative behavior can accomplish construction of huge nest sites, widespread foraging for food, and constant vigilance against predation or parasitism. For social insects, the benefits outweigh the liabilities. Social behavior is an adaptation that promotes survival and reproductive success of the species.

Relatively few insects are classified as eusocial -- the distinction is limited to the following groups:

Order Isoptera

Termites -- all species

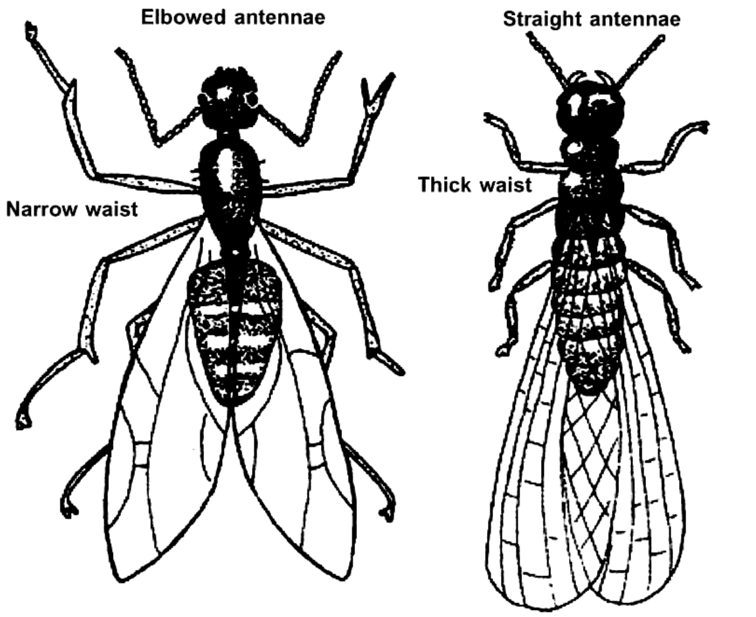
Order Hymenoptera

Ants -- all species (family Formicidae)
Bees -- about 600 species in the family Apidae
Wasps -- about 700 species in the family Vespidae

12.3 Termites

Termites are the members of order Isoptera. All isopterans are eusocial insects. Termites feed primarily on the cellulose and lignin found in plant cell walls; these compounds are the main ingredients of wood and all paper products. Termites cannot digest the cellulose directly so they rely upon symbiotic bacteria and protozoa living within their intestines to supply most of the enzymes needed for cellulose digestion.

Termites are sometimes called white ants. They may resemble ants in size, but they are not ants. They are distinguished from ants by the absence of a constriction or peduncle between the thorax and the abdomen. Ants have unequal wings (anterior pair is larger), whereas the termites have equal wings. Termites live on wood and are nocturmal, whereas the ants live on sweet chemicals and anima's matter and are diural. *Microtermesobesi*and *odntotermesobsus* are two common species of termites found in India.



Ecologically, termites play an important recycling role in the environment by helping to break down dead wood and other plant tissues. They become pests when their appetite for wood and wood products extends to human household items likefurniture, building materials, cardboard, and other valuable products.

Social Organization and Caste Differentiation

Each termite nest or colony can have hundreds, thousands, or even millions of members. In fact, the termite colony is really a large, extended family. Within this family, various groups of individuals have differentfunctional roles according to a "caste system".

The colony of termites is well managed by division of labour as termites exhibit polymorphism. Colony comprises two major castes (A) Fertile caste (B) Sterile Caste.

(A) **Fertile caste**: The fertile caste is of the following three forms:

a. **Long winged adults or colonizing Adults:** winged adults are produced in good number in rainy season and are actually winged males and female. Male and female individuals go on nuptial flight and copulate in the sky. After fertilization the female may have a new colony separately. Males have well developed eyes and wings. Long winged adults are of two types.

i. **Queen:** The queen of *M. abesi* is 5 to 7.5 cm. in length. The sole function of the queen is egg laying. She lays about 70,000 to 80,000 eggs in 24 hours. The life span of a queen is recorded to be 5 to 10 years. The queen lives n royal chamber of the nest and feeds royal jelly. The queen is well served by the workers.

ii. **King:** The king is father of the colony living with the queen in the royal chamber. It is developed from an unfertilized egg by feeding on nutritive diet. It fertilizes the queen repeatedly to produce fertilized eggs for the hatching of the winged male, female and workers. Life of the king is shorter than the queen. So the king is replaced by a new one.

Both true kings and queen have two pairs of wings in the beginning but wings are ultimately discarded and only their truncated base remains present.

b. **Short-winged adults(Brachypterous):** These are supplementary or substitute orneotenic king and queen. Body is less pigmented. The two pairs of wing are short, vestigial and pad-like.

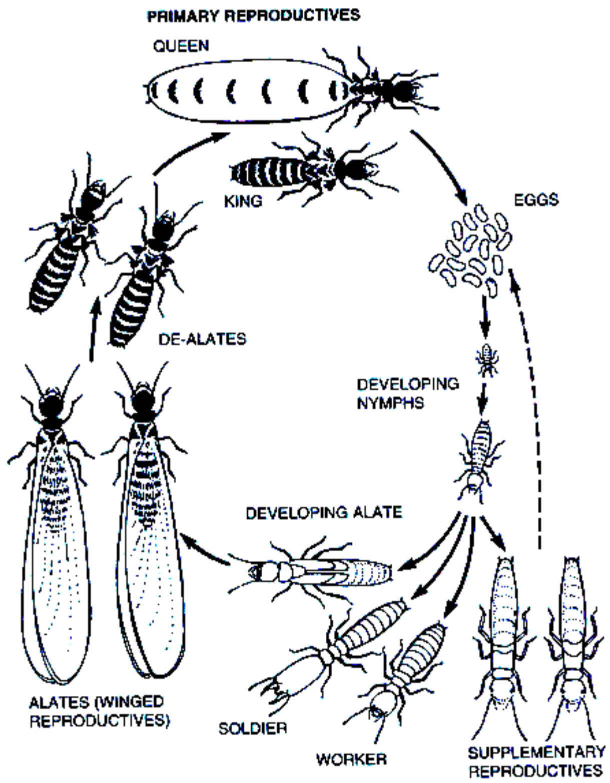
c. **Wingless form (Apterous):** There are worker-like substitute kings and queens which occurs in the more primitive species. The body is without pigmentation. There are no traces of wings.

(B) **Sterile castes**: These are form with rudimentary reproductive organs. This is of three types:

a. **Workers:** The workers are numerous and the largest group. They perform all the duties of the colony except reproduction. The body has little or no pigmentation. The workers are commonly dimorphic, but sometimes trimorphic comprising small, intermediates and large individuals.These soft-bodied, wingless individuals perform all of the hard labor in the colony: they clean, maintain, and repair the nest, gather food and water, care for the young, and construct new tunnels and galleries as the colony grows. These juveniles all have the genetic capacity to undergo additional molts and become soldiers or reproductives, but most will spend their entire lives as workers.

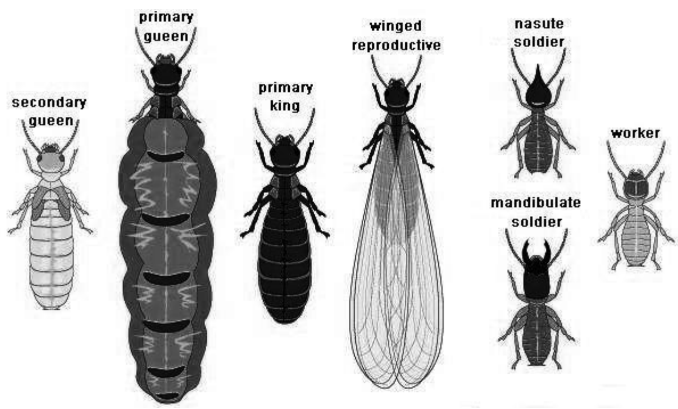
a. **Soldiers:** The soldiers are highly specialized. Soldier caste are larger in size but fewer in number than the workers.They are concerned with the defense of the colony against predictors. They are also wingless,pigmented and large handed individuals with projected prominent mandibles. In some species three grades of soldiers-small, medium and large are present.

b. **Nasutes:** In higher genera (*Edutermes*) the mandibulate soldiers are replaced by other form called the nasutes. Their head is prolonged into a rostrum, lack jaws but have a large gland in the head that shoots defensive chemicals through a nozzle at the front of the head. Head have the opening of a large frontal gland at its apex. The sticky secretion of the gland is inflicted upon their enemies in warfare and is used to dissolve hard substances, like concrete which fall in the way of the workers when building nest.



Role of Pheromones

The termite's caste system is regulated by pheromones. The king and queen each produce special pheromones that circulate throughout the colony and inhibit workers of the same sex from moulting into reproductive adults. A death in the royal family or an increase in the size of the colony can results in a lower concentration of the corresponding pheromone and, subsequently, one or more workers will moult into replacement reproductives. Likewise, the concentration of sex-specific soldier pheromones regulate the numbers of male and female soldiers to fall within an optimal range based on colony size. Excess numbers of soldiers or reproductives may be killed and eaten by the workers.



Nest of Termite (Termitaria)

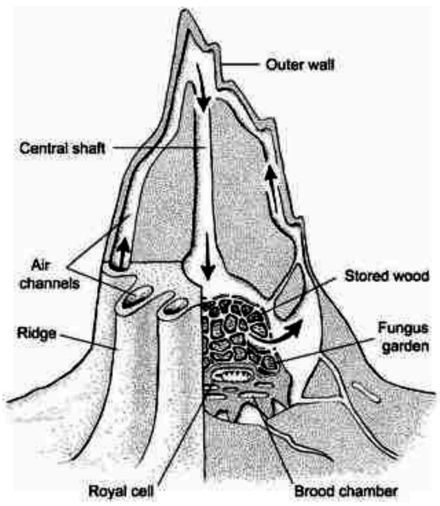
The primitive termite species feeds upon wood cellulose and excavate galleries in wooden structure. Some species construct carrion nestof masticated wood. These carrion nests are ovoid or rounded in shape. The nest may attain the sizeof football and placed up the trees.

Subterranean termites usually construct underground nests and have the ability to tunnel through the soil to find new food resources. These colonies are often long-lived and may grow to include several million individuals. The subterranean termites that live in North America and Europe often invade wooden structures above the ground by building earthen tubes that serve as protective tunnels between the nest and their food source. These tubes are good evidence of a termite infestation.

The termites are the most efficient engineers that the entrance to their mounds always faces north. They build excellent natural air conditioning systems, which modern day architects are at pains to figure out. Many species burrow in the ground and constructs a nest or termitarium. They consist numerous tunnels and chambers and may be entirely subterranean or with a mound above the surfaces. Suchtermitaria may be a few meters high and 9 meters in basal diameter. The termitaria are made up of sand particles which are cemented together by saliva and faecal matter of termites.This material on drying becomes hard like cement.

In Africa and Australia, other subterranean species mix bits of soil with saliva to build nest mounds that are up to 20 feet (6 meters) tall. The inside of the mound is divided into numerous chambers and galleries. The king and queen live in a special cell deep inside the mound. The female's abdomen grows in size until it is large enough to hold many thousands of eggs. The queen lays these eggs at the rate of several thousand a day. Worker termites carry the eggs away to specially constructed cells in the nest. There the workers care for the young as they hatch from the eggs.

Some of the mound-building termites cultivate underground fungus gardens. They collect dead plant material, mix it with saliva and their own waste products to create a paste, and inoculate this substance with the spores of a symbiotic fungus. The termites feed on special structures produced by the growing fungus.



Types of Termites

1. **Drywood Termites**

This is an extremely common type of termite found in many parts of the world. They can be easily recognized by the hexagonal pellets that these species leave behind after eating the untreated wood. The dry-wood termites eat the wood from within and create a hollow. If we simply touch wood in those hollow spaces, the pieces tend to wither and fall down. There are further sub-classifications of dry-wood termite. All these sub-categories have a common habit of building tunnels along the grain of the wood. The various species of drywood termites based on their physical appearanceare as follows-.

- **West Indian Drywood Termites** – The swarmers have a body length of around 6mm or greater with a head width of bigger than 1 mm. These species tend to swarm at nights. The soldier species have a 5mm long body and head bigger than 1 mm width. The head of this termite is rough without an identifiable frontal ridge.
- **Indo-Malaysian Drywood Termites** – The swarmers have a body length lesser than 5mm and the head smaller than a 1mm width. These species swarm during the morning hours. Soldier varieties of the Indo-Malaysian dry wood termites have 3-4mm long body and their heads have a distinct front rim.
- **Western Drywood Termite** – The swarmer variety of this termite has a dark brown body with a reddish-brown color on the head. They swarm in the daytime. The soldier species have an extra-long third antenna section that succeeds the length of the subsequent antennas by at least three times. These varieties are more common in places with low elevations.

2. **Subterranean Termites**

The second most prevalent type of termite is the subterranean termite. This variety is generally found in premises built on elevated foundations. These species can survive only underground, as they need high moisture levels to thrive. They build mud tubes to maintain the requisite humidity levels. They can also construct the mud tunnel on walls, cracks, wood and anything that comes in direct contact with the ground.The various species of these termites based on their physical appearance are as follows-.

- **Eastern Subterranean Termites** – They are generally found in North America and found in swarms of thousands. They swarm mainly during the spring season. We can easily identify them by finding mud tubes or the wings of the king and queen termites.
- **Western Subterranean Termites** – They enter our homes through cracks in the foundation and other gaps which are as small as 1/16″ in width. We can identify them through the colonies underneath the frosty level and above the water table in the ground. They eat the cellulose part of the wood found in dressers, furniture, walls and floors.
- **Desert Subterranean Termites** – They are commonly found in the dry desert climatic conditions and have long mouths than wider ones found in other species. If we find a small mud tube hut hanging from ceilings, wooden walls, shelves, overhangs and the like, then we can be sure that our house has become a victim of the desert subterranean termites.

3. Dampwood Termites

The dampwood termites thrive in high moisture conditions, and do not require staying underground or in contact with the soil to survive. They are identified by the traces of the dampwood species near water leaks, in wall voids. They are also found in moist and decaying wood in dead trees, stumps and logs. If we find exterior damage to wooden furniture, floors or ceilings, then there will be surity about the existence of dampwood termites. The intensity and pattern of wood damage basically depend on the level of wood decay. These termites are visibly bigger than other termite species. The different varieties of dampwood termites and all have similar identification traits. The immature termites work in colonies and use their faecal pellets to seal their living spaces so as to prevent outside air from entering.

4. Formosan Termites

Formosan termites are the most destructive species of termites and are sometimes, considered as part of subterranean species in most places. They can be easily distinguished from other termites due to their comparatively larger size and yellowish brown bodies. These Formosan termites can form cartons inside the wood to retain water for their colony till they find a perennial water source. Their colonies are very large, numbering to thousands and millions of members in each colony.

12.4 Bees

Honey bees are social insects, which mean that they live together in large, well-organized family groups. Social bees are highly evolved insects that engage in a variety of complex tasks not practiced by the multitude of solitary insects. Communication, complex nest construction, environmental control, defense, and division of the labor are just some of the behaviors that honey bees have developed to exist successfully in social colonies. These fascinating behaviors make social bees the most fascinating creatures on earth.

Approximately more than 20,000bee species have been described worldwide. Nearly all of these species use pollen and nectar from flowering plants as food for themselves and their offspring. Physical adaptations for this lifestyle include branched (or plumose) body hairs for catching and holding pollen, combs (scopae) and baskets (corbiculae) for collecting and carrying the pollen, and chewing and lapping type mouthparts for sipping nectar from flowers. Some bees collect nectar and then convert it into honey. This process occurs in the bee's crop where sucrose in the nectar undergoes enzymatic conversion into glucose and fructose. The honey is regurgitated for storage or mixed with pollen and fed to developing larvae. Some bees have abdominal glands that secrete wax. This wax, alone or mixed with other substances, is often used for construction of the nest site. Although most bees are solitary or subsocial, the family Apidae contains three distinct groups that exhibit eusocialbehaviour: these are commonly known as stingless bees, bumble bees and honey bees.

Social Organization and Caste Differentiation of Honeybee

A honey bee colony typically consists of three kinds of adult bees: workers, drones, and a queen. Several thousand worker bees cooperate in nest building, food collection, and brood rearing. Each member has a definite task to perform, related to its adult age. But surviving and reproducing take the combined efforts of the entire colony. Individual bees (workers, drones, and queens) cannot survive without the support of the colony.

In addition to thousands of worker adults, a colony normally has a single queen and several hundred drones during late spring and summer. The social structure of the colony is maintained by the presence of the queen and workers and depends on an effective system of communication. The distribution of chemical pheromones among members and communicative “dances” are responsible for controlling the activities necessary for colony survival. Labor activities among worker bees depend primarily on the age of the bee but vary with the needs of the colony. Reproduction and colony strength depend on the queen, the quantity of food stores, and the size of the worker force. As the size of the colony increases up to a maximum of about 60,000 workers, so does the efficiency of the colony.

Permanent houses, made up of sheets of wax (honey comb) are made by nearly 500 species of social bees. In the spring season a honeybee colony that has grown sufficiently large will split in two, with the old queen and half herworker along with a daughter who will become a new queenmake chambers in the ground in cliff, and in hollow trees. There are often many such sites within range of the waiting swarm,but only some motivate a worker to perform a dance back at the swarm a dance that communication information about the distance and quality of the potential new home. Colony of honeybees consists of three castes Queen, Drone and workers.

1.Queen

Each colony has only one queen, except during and a varying period following swarming preparations. Queen is a fertile female only one queen is found in a colony. The size of the queen is largest among other castes of bees. Queen can be easily identified by its long abdomen strong legs and short wings. The queen has ovipositor on the tip of the abdomen. The contribution of queen for its scullery is to lay eggs.

Queen is the only sexually developed female, her primary function is reproduction. She produces both fertilized and unfertilized eggs. Queens lay the greatest number of eggs in the spring and early summer. During breeding season, queens lay up to 1,500 eggs per day. They gradually slow down the process of laying eggs in early October and produce few or no eggs until early next spring - January. One queen may produce up to 250,000 eggs per year and possibly more than a million in her lifetime.

A queen is easily distinguished from other members of the colony. Her body is normally much longer than either the drone's or worker's, especially during the egg-laying period when her abdomen is greatly elongated. Her wings cover only about two-thirds of the abdomen, whereas the wings of both workers and drones nearly reach the tip of the abdomen when folded. A queen's thorax is slightly larger than that of a worker, and she has neither pollen baskets nor functional wax glands. Her stinger is curved and longer than that of the worker, but it has fewer and shorter barbs. The queen can live for several years, sometimes for as long as 5, but average productive life span is 2 to 3 years.

The second major function of a queen is producing pheromones that serve as a social "glue" unifying and helping to give individual identity to a bee colony. One major pheromone is termed as queen substance. It is produced by her mandibular glands, but others are also important. The qualities of the colony depend largely on the egg-laying and chemical production capabilities of the queen. Her genetic makeup is along with that of the drones she has mated withcontributes significantly to the quality, size, and temperament of the colony.

About one week after emerging from a queen cell, the queen leaves the hive to mate with several drones in flight. Because she must fly some distance from her colony to mate, she first circles the hive to orient herself to its location. She leaves the hive by herself and is gone approximately 13 minutes. The queen mates, usually in the afternoon, with seven to fifteen drones at an altitude above 20 feet. Drones are able to find and recognize the queen by her chemical odor of pheromone. If bad weather delays the queen's mating flight for more than 20 days, she loses the ability to mate and will only be able to lay unfertilized eggs, which result in drones.

After mating the queen returns to the hive and begins laying eggs in about 48 hours. She releases several sperm from the spermatheca each time she lays an egg destined to become either a worker or queen. If her egg is laid in a larger drone-sized cell, she does not release sperm. The queen is constantly attended and fed royal jelly by the colony's worker bees. The number of eggs the queen lays depends on the amount of food she receives and the size of the worker force capable of preparing beeswax cells for her eggs and caring for the larva that will hatch from the eggs in 3 days. When the queen substance secreted by the queen is no longer adequate, the workers prepare to replace her. The old queen and her new daughter may both be present in the hive for some time following supersedure.Supersedure is the act or process of superseding; especially the replacement of an old or inferior queen bee by a young or superior queen.

New virgin queens develop from fertilized eggs or from young worker larvae not more than 3 days old. New queens are raised under three different circumstances: emergency, or swarming. When an old queen is accidentally killed, lost, or removed, the bees select younger worker larvae to produce emergency queens. These queens are raised in worker cells modified to hang vertically on the comb surface. When an older queen begins to fail because of decreased production of queen substance, the colony prepares to raise a new queen. Queens produced as a result of swarming are usually better than emergency queens since they receive larger quantities of food of royal jelly during development. Like emergency queen cells, supersedure queen cells typically are raised on the comb surface. In comparison, queen cells produced in preparation for swarming are found along the bottom margins of the frames or in gaps in the beeswax combs within the brood area.

2.Drone

Male member of colonies are called as drones. Drones are haploid fertile males. The size of drone is smaller than queen but larger than sterile femalesi.e. workers. They copulate with the queen and fertilize her eggs.

Drones are largerthan worker and smaller than queen bees in the colony. They are generally present only during late spring and summer. The drone’s head is much larger than that of either the queen or worker, and its compound eyes meet at the top of its head. Drones have no stinger, pollen baskets, or wax glands. Their main function is to fertilize the virgin queen during her mating flight. Drones become sexually mature about a week after emerging and die instantly upon mating. Although drones perform no useful work for the hive, their presence is believed to be important for normal colony functioning.

While drones normally rely on workers for food, they can feed themselves within the hive after they are 4 days old. Since drones eat three times as much food as workers, an excessive number of drones may place an added stress on the colony’s food supply. Drones stay in the hive until they are about 8 days old, after which they begin to take orientation flights. Flight from the hive normally occurs between noon and 4:00 p.m. Drones have never been observed taking food from flowers.

When cold weather begins in the fall and pollen or nectar resources become scarce, drones usually are forced out into the cold and left to starve. Queenless colonies, however, allow them to stay in the hive indefinitely.

3.Workers

Workers are the smallest and sexually undeveloped females. They constitute the majority of members occupying the colony. Under normal hive conditions do not lay eggs. These are diploid sterile females their sterility is due to diet effect queen substance and the pheromone. Their numbers in colony is the highest.

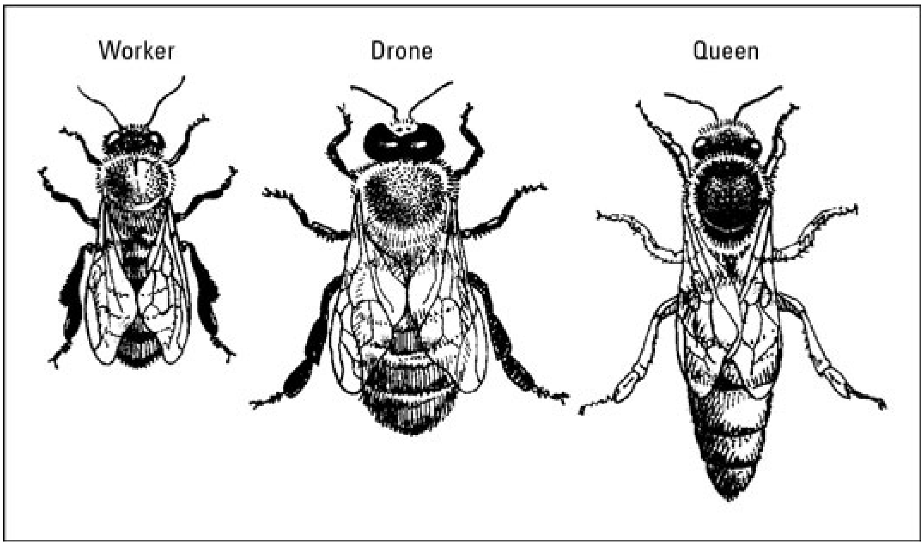
Workers have specialized structures, such as brood food glands, scent glands, wax glands, and pollen baskets, which allow them to perform all the different responsibilities of the hive. They perform all the functions of the colony except egg laying. Workers have behaviour of doing all the works of the colony such as collection of pollen grains, water and nectar from flowers, cleaning and defending the colony, nursing embryo etc. from their ancestors.

They clean the cells and maintains the hygienic conditions of hive, feed the brood, care for the queen, remove debris, build beeswax combs, guard the entrance, and air-condition and ventilate the hive during their initial few weeks as adults. Later as field bees they forage for nectar, pollen, water, and plant sap.

The life span of the worker during summer is about 6 weeks. Workers reared in the fall may live as long as 6 months, allowing the colony to survive the winter and assisting in the rearing of new generations in the spring before they die.

Numerous adaptations have taken place in the body of worker bee to perform various factions of the comb. Its body is hairy and legs are modified. When workers visit a garden of flower and sit on a flower pollen grains adhere to these hairs and other parts of the body Worker clean off pollen with the help of a special structure (the cleaners) present on each fore legs. Pollen brushes are present on every leg and pollen grains are stored in the pollen basket present on the outer surface of tibia on hind legs. Nectar and water is collected in crop by sucking through mouth parts.

Worker bees possess Nabokov scent gland in their abdominal region. A pheromone is released from this. This defensive organ is modified ovipositor having a large poisonous storage sac and a sting. Poisonous storage sac contains a poisonous chemical. This chemical is injected into the body of enemy through sting. Worker bees attack collectively to the intruder and sting the intruder collectively.



Nuptial Flight

Most interesting part in the life cycle of honeybee is its way of mating. Mating takes place during a fight called nuptial fight. Virgin queen takes a flight followed by males. A few males only succeed in mating. Queen and other males return to their comb. But now worker bees allow only the queen and all males are driven away and they die in nature. Polyandry is relatively rare in insects where a single female mates with several mates. But polyandry is common phenomenon in honeybee. Queen honey bee mates with several drones in succession during her nuptial flight.

Bee Hive

The highest degree of nest construction among insects is found in bees. The architecture of the nest is unsurpassed and unparalleled in the animal kingdom. The hive and comb of the bees are formed mainly by workers. A comb is a vertical sheet of wax, composed of a double layer of hexagonal cells projecting in both directions from central wax-sheet.

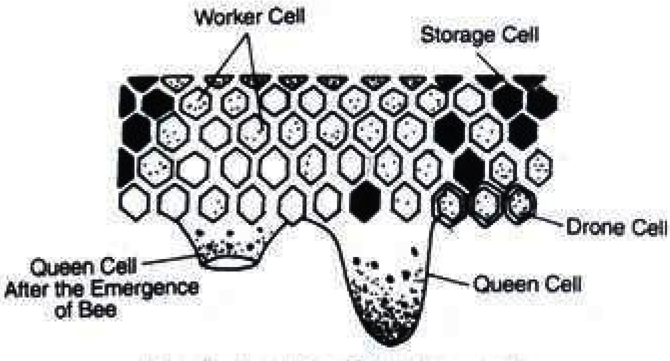
The worker bees produce wax for the formation of the new hive and are known as builders. New hive is made hanging vertically from rock buildings or branches of trees consists of thousands of hexagonal chambers of cells made up of wax secreted by the builder's abdomen The resins and gums secreted by plants are also used for construction and repair of the hive.

Comb hangs vertically downward, while cells are horizontal in position. The hexagonal shape of cells accumulates maximum space in minimum use of wax and labour. The wax used in building of a comb is secreted from the wax glands present in the abdomen of worker bees. This wax has the highest melting point i.e., 140° F. Before use, the wax is masticated and mixed with secretions of the cephalic glands to convert into a plastic substance.

The resinous substance called “propolis”, prepared from pollen, is used in making the comb water—proof, and it also helps in filling the cracks and crevices in the hive.

The cells of the comb are of various types. The “Storage cells”, which contains honey and pollen are generally built on the margin and at the top of the comb. The “brood cells”, which contains the young stages, are built in the centre and the lower part of the comb. Brood chamber is further divided into three types, namely Worker-chamber, where developing workers are reared; Drone-chamber, where developing drones are reared and the Queen-chamber, which is larger than other and where the larvae developing into queens are reared. There is no special chamber for adults. They move on the surface of the comb.

In *Apis dorsata* brood cells are similar in shape and size but in other species brood cells are of three types viz worker cell for workers drone cells for drones and queen cell for the queen cell is used once only while rest are used a number of times there are no cells for lodging the adults. They generally keep moving about on the surface of the hive. The cells are mainly intended for the storage of honey and pollen especially in the upper portion of the comb.



Types of Bees

- **Honey bees** include the well-known European honey bee (*Apismellifera*) as well as 8 other species of *Apis* that are native to Europe, Asia, and Africa. These bees usually nest above ground, often inside hollow trees. They construct vertical wax combs with individual hexagonal cells for storing honey and rearing brood. During cold winters, the bees cluster together, feeding on stored food reserves and sharing their body heat.
- **Bumble bees** are large, fuzzy bees that typically nest in thick tufts of grass or in shallow underground cavities. About 300 species of eusocial bumble bees have been described worldwide but their distribution is almost entirely limited to temperate zones in the northern hemisphere. Colony structure is largely seasonal. Mated queens hibernate during the winter and emerge in early spring to build a small nest site containing a "honey pot" and several brood cells. After gathering a supply of nectar and filling her "honey pot", each queen lays a few eggs and "singlehandedly" rears her first brood -- all daughters. When these offspring become adults, they remain unmated, stay with the queen, and serve as the first members of the colony's worker caste. Thereafter, the queen does very little except lay eggs while her workers perform all tasks related to gathering food, enlarging the nest, and caring for the young.
- **Stingless bees** include about 300 eusocial species that are mostly tropical or sub-tropical in distribution. They are called "stingless bees" because the sting is reduced in size and rarely used for defense. These bees often nest in hollow trees or rock crevices. They collect nectar and

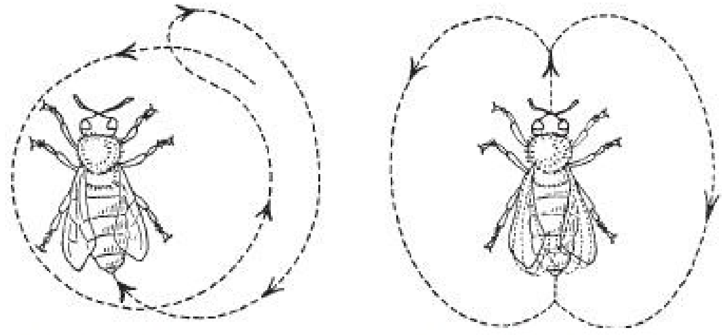
pollen from flowers and store honey in large egg-shaped pots made of cerumen, a mixture of beeswax and plant resin. The honeypots are usually arranged in an irregular perimeter around a central brood comb that is constructed in horizontal layers.

- Most species of stingless bees are relatively small (less than 1 cm in length) and live in colonies that contain one queen and 50-1000 workers. A few species, however, are as large as European honey bees and may have over 40,000 workers living together. Both queens and workers develop from fertilized eggs, but queen larvae have larger brood cells and receive more food than worker larvae. Males (drones) develop from unfertilized eggs (often laid by unmated workers). Most of the stingless bees form perennial colonies with the ability to replace the queen when she dies. Large colonies may divide by swarming, but workers usually build and provision a new nest before it will be occupied by a young queen and a group of workers from the old nest.

Bee Dance (Beecommunication)

Honeybees are with complex behaviour and social organization. This tiny insect detect polarized light, memorizes the details of their environment, learn and communicate about food source among –members of comb.

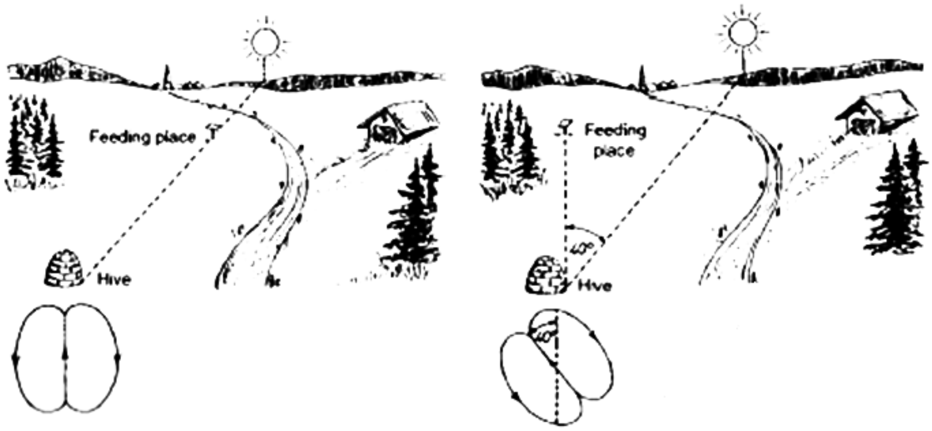
Karl von Frisch after 20 years of research work could reveal that worker bees communicate information about the load of food source through "bee dance". “The dance is performed on the hive”. Frisch revealed his work in the year 1967 and got Nobel prize for this contribution in the year 1973. The information given by stout bees to the members of her colony by dance is called as "language of the bees” or we can say that the dance displays of bees encode fairly specific information about the distance and direction to suitable foraging sites.



Round dance Waggle dance

If the forager bees has found a rich new food source, a distance within 50 meters form the hive, she performs roughly a circular path called "round dance".She moves in circles alternately to the left and to the right, turning first one way and them the other way. Other workers follow her in round dance and are then stimulated to set out on foraging flights.

If the food source is more than 50 meters from the hive a forager performs a "Waggle dance".In a waggle dance she moves in a narrow semicircle, turns along its diameter, making a figure of '8'. This waggle dance shows information about both the direction and the distance of the food source.



A foraging bee on the way to a discovered food source notes the angle between the food source, hive and sun. During a waggle dance she transposes this information onto the surface of the comb. If the bee walks vertical waggling straight up the comb. If the bee walks vertical waggling strait up the comb, the feeding place will be found by flying directly towards the sun. If the honeybee walks horizontal and waggling straight down the comb, the food is located directly away from the sun. If food source is positioned to the right of a line between the hive and the sun waggle oriented at 90^0 to the right on the comb. If food source is positioned 90^0 to the left of a line between the hive and the sun forager move horizontal and waggle runs oriented at 90^0 to the left on the comb, in waggle dance, sun-compass information about food source is converted into a symbolic code based on gravity. Bees are very sensitive to ultra violet rays and in addition they can orient to the plane of polarization of light coming from a blue patch of sky.

12.5 Ants

Ants communicate with each other through tappings with the antennae and smell. They are considered, together with the bees, as one of the most socialized animals. They have a perfect social organization, and each type of individual specializes in a specific activity within the colony. They are intelligent creatures and each ant is considered then as an individual cell of a bigger organism.

There are over 8,800 species of ants in the family Formicidae -- all of them are eusocial. There are more species of ants than all other social insects combined. They are also the most ecologically diverse group in terms of distribution, life history, feeding strategies, and specialized adaptations. As a group, ants consume a wide variety of food, but individual species usually tend to specialize: some are primarily carnivores, some gather seeds and grains, while others concentrate on sweets (nectar and honeydew).

The ants are among the most highly evolved social insects. Like honeybee and termites they also have a very complex social organization. About 90% ant species are social. Six species of ants are:

1. *Monomorium* : Large and black ants living in cervices of walls, trees, trunks etc.
2. *Componotus* : Common back, house ands
3. *Solenopsis*: Small and red, house ants
4. *Dorylus* : Winged ants which appear around light after rains.
5. *Aenictus* : Common and gregarious ants.
6. *Oecophylla* : Red, tree ants.
7. *Formica* : Make mound nest.

Social Organization in Ants

The ant colony is made up of one or more fertile egg-laying queen, hundreds or thousands of adult female workers, a nursery for rearing eggs, larvae, and pupae, a storage area for food reserves, and a disposal site for waste and dead bodies.

During two or three days a year there will also be drones, which seem to have only a reproductive function.The queen emits an scent that makes all the workers behave in the way they do. An ant that loses its way to the nest does not live long.

Most new colonies are founded in late spring or early fall after an annual "swarming" event in which hundreds or thousands of winged ants which are virgin males and females and emerges from their nests and fly into the air for the purpose of mating. After returning to earth from this nuptial flight, the male wanders off and dies. The new queen sheds her wings and scouts around for a suitable homesite. She lays a small clutch of eggs and cares for them until they mature into her first batch of workers which are all females. Thereafter, the queen devotes herself to laying eggs while the workers forage for food, care for the young, and enlarge the nest.

In some species, each nest contains only a single queen (monogyny) while other species may have several queens living together peacefully in the same nest and sharing in egg production (polygyny). In single-queen colonies, all of the workers are sisters so there is a selective advantage for mutual cooperation. Death of the queen, however, will result in death of the colony because the workers have no way to replace their queen. In multiple-queen colonies, the death of a single queen has less impact. New queens may be adopted or adjacent colonies may join together. Colony survival is maximized at the expense of individual queens who gain no selective advantage if their own daughters are rearing the offspring of another queen.

In some ants, all workers are similar in size and appearance. But in other species, workers may vary in size and some individuals may have physical characteristics that make them more suited for some jobs than for others. The smallest individuals, sometimes called minors (or minims), generally work inside the nest caring for the queen or feeding the larvae. Larger individuals may forage for food or enlarge the nest. The largest ants, called majors (or maxims), often have huge mandibles and powerful jaw muscles. They often serve as soldiers, standing guard at the nest entrance, protecting foragers from predation, or defending the colony from raids by other ants.

Caste Differentiation in Ants

The ants show an extreme case of polymorphism According to Imms (1948) at least 29 distinct types of morphologically different individuals are known. The main castes are queens, workers and mates.

1. **Queen or Gynes**

   These are the fertile females: Queen is larges is size in comparison to other castes of their species. The antennae and legs are relatively shorter and stouter and the mandibles are well developed. Some species are winged while some species are wingless. Usually large individuals are termed macrogynes, and dwarf ones, microgynes. Unlike honeybees, a colony of ants contains several queen.

   An egg laying worker, gynaecoid, occurs in colony. She becomes normal queen if queen is lost due to any reason. Rarely there occur some peculiar individuals called gynandromorphy. They bear external secondary sexual characters of both male and female.

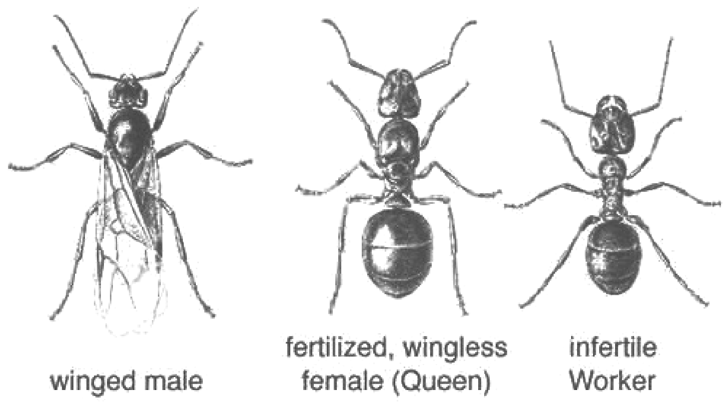
2. **Workers of Ergates**

   Sterile female are called workers or ergates. Ergates are smallest in size. They are characterized by a reduced thorax, and small eye. Workers are mostly dimpohic. The larger workers are called the macregates and dwarf individualsmicregates. Macregates are called the wrestlers of the insect world for their ability to lift too many weights. They also have amazing sense of direction. Soldiers are modified workers (sterile female). They are without wings, with distinct heads and powerful They protect the - from enemies. Besides protection they serve to crush e seeds and other hard food for inmates.

   Number of army ants in a colony is very huge containing up to 22 million individuals- While on march they eat up everything edible in their path. Army ants have three types of workers. Small worker perform the task of feeding the developing broods. Intermediate size of workers act as foragers or scout ants. These search the site of food. Largest size of workers is soldiers defending their colony. Some soldiers attack the colony of the insects and capture the young larvae and pupae of other ant colonies. There capture larvae and pupae after hatching are used a slaves.

3. Males or Aners

These are small, fertile winged individuals. They bear proportionately smaller head, reduced mandibles, longer antennae, well developed reproductive organs and genitalia. The larger individuals are called the macraners and the smaller one micraners.

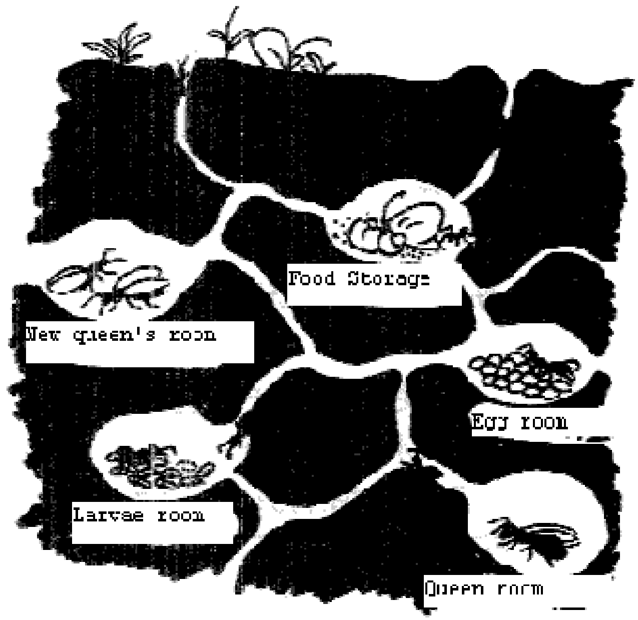


Role of Pheromones

Pheromones play very important role in the maintenance of the social organization of an ant colony. Alarm, social cohesion, recruitment, and trail marking pheromones are among the list of semiochemicals that have been reported in ants. Each colony also has a distinctive taste or odour which members use to identify nestmates and exclude invaders. Regulation of caste is not well-understood. Apparently, all female eggs are identical when laid. Whether they mature into minors, majors, soldiers, or new queens depends on the care and feeding they receive as they grow and mature. To some extent, this may depend on the needs of the colony as manifested through feedback loops involving photoperiod, food supply, temperature, and many other variables.

Nest of Ants

The new colony is founded by a single newly fertilized queen. Some species do not construct nests. They simply take abode in cervices, holes under stones, or logs. Some species temporarily occupy nests other ants, a relationship termed parabiosis. Most species make their own nest. The nests or formicaries are of different types located in different places. Ants make subterranean nests excavating galleries in the-grounds, used as nurseries for brood, granaries for storing food. Many species make mound nests. Such mound nests are well exhibited by species of *Formica*. *Formica rufa* make mounds of60-160cm. in diameter. Some species construct suspended nests made of earth carbon which is saliva mixed with Vegetable matter or silk hanging from trees in tropics and containing anastomosing galleries and chamber.



African weaver ants (*Oecophyllalonginoda*) and Asian weaver ant (*Oecophyllasmaragdina*) construct large conspicuous nests on tree by weaving together several leaves with silk. They obtain the silk from their own larvae. The colony of weaver ants consists of a single queen and two kinds of workers, the larger major workers who forage, construct the nest, and take care of the queen, and the smaller minor workers who care for the eggs and young larvae.The adult worker cannot product silk. The silk is produced by the larvae. It is well known to us that in most insect species the larvae use their silk to spin cocoon inside which the pupae undergo metamorphosis. The major weaver ant workers who need silk, hold larvae together during nest construction to obtain silk from these larvae. While some major workers maneuver and hold leaves together, other major workers hold larvae in their mandibles and weave them across the leaf This makes the larvae release strands of silk from silk glands underneath their mouth. Male larvae have smaller silk gland and contribute less silk for nest construction or cocoon.

Types of Ants

With more than 8,800 described species, ants are the most ecologically diverse of all social insects. The following list includes some of the more common groups

- **Harvester ants** usually live in arid environments and feed primarily on seeds. Many species build elaborate underground nests that may reach depths of six feet or more.
- **Army ants** are nomadic predators that do not have permanent nests. They include legionary ants which live in South America, and driver ants which live in Africa.
- **Slave-maker ants** raid the colonies of other species and steal worker larvae and pupae. Once the slaves mature, they work for their "owners" until they die.
- **Leafcutter ants** (also known as parasol ants) are gardeners. They chew up plant leaves into a pulp and use it to fertilize a fungus they grow for food in underground gardens.
- **Weaver ants** build nests in trees. Workers interlink their bodies, pull branches into position, and tie the leaves together with silk spun by their larvae.
- **Honey-pot ants** feed on honeydew excreted by aphids. Some workers engorge themselves with food reserves until their abdomens swell to the size of marbles.
- **Fire ants** are an invasive species with a very painful sting. They respond aggressively to any disturbance of their nest.
- **Thief ants** are very small. They raid the food supplies of larger ants and then escape through tunnels that are too small for the bigger ants to enter.
- **Carpenter ants** build their nests in wood. Unlike termites, they do not eat the wood but they may still cause serious damage to homes and other wooden structures.

12.6 Summary

Insect society is more organized and functional in many ways in comparison to any other society. It is real paradise where each member ceaselessly keeps on contributing for the welfare of the society and race continuity without any personal greed, lust of jealousy. Most species of honeybees, ants and wasps of order Hymenoptera and termites of order isoptera of class Insecta are perfectly social .

12.7 Self Assessment Questions

1. Define Eusocial behavior.
2. What do you mean by Presocial, Subsocial, Parasocial species ?
3. Explain the social organization and caste differentiation in termites in details.
4. Describe the importance of pheromones in termites.
5. Write an essay on Social organization of bees.
6. Write a note on different types of bees.
7. Describe the structure of bee hive.
8. Explain the structure of termitaria.
9. Describe the Social organization of ants in details.
10. Explain the role of pheromones in social insects.

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Unit – 13

Pest management

Structure of the Unit

13.1 Objective

After going through this unit you will be able to answer the following question

- How and why insects attain pest status?
- What are important parameters for pest categorization?

- What are important methods of insect control?
- Find out the important prophylactic, cultural and physical practices for pest management?
- What is the importance and history of plant quarantine?
- What are the important provisions of different acts related to plant quarantine?
- What are the importance of organizations *viz.,* DPPQS, NBPGR and APEDA in plant quarantine?

13.2 Introduction

Pest management is an application of technologies to achieve a satisfactory reduction of pest numbers and to maintain the pest population below levels that causes economic damage. It includes multiple tactics such as the use of natural enemies, cultivation of resistant crop varieties and insecticides etc. applied in a compatible manner. It also includes the use of such tactics that help in the conservation of environmental qualities. There are many tools for pest management but no one methods are without drawbacks. For convenience of studies, the pest management may be group in to preventive tactics such as cultural practises, physical and mechanical measures and legal control that prevent the insect to attain a pest status while others are curative tactics such as biological, bio-pesticide and chemical control that reduce the number of insect infesting the crops or human belongings.

Insect migration from one place to other is frequent phenomenon. The natural barriers are the only preventive measures of insect dispersal from one geographic to others. In past, there were no restrictions to carry plant materials. Now, Legal restrictions also play an important role to check the pest dispersal from one geographical area to other areas. Therefore, different countries established various institutes to execute rules and regulations to prohibit to dispersal of invasive pests and diseases.

13.3 Concept of pest: How and why insect have become pests?

13.3.1 Concept of pest: The word '**Pest'** derived from the Latin word '**Pestis'** meaning Plague. The term 'pest' is used broadly to insects, other invertebrate like nematodes, mites, snails, slugs, etc. and vertebrates like rats, birds, jackal etc., that cause significant and economic loss to crops, stored produce and animals. An insect (or any other living being) whose population increases to such an extent as to cause economic losses to crops or a nuisance and health hazard to man and his belongings will be declared a pest. An insect may be a pest at one place (or in one season) but may not be so at another place (or in the next season), therefore, being a pest or not is only a matter of insect numbers. For example, Painted lady butterfly, *Pyrameis cordui*, is only a thing of beauty in England where as in France it is a pest of artichokes. The population of pest never remains constant for long, but it tends to oscillate all the time about a theoretical optimum for the species. The following factors directly connected with men become civilized are responsible to convert insect into pest:

1. Cultivation of crop led to a concentration of host plants provide easily available food to enable the insect to flourish.
2. Domestication and large –scale cropping/breeding of livestock provided ideal conditions for their multiplication.
3. Storage of grains necessitated by large scale cultivation encouraged insects to thrive in food stored in plenty.
4. The increase in human population attracted many insects like, mosquitoes, lice, bed bugs etc. they become human parasites. Later, as the society evolved, the creation of families and villages would have lead to crowded living, favoring the spread of those parasites and with them the diseases (Pathogens) they carried.
5. Finally, deforestation necessitated by man’s needs for greater cultivation, habitation, establishment of large industries, etc., made forest insects, migrate to fields and become pests of such plants and animals which they would otherwise have not cared for.

Damage boundary is the lowest level of injury caused by pest where the damage can be measured. Insect pests are divided into negligible, minor and major pests depending upon the severity of damage caused on the crop yield. Those insects that cause less than 5% loss in yield, is said to be negligible. Insects which normally cause a loss ranging from 5 to 10% are said to be minor pests and those which cause a loss of 10% or more in general called as major pests.

13.3.2 Categories Of Pests

13.3.2.1 Based On Occurrence

- **Regular pest:** These are generally occurs in abundance during a crop season and have close association with crop. Ex. thrips on chillies, aphids on mustard & shoot & fruit borer on brinjal
- **Occasional pest:** Infrequently occurs, population is affected by unusual weather conditions or the injudicious use of insecticides, no close association with crop. Ex. caseworm of rice, mango stem borer, castor slug caterpillar
- **Seasonal pest:** These are occurs mostly during a particular part of the year in crop. The incidence of these pests is largely governed by the climatic and weather conditions in a locality or place. Ex. red hairy caterpillar on groundnut (April -May in Pollachi tract and during August in Madurai district in south India), rice grasshoppers, *Oxya* spp. and *Hieroglyphus banian* (nymph hatch out in June- July after receipt of rains).
- **Persistent pests:** These pests are occur on the crop throughout the year, and are difficult to control. Ex. chilli thrips, mealy bug on guava
- **Sporadic pests:** These pests occur in isolated localities during some period. Ex. coconut slug caterpillar, rice ear head bug

13.3.2.2 Based on level of infestation

- **Epidemic Pest:** Pests which come suddenly in a severe form in a region or locality at a particular season or time only. Ex. rice hispa, *Dicladispa armigera*, rice leaf roller, *Cnaphalocrocis medinalis* etc.
- **Endemic pest:** Pests which come regularly and confined mostly to a particular area or locality. Ex. red hairy caterpillar *Amsacta albistriga* on groundnut in Kurnool, Rice gall midge in Madurai and Mango hoppers in Periyakulam etc.

13.3.3 Causes for pest outbreaks in agro-ecosystems: The insect's pest problems in agriculture are probably as old as agriculture itself. However, under subsistence agriculture the pest numbers were generally low as the productivity was poor. The insects under favourable conditions multiply enormously and different species multiply at different rates. When the numbers of an insect increases, it reaches the pest status. Rapidly increasing human population during last century has necessitated intensification of agriculture through expansion of irrigation facilities, growing of new crops, introduction of improved and exotic varieties, and application of increased amounts of agrochemicals. Modern agriculture technologies have resulted in increased higher yields and it has also contributed in severe outbreaks of insect pests in agricultural crops. There are two major categories of pest out breaks *viz*., eruptive and gradient. The eruptive outbreak spreads out from local epicentres and cover large areas. This outbreak is self-perpetuating i.e. once initiated positive feedback processes operating at high population densities maintain the outbreak. Whereas gradient outbreak does not spread from local epicentres and not cover large areas and it is not self-driven and is entirely dependent on external environmental or internal genetic conditions. This type of outbreak arises and subsides as its driving forces change in time and space. The following are important factors which enhanced pest outbreaks:

- **Use of high yielding varieties and introduction of new crops:** Mostly improved strains of crop plants are susceptible to pests. Sometimes, the insects, which are considered of minor importance, become major importance with the introduction of new varieties and strains. The improved combodia cotton strains are highly susceptible to the spotted bollworm, *Earias* sp. and the stem weevil *Pempherulus affinis*. The spread of rice cultivation into the non-traditional north-western States like Punjab and Haryana has brought up the problem of white backed plant hopper (WBPH). The hybrid sorghum CSH-1 was severely attacked by shoot fly, *Atherigona varia soccata* stem borer, *Chilo partellus* and ear head gall midge, *Stenodiplosis sorghicola*.
- **Indiscriminate use of pesticides:** Sometimes use of insecticides as a prophylactic or curative measure results in reducing one of the competitive species of pests while allowing the others to multiply. Repeated use of same insecticides may also lead to the secondary infestation in which it is not effective. Continuous spraying of carbaryl on cotton against bollworms and on brinjal against shoot and fruit borer

results in the mite infestation which is often very severe. Indiscriminate use of pesticides also destroys the natural enemies of the pest and sometimes leads to the pest outbreak.

- **Excessive use of nitrogenous fertilizers:** Heavy use of inorganic nitrogenous fertilizers develops congenial conditions for rapid multiplication and subsequent outbreaks of pests. Application of nitrogenous fertilizers gives luxurious growth of the crop and makes it more vulnerable to insect attack as in case of cotton which show higher incidence of sucking insects like whiteflies, aphids and leafhoppers etc. because there will be no competition for food.
- **Destruction of forests and bringing forest area under cultivation:** The destruction of forest over larger areas for cultivation affects on weather factors *viz.,* temperature, humidity, rainfall, wind velocity etc., in that locality and thus set conditions favorable for some insects to develop enormously. The insects feeding on the trees and plants in the forest area are driven to neighboring areas where they may infest the cultivated crops and become new pests.
- **Introduction of a new pest in a new area:** When an insect gets introduced into a favorable new area without its natural enemies it becomes more abundant. The wooly aphid, *Eriosoma lanigerum*, became a serious pest of the apple in Niligiris as there was no natural enemy of the pest to check its multiplication. It was brought under control only when its specific parasitoid, *Aphelinus mali* was introduced from Punjab.
- **Monoculture (intensive and extensive cultivation of crops without proper crop rotation):** When a single crop is raised over extensive area, limitation of food gets nullified and there is no competition for food and shelter and these results in the increase in pest populations. The effect is more pronounced if the cropping is done in more than one season for the year. The incidence of borers is high when sugarcane crop is raised over extensive areas continuously. Cotton mono-cropping over large areas, prolonging the crop growth beyond the regular duration and non removal of crop residues before the next crop accentuates population of American bollworm *Helicoverpa armigera* and pink

bollworm *Pectinophora gossypiella* even if there is crop rotation with closely related crops or when there are alternative food plants for the insect pests concerned, again the population of insect pests is likely to increase. Cotton followed by okra increases the incidence of pests like bollworms, whiteflies, mites etc.

- **Accidental introduction of foreign pests:** Immature and adult stages of certain insects adhere closely to the plants such as scales and aleurodids and those which bore into the tissues of plant parts such as leaf miners, stem borers, gall insects etc., and are more liable to be introduced into other countries. Some of such insects introduced into India from foreign countries are the diamond back moth, *Plutella xylostella* on cruciferous vegetables the San Jose scale, *Quadraspidiotus perniciousus* on fruit trees on hills, the green mealy bug, *Coccus viridis* on coffee and the potato tuber moth, *Phthorimoea operculella*, cotton cushiony scale, *Icerya purchase,* Spiralling whitefly, *Alerodicus dispersus*, Coconut mite *Aceria guerreoronis* etc.
- **Destruction of natural enemies**: The natural enemies keep the insect pests under check. The destruction of these either by man or other agencies tends to increase the population of insect pests in an area. Sometimes the weather conditions may be favorable to the pest and unfavorable to its natural enemies. The insecticides may often affect the parasitoids and predators more than the host insects. DDT kills parasitoids and predators and thus encourages aphids, scales mealy bugs and spider mites to multiply into enormous proportions. Insecticides may also alter crop physiology to make the plant more susceptible to attack by insects or they may even directly stimulate reproduction of surviving insects.
- **Large scale storage of food grains:** Storage of food grains in large scale also leads to pest problems, if poorly managed. Large scale stored food grains are favorable for storage insects to breed and multiply.
- **Biotypes of pest species**: Insects have great adoptions for their survival. There are several insect species that develop biotypes that are able to develop and multiply even on resistant crop cultivars. Several biotypes

of aphids on mustard crop, gall midge and brown plant hopper on paddy and white fly on cotton etc. have been observed in India.

13.4 Insect control: Basic idea

Insect Control: Any factor that is capable of making life hard for the insect that will repel or interfere with its feeding, mating, reproduction or dispersal can be taken as a method of insect control in its broadest application. There are two ways in which insect pests are controlled.

13.4.1 Natural control: In nature, there are two sets of tendencies namely the biotic potential tending to increase the population and the environmental resistance tending to reduce the population. As such there is a constant interaction between these two opposing forces and then maintains a dynamic equilibrium known as Balance of life. It is evident from the above that in any case, the insects or other animals never attain the high density which they are potentially capable of doing which is because of environmental limiting factors like abiotic factors comprising mainly temperature and humidity which at too high or too low levels adversely affects insects. Natural disturbance like heavy rain, hail storms, snow, sand storms, dust storms, and very high wind velocity are adverse to insect life. Biotic factors *i.e.* limitation of food, competition for food and space and natural enemies act adversely depending on the density of population.

13.4.2 Applied control: Those control measures in which men's interventions are associated are called applied control. Early human had to live with and tolerate the ravages of insect pests and pathogens, but gradually learned to improve their condition through trial and error experiences. These improvements led to the beginning of pest control. Prior to the emergence of crop protection sciences and even before the broad outlines of the biology of pests were understood, humans evolved many cultural and physical control practices for protection of their crops. Cultural practices *viz.* crop rotation, clean cultivation, mixed cropping, use of traps crops, hoeing etc. were most important to preventing crop losses used by farmers in ancient times. Some of these control practises are still valid and useful to-day. Depending on the time of taking action the applied control measures may be

- Preventive or prophylactic *i.e.* action taken to prevent the occurrence or spread of infestation and
- Curative or remedial measures *i.e.* measures which are taken to kill the already existing pest population

13.5 Various method of insect control

Various methods of insect control: Several techniques available for controlling individual insect pests and are conveniently categorised in increasing order of complexity as - cultural, mechanical, physical, biological, genetical, regulatory and finally chemical. The main important practices are mentioned under different heading:

13.5.1 Cultural methods: Following agronomic practices come under cultural methods by which we can manage the insect pest of crops.

a.	Use of resistant varieties	f.	Pruning or thinning and proper spacing
b.	Crop rotation	g.	Planting of trap crops
c.	Crop refuse destruction	h.	Crop sanitation
d.	Tillage of soil	i.	Water management
e.	Variation in time of planting or harvesting	j.	Judicious and balanced use of fertilizers

13.5.2 Mechanical methods: a. Hand destruction, b. Exclusion by barriers, c. Use of traps

13.5.3 Physical methods:

a. Application of heat: Hot water treatment, exposing of infested grain to sun and super heating of empty godowns at 50 ^{o}C to kill hibernating stored grain pests.
b. Manipulation of moisture: Reduction of moisture content of grains helps to prevent from the attack of stored grain pests.
c. Radiant energies: Radio frequencies, infrared light, ultra violet and invisible lights and ionising radiations etc.

13.5.4 Biological control:

a. Protection and encouragement of natural enemies
b. Introduction, artificial increase and colonization of specific parasitoids (egg, larval & pupal parasitoids) and conservation of natural enemies
c. Propagation and dissemination of specific bacterial, viral, fungal and protozoan diseases.

13.5.5 Genetic methods: Use of sterile male technique

13.5.6 Regulatory methods: Plant quarantine (Foreign & Domestic quarantine)

13.5.7 Chemical methods: Use of attractants, repellents, growth inhibitors & insecticides etc.

13.6 Prophylactic and cultural methods

Prophylactic and cultural methods

13.6.1 Prophylactic methods: It's includes some culture practices, legal measures and chemical practises, which are used to keep away the pests from crops. These are effective especially in the case of certain pests which are known to occur in an area year after year or season after season.

a. **Deep ploughing:** Several insects which live or hide in the soil get exposed to sun as well as predators like birds etc due to deep ploughing. Ex. Larvae and pupae of many insect pests
b. **Field and plant sanitation:** Regular removal of weeds, grasses which act as alternate hosts and pest affected part of plants will eliminate the source of infestation of the pest. By periodical removal of grasses from bunds, the mealy bug attack on the rice crop can be minimized , and by clipping of the dried branches of citrus further multiplication of the stem borer can be avoided.
c. **Growing pest resistant varieties:** Certain varieties of crops are inherently less damaged or less infested than others by insects. These are called resistant varieties. Ex. GEB-24 and MTU–5249 resistance to paddy BPH, Surekha variety to gall midge, TKM -6 and Ratna for stem borer and Northern spy variety of apple due to hard sclerenchymatous root tissue is resistant to wooly aphids.

d. **Others prophylactic measures:**

i. Treatment of seeds and seed material with chemicals to protect the crop from pests (groundnut seed treated with chlorpyriphos 0.02%a.i. affords protection against root grub; imidacloprid 70 WS at 10 g/kg cotton seed recorded leafhopper and whitefly below ETL level up to 35 days of sowing)

ii. Swabbing tree trunks to ward off borer incidence (trunks of coffee bushes swabbed with chlorpyriphos 0.05% emulsion to prevent attack by coffee white borer)

iii. Change of banana from perennial to annual crop reduced the infestation of banana rhizome weevil *Cosmopolitus sordidus* in addition to giving increased yields.

iv. Periodical raking up of manure pits to prevent breeding of rhinoceros beetle

v. Periodical drying of harvested and stored produce to prevent infestation by stored product pests

vi. Adjusting the time of sowing (Early sown sorghum in kharif reduces the infestation of shoot fly, timely and synchronous planting has been found to reduce bollworm damage in cotton and stem borer damage in sugarcane)

vii. Application of oil over stagnant water in ponds and pools to prevent mosquito breeding.

In addition to these, all the legal measures taken to prevent the entry of pests from foreign countries and the spread of pests from one region to another within the country as detailed under the legal methods of control as also most of the cultural and mechanical methods are prophylactic in nature.

13.6.2 Cultural methods: The manipulation of cultural practices at an appropriate time for either eliminating or reducing or avoiding pest population to cause damage in crops is known as cultural control. The cultural practices are designed to hit at some weak point in the seasonal history or make the environment less favourable for the pests and or more favourable for its natural enemies. It is the cheapest among all methods.

i. **Crop rotation:** Crop rotation is most effective practice against pests that have a narrow host range and dispersal capacity. Lady's finger followed by cotton will suffer from increased infestation of pests. Hence if a non-host crop is grown after a host crop, it reduces the pest population. Ex. Cereals followed by pulses. Groundnut with non leguminous crops is recommended for minimizing the leaf miner incidence.

ii. **Trap cropping:** Growing of susceptible or preferred plants by important pests near a major crop to act as a trap and later it is destroyed or treated with insecticides. Trap crop may also attract natural enemies thus enhancing natural control. Ex:

	Trap crop	Main crop	Insect pest
a.	Castor	Chillies	Tobacco caterpillar *Spodoptera litura*
b.	Tomato	Citrus	Fruit sucking moths *Otheris spp*
c.	Marigold	Cotton	American bollworm *Helicoverpa armigera*

iii. **Mixed cropping:** it is intended for getting some produce when one crop is attacked; the other escapes and comes up well. Ex. Garden peas and sunhemp.

iv. **Trimming field buds:** Grasshopper eggs, which are laid in field bunds, are destroyed by trimming field bunds.

v. **Some other practices specially adopted for certain pests**

- Raking up and hoeing of the soil around grounds in mango and other fruit trees serves to destroy pupae of fruit flies
- Root weevil, *Echinonemus oryzae* damage in rice can be overcome by applying 20 kg ammonium sulphate and 40 kg single super phosphate in rice
- Adoption of high seed rate in sorghum and later removal and destruction of shoot fly (*Atherigona soccata)* affected plants
- Trash mulching @ 3 t/ha 3 days after planting or earthing up at a month or two after planting to minimize early shoot borer (*Chilo infuscatellus)* attack in sugarcane
- Destruction of crop residue: Stubbles of sugarcane and paddy that harbour borers should be ploughed up and burnt.

- Periodical drying of stored produce against stored grain pests.
- Pruning of dried twigs/ branches to eliminate pests like scales and orange borer

13.7 Quarantine regulation

Quarantine regulation: In ancient time, man carried required seeds and plants wherever he moved. This practice is still continuing in the civilized settlements of mankind. As a consequence, many plant types have moved from their centres of origin, to an entirely new regions / continents, where they got well established and naturalized. The pests associated with plants and seeds also moved along unnoticed into a new region, where they caused severe damage, not only to the plants with which they associated but also started to infect / infests many other plant types in the introduced region. The realization of the economic, social consequences happened due to indiscriminate and unscientific movement or trade of plants, seeds and plant materials, necessitated the countries or provinces to start regulating the movement of plants and plant materials. Therefore, in olden days the term **“**Quarantine**”** was originally applied to the period of detention of passengers arriving in ships from countries where epidemic diseases such as bubonic plague, cholera and yellow fever were prevalent. The ship’s crew and passengers being compelled to remain isolated on board long enough to permit latent cases of diseases to develop and be detected before any persons were allowed to land. The word “quarantine” is derived from the Latin words **“quarantum”** or **“quaranta giorni”** meaning forty; that is to say a forty day period. Fixing of the period as forty has no scientific relevance at that time, but merely as practical measure based on necessity. Since the term Quarantine is so aptly fitted to and so firmly associated with an entirely unique situation, it was carried over from the human disease field into similar animal disease field and later adopted to cover protective efforts for the exclusion of pests and diseases of farm and horticultural crops, as well as forest and fruit trees.

13.7.1 Some definition of pests, pesticides and transgenic etc. as per Govt. notification:

- **Pest** means any biotic agent capable of causing any injury or damage to plants and plant products and include any form or stage of insects, mites, snails, slugs, worms, nematodes, algae, fungi, protozoa, bacteria, actinomycetes, viruses, viroids and molecutes and also include genetically engineered or modified organisms and weeds. (PQ Order)

- ***Quarantine Pest*** means a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (PQ Order)
- ***Alien Species*** (non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce. (IUCN,2000)
- ***Alien Invasive Species*** **means** an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity. (IUCN,2000)
- ***Ecosystem*** means the complex of a community of organisms and its environment.
- ***Weed*** It is defined as “A plant considered undesirable, unattractive, or troublesome, especially one growing where it is not wanted”. Or in simple words “A plant that interferes with management objectives for a given area of land at a given point in time”.
- ***Pesticides*** are any substance or mixture of substances intended for preventing, destroying, or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals, causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances that may be administered to animals for the control of insects, arachnids, or other pests in or on their bodies. The term

includes substances intended for use as a plant growth regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit. Also used as substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport (According to FAO)

- **Transgenic** are an organism whose genome has been altered by the transfer of a gene or genes from another species or breed.

13.7.2 Importance of plant quarantine Importance of plant quarantine: Since the dawn of civilization, man utilized his best possible efforts to domesticate the bounty of nature as per his needs. It is not just in recent years that the countries are being invaded by alien species, since time immemorial, man started to move with plants and animals wherever he fancied. In a way it paved way for species richness in newer area and domestication has become part of human settlement. It is not true that all alien species are harmful or dangerous, even the invasive species are not so dangerous in their place of origin, as the invasiveness is curtailed due to influence of many factors of the particular ecosystem. The alien species become invasive in newer area due to absence of natural enemies and congenial environmental parameters. Some alien species became beneficial and some became nuisance. To promote safe trade of agricultural materials across trans-boundary movement around the world implementation of plant quarantine system has become a necessity to safeguard biodiversity of a nation. Plant quarantine acts as a filter and not as a barrier of trade. The entry of a single exotic insect or disease and its establishment in the new environment continues to cause great national loss (table 1) till such time it is brought under effective control. In certain cases a country has to spend a few million rupees before success in controlling the introduced insect pest or disease is achieved.

Table1. Losses caused by introduced plant diseases

Disease	**Host**	**Country**	**Introduced from**	**Losses caused**
Blight	Chestnut	U.S.A.	Eastern Asia	$ 100-1000 million
Powdery mildew	Grapevine	France	U.S.A	80% in wine production
Canker	Citrus	U.S.A	Japan	$ 13 million; 19.5 million trees destroyed
Dutch elm	Elm	U.S.A.	Holland	$ 25 million -$ 50,000 disease million
Downy mildew	Grapevine	France	U.S.A	$ 50,000 million
Bunchy top	Banana	India	Sri Lanka	Rs.4 crores
Wart	Potato	India	Netherlands	2500acres infected

13.8 Quarantine restrictions

Quarantine restrictions

13.8.1 Domestic quarantine restrictions in movement of agricultural produce, seeds and planting materials: Under the DIP Act 1914, the Directorate of Plant Protection, Quarantine and Storage has the responsibility to take the necessary steps and regulate the inter-state movement of plants and plant materials in order to prevent the further spread of destructive insects and diseases that have already entered the country. The sole object of enforcing domestic quarantine is to prevent the spread of these pests and diseases from infected to non-infected areas. According the then Madras Government enacted the "Madras Agricultural Pests and Diseases Act" in 1919 and perhaps it was the first state to enact such an act in this country. This act was passed to prevent the spread of a pest, disease or weed from one part of the state to another and to make it incumbent on the part of the growers to carry out the prescribed remedial measures. Under this act the state govt. may notify an insect as a pest for the purpose of enforcing the provisions under the Act. They also have to notify the areas affected; the remedial measures to be undertaken, the government staffs or classes of Govt. staff who will be the Inspecting Officers under the Act and the time for which the notification will be in force. If the cultivator or occupant of a premise does not adopt the control measures envisaged in the Act the Inspecting Officers will themselves carry them out and arrange to recover the money through land revenue; in addition the cultivator will be prosecuted. Most of the states in India have plant quarantine laws to avoid entry of plant pests and diseases. The State Pest Act has been in force in respect of the following cases:

1. **Cotton bollworms and stem weevil:** Bollworms (*Earias vitella* F*., E. insulana* and *Pectinophora gossypiella*) and the stem weevil, *Pempherulus affinis* caused severe losses to combodia cotton in 1918 and this infestation was due to allowing the crop in the field continuously for two or three years thereby facilitating uninterrupted breeding of the pests. Therefore, Pest Act was enforced (with the objective to keeping the lands without cotton for sometime will help starve out the insect) to stipulating that the previous crop of cotton should be removed before 1st August and the succeeding crop should not be sown earlier than 1st September each year in Coimbatore, Salem, Madurai and Tiruchirapalli districts. However, since the cotton growing season in these districts are not uniform, the Act was latter subjected to a few modifications so as to suit the seasons in each of these tracts.
2. **Coffee white borer:** The Pest Act was enforced in 1946 and has been in force in parts of Salem, Madurai, Coimbatore and the Nilgiris. All infested coffee plants are to be removed and destroyed by 15th December every year. The stems and branches of the bushes should be swabbed with lindane emulsion before the emergence of the beetles, which takes place in two periods, April-May and October-December so as to prevent them from laying eggs.

3. **Bunchy top of banana:** The export and the transport from the States of Assam, Kerala, Orissa, West Bengal, Tamil Nadu to any other State of Banana plant or any other plant of the genus Musa, including sucker, stem, leaf, flower, and any other part thereof which may be used for propagation, or the materials of banana plant or any other plant of the genus *Musa*, which are used for packing and wrapping, excluding the banana fruit is prohibited.
4. **Banana mosaic:** The export and transport from the States of Maharashtra and Gujarat of any plant of Banana or any other plant of genus Musa including the sucker, stem, flower and any other part thereof, but excluding leaf and fruit thereof is prohibited; vide Government of India notification No. F. 6-10-PPS dated the 11th April, 1961.
5. **Potato wart:** The export to potato tubers from the State of West Bengal to any other State or territory of India is prohibited.
6. **Apple scab:** The Directorate of Horticulture, Himachal Pradesh worked out a detailed scheme for the eradication of scab, and also issued a notification No.NIC.20/76 dated 28th December 1978, prohibiting the export of planting material of apple outside the State.
7. **Coffee berry borer:** The Govt. of India invoked the pest act for restricting movement of coffee from infested areas to uninfected areas in November, 1992. The rule is still in force with regards to seed supply to non-traditional areas and North Eastern region.
8. **Fluted Scale (Icerya *purchasi* Maskell):** The incidence of this pest was found localised within the limits of the Nilgiris and Kodaikanal. Therefore, steps were taken to prevent its further spread. None of the plants listed as alternative hosts was permitted to be transported from the notified areas without inspection and fumigation.

In Tamil Nadu as per Madras Pests and Diseases Act of 1919, quarantine regulations are periodically enforced. e.g., cardamom mosaic prevalent in Anamalai area of Coimbatore District and is free from Nelliampatti area. Hence the movement of diseased plant material from Anamalai to Nelliampatti area is prevented.

13.8.2 International quarantine restrictions in movement of agricultural produce, seeds and planting materials: All countries in the world have restrictions on the import of plant or plant materials to prevent the entry of foreign pests. The enforcement of the quarantine measures is supported by legal enactments, called quarantine laws. The imported plants and plant materials have to be thoroughly examined at the port of entry for the presence of any foreign insects or of their any other life stages. An insect which is apparently harmless or a very minor pest in its native country can turn to be a potential pest in a new country. As such the entry of all pests, irrespective of their status in the country of origin, is to be prevented and any infested material has to be disinfested by suitable means at the port of entry.

Presently, there are 35 PQS's functioning at various Seaports, Airports and Land frontier stations, in addition to 61 In-land depots to carry out plant quarantine inspection and to facilitate safe import of plants/ plant materials. These operations operate under the provisions made under the government of India's Destructive Insects and Pests Act of 1914 (DIP Act). The importation of consignments of plants from foreign countries has to done only through any of these ports. The consignments should be accompanied by certificates issued by the officers of the Department of Agriculture of the exporting country as to their freedom from pests and diseases; these certificates are called phytosanitary certificates. At the port of entry these consignments are inspected and if necessary fumigated to kill the pests carried by them. Import of plant by post or air is not permitted except by experts for scientific purposes. Import of potato tubers into our country from areas known to be infested with ward diseases or golden cyst nematode of potatoes is totally prohibited. Restrictions have been imposed on the importation of rubber seed, sugarcane setts and coffee and cotton seeds to guard against the West Indies sugar weevil, *Sphenophorus sacchari*, the coffee berry borer *Hypothenemus hampei* and the Mexican boll weevil, *Anthonomus grandis* Boheman. However, much other plant material can be imported provided they are accompanied by phytosanitary certificates. In same way, all exports of commodities from this country like bulk consignment of pepper, tamarind and cardamom have to be accompanied by phytosanitary certificates.

13.9 Case histories of exotic pests/diseases and their status

Case histories of exotic pests/diseases and their status: Some of devastating incidences which had taken place in the late 17th and early 18th century lead to the creation of plant quarantine at global level.

13.9.1 Case histories in foreign countries

- **Great Famine of Irish:** Potato was introduced into Ireland as a garden crop and during late 17th century it was consumed as supplementary food. By early 18th century, it assumed the status of staple food for the poor during winter season and as well considered as agrarian economy as it fetched more money and hence grown in more acreage (<60%). In 1843-44, a new disease started to destroy the crops and was identified as late blight of potato, *Phytophthora infestans*. Late blight of potato infection completely destroyed potato crop in 1845, which lead to the starvation and death of 1 million people and migration of another 1 million from Ireland from 1845 to 1852. The unfortunate event of late blight devastation occurred due to incursion of *Phytophthora infestans* from USA, which caused loss of around £3,500,000 potatoes.

- **Toppling of Grapevine industry in Europe:** Introduction of powdery mildew (*Oidium tuckeri*) into Europe with American grape-vines is classical example of trans-boundary movement of plant pest. Its pathogenicity on European grape vine was unknown at that time and the disease spread like wild fire on European grape vines (1850). To control powdery mildew, root-stocks of resistant varieties were imported from America (1854). However, these grape vines carried *Phylloxera vastatrix*, a root inhabiting aphid of grape vines. To combat this pest, more American vines resistant to *Phylloxera* were introduced, but these additional introductions brought with them the downy mildew (*Plasmopara viticola*), and black rot (*Guignardia bidwellii*). In France, where the vine industry was thriving, had to face the brunt of these pest incursions and many business men abandoned vine production and emigrated to Algeria and other countries. Further, these incidences lead to the formulation of Bordeaux mixture pesticide.

- **Colossal toad menace:** The cane toad, *Bufo marinus*, native of central and south America, was introduced into Australia by the sugarcane industry to control two pests, the grey backed cane beetle (*Dermolepida albohirtum*) and frenchie beetle (*Lepidiota frenchi*). 101 toads were imported in June1935 and within 6 months the population exploded to 60000 and was released in the cane fields. Initially, the bio-control agent was so successful, whereas it became a environmental menace in a short period of time, causing ecological imbalance replacing the native frogs due to its over population, further, it became the reason for extinction of snake and fox species due to consumption of this poisonous toad. Even the tadpoles are poisonous.

- **Green Cancer of Tahiti:** The prolific tree, *Miconia calvescens* has overrun Tahiti's native forests. Miconia is one of the most destructive invaders in tropical rain forest habitats. It is a serious threat to ecosystems in the Pacific because of its ability to invade intact native forests. Miconia has earned itself the descriptions such as the 'green cancer of Tahiti' and the 'purple plague of Hawaii'. Once miconia is established at a certain place it drastically changes the ecosystem and biodiversity of that environment.
- **Food turned foe:** Philippine rice farmers have lost nearly US$1 billion in crops to the invasive golden apple snail, *Pomacea canalicualata* which was originally introduced from South America to south-east Asia around 1980, as a local food resource and as a potential gourmet export item. The markets never developed; the snails escaped or were released, and became a serious pest of rice.

13.9.2 Case histories in India: Several new pests have been introduced into India in the past, which are causing major crop loss, economical damage and environmental degradation and become major constraint in some of agricultural commodities.

- **Potato:** Potato wart introduced from Netherlands, Potato cyst nematodes from UK, Potato tuber moth from Italy & Late blight of Potato from Europe
- **Coconut:** Eriophid mite from Sri Lanka
- **Banana:** Bunchy top of banana virus from Sri Lanka
- **Rubber:** Powdery mildew from Malaysia
- **Sunflower;** Downy mildew from USA

- **Apple:** Codling moth from Pakistan, San Jose Scale from USA
- **Coffee:** Coffee berry borer from Sri Lanka

13.10 Plant protection organisation in India

Plant protection organisation in India

13.10.1 Directorate of Plant Protection, Quarantine & Storage (DPPQS): The Directorate of Plant Protection, Quarantine & Storage (DPPQS) established under Department of Agriculture & Cooperation of Ministry of Agriculture, Government of India, is an apex plant protection organisation in the country having the following key functions:

- To enforce Plant Quarantine Regulations issued under The Destructive Insects & Pests Act, 1914 and amendments issued there under to prevent introduction & spread of exotic pests;
- To implement the provisions of The Insecticides Act, 1968 and rules framed there under for effective control over use of pesticides;
- To fulfill international commitment and obligations in respect of locust control and phyto-sanitary measures;
- To introduce and popularize innovative plant protection technologies such as integrated pest management (IPM) practices;
- To impart training in areas of plant protection technology, pesticide quality testing & pesticide residue analysis etc. ;
- To coordinate and liaison with State/Union Territory Governments in all matters relating to plant protection

The Plant Protection Adviser to the Government of India heads the Directorate of Plant Protection and Quarantine Station, which is located at N. H. IV, Faridabad-121001 (Haryana). The Directorate implements five central sector schemes in the area of plant protection viz., expansion of plant quarantine facilities, integrated pest management programmes, implementation of Insecticide Act, locust control and training in plant protection.

Though the Directorate was formed in 1946 with plant quarantine wing, the first Plant Quarantine Station (PQS) was established at Mumbai in 1949 followed by the PQS at Chennai in 1950, Amritsar in 1954, Cochin in 1955, Kolkata in 1956, Visakhapattinam in 1957 and at Tuticorin and Bhavnagar in 1968. At present, there are 35 PQS's functioning at various Seaports, Airports and Land frontier stations, in addition to 61 In-land depots to carry out plant quarantine inspection and to facilitate safe import of plants/ plant materials. All member countries of IPPC need to establish National Plant Protection Organization (NPPO) for implementation of phytosanitary measures, import regulations to promote safe agricultural trade through plant quarantine system; DPPQS is the NPPO for India.

13.10.2 National Bureau of Plant Genetic Resources (NBPGR): This bureau has been designated as the national nodal agency for issuing permission to public and private sector agencies for import of seeds and germplasm, transgenic planting material or genetically modified organisms(GMOs) for research and experimental purpose. Permits for import of transgenic and genetically modifies organisms are issued only after the Review Committee on Genetic Manipulation (RCGM) accords the import clearance. The RCGM is set up by the Department of Biotechnology under the provisions of the rules for the manufacture, use, import, exports and storage of hazardous micro-organism, genetically engineered organism or cells, made under the Environment (Protection) Act, 1986. NBPGR has a separate Division of Plant Quarantine with goods equipments facilities. NBPGR has established a regional plant quarantine station at Hyderabad that takes care of the quarantine needs of the International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Directorate of Rice Research and other research organisation in the region. Some crop specific Indian institutes are also entrusted with the responsibility of post entry isolation growing facilities and desired scientific expertise. These institutes are Central Tobacco Research Institute, Rajahmundri, Central Plantation Crops Research Institute, Kasargod, Central Tuber Crops Research Institute, Thiruvananthapuram, Central Potato Research Institute, Shimla and Sugarcane Breeding Institute, Coimbatore.

Forest Research Institute (FRI) Deharadun for import of forest plants

Botanical Survey of India (BSI), Kolkata for import of ornamental plants to enforce quarantine laws in India.

13.11 Acts related to registration of pesticides and transgenic

Acts related to registration of pesticides and transgenic

13.11.1 Insecticides Act, 1968: The Insecticide Act, 1968 has been enforced on 2nd September, 1968 by the Government of India to regulate the import, manufacture, sale, transport and distribution and use of insecticides with a view to prevent risk to human beings or animals. The government of India also constituted the Central Insecticide Board (CIB) to advise the state and central governments as per this act. The insecticide rules of 1971 framed under the Insecticides Act 1968 had come in to force in 1971. There are nine chapters in the insecticide rule, 1971 relating to the functions of CIB, RC, CIL, grant of licenses, packing, labelling, first aid, antidote protective clothing's etc. Under this act and rules, there is compulsory registration of the pesticides at the Central level and licence for their manufacture; formulation and sale are dealt with at the State level. With the enforcement of the Insecticides Act in the country pesticides of very high quality are made available to the farmers and general public for house-hold use, for protecting the agricultural crops from the ravages of their pests, humans from diseases and nuisance caused by public health pests and the health hazards involved in their use have been minimised to a great extent. For the effective enforcement of the Insecticides Act, the following bodies have been constituted at the Central level.

13.11.1.1 Central Insecticide Board (CIB): The Government has constituted Central Insecticides Board under the Chairmanship of Director General of Health Services with 29 members from different speciality and government organisations.

Functions of CIB:

- To advise the Central and state Governments on technical matters on technical matters arising out of administration
- To specify the uses of the classification of insecticides on the basis of their toxicity

- To advise tolerance limits for insecticides, residues and an establishment of minimum intervals between the application of insecticides and harvest in respect of various commodities
- To specify the shelf-life of insecticides

13.11.1.2 Registration committee: Registration Committee consisting of a Chairman and other five persons who shall be members of the Board. The main objective of the committee is to register insecticide after scrutinizing their formulae and verifying claims made by the importer or the manufacturer, as the case may be, as regards their efficacy and safety to human being and animals. The function of the registration committee is to specify the precautions to be taken against poisoning through the use or handling of insecticides. For import and manufacture of insecticides, registration certificate is essential and a separate certificate for each insecticide. This committee has power to prohibit the import, manufacture and sale of pesticides and also confiscate the stocks. The offences are punishable and size and other penalties are prescribed. Both the Central and State Governments are empowered to make rules, prescribe forms and fees. This committee give three types of registration viz., provisional, regular or full and repeat registration.

13.11.1.3 Central Insecticide Laboratory:

1. To analyze samples of insecticides and submission of certificates of analysis to the concerned authority;
2. To analyze samples of materials for insecticide residues
3. To carry out such investigations as may be necessary for the purpose of ensuring the conditions of registration of insecticides;
4. To determine the efficacy and toxicity of insecticides

13.11.2 Regulatory measures specific to transgenic seeds: Bio-safety concerns have led to the development of regulatory regimes in many countries for research, testing, safe use and handling of GMOs and products thereof. India is one of the earliest countries to establish a bio-safety system for regulation of GMOs. Acknowledging the potential of Genetic Engineering and its relevance to India, Ministry of Science and Technology provide sufficient impetus for research and monitoring of transgenic seed development. The measures of transgenic regulation fall under the Environment and Protection Act, 1986 and EPA rules, 1989. The Rules 1989 also define the competent authorities and composition of such authorities for handling of various aspects of the Rules. Presently there are six committees. The mandate of the six Committees notified under Rules 1989 is as follows:

- **Recombinant DNA Advisory Committee (RDAC):** The functions are of an advisory nature and involve review of developments in biotechnology at national and international levels and recommend suitable and appropriate safety regulations for India in recombinant research, use and applications from time to time.
- **Review Committee on Genetic Manipulation (RCGM)** established in 1986 under the Department of Biotechnology, ministry of Science and technology is to monitor the safety related aspects in respect of on-going research projects and activities (including small scale field trials) and bring out manuals and guidelines specifying procedure for regulatory process with respect to activities involving geneti-cally engineered organisms in research, use and applications including industry with a view to ensure environmental safety.
- **Genetic Engineering Appraisal Committee (GEAC)** established under MoEFCC is the apex body to accord notified under Rules 1989. For approval of activities involving large scale use of hazardous microorganisms and recom-binants in research and industrial production from the environ-mental angle. The GEAC is also responsible for ap-proval of proposals relating to release of genetically engineered organisms and products into the environment including experimen-tal field trials (Biosafety Research Level trial-I and II known as BRL-I and BRL-II).
- **State Biotechnology Coordination Committee (SBCC's)** have a major role in monitoring. It also has powers to inspect, investigate and take punitive action in case or violations of statutory provisions.
- **District Level Committees (DLCs**) have a major role in monitoring the safety regulations in installations engaged in the use of genetically

modified organisms/hazardous microorganisms and its applications in the environment.

- **Institutional Bio-safety Committee (IBSC)** is established under the institution engaged in GMO research to oversee such research and to interface with the RCGM in regulating it.

13.12 History of quarantine legislations

History of quarantine legislations: The first legal restrictions to hinder the spread of disease were enacted against human disease. It was the dangerous outbreak of bubonic plague, which swept through Europe during the 14^{th} century that led the Venetian Republic to appoint three guardians of public health, to exclude infected and suspected ships and to make the first quarantine of infected areas in 1403. The first plant quarantine law was promulgated in Rouen, France in 1660 to suppress and prevent the spread of common barberry, the alternate host for wheat stem rust (*Puccinia graminis* Pers.). Among other countries, the first few to establish plant quarantine services were

- Indonesia enacted a law to prohibit importation of coffee plants and beans from Sri Lanka in 1877
- In USA, the PQ work started well ahead in 1891 when the State of California initiated seaport inspection at San Pedro, probably the first in the world. The Federal Plant Quarantine Act was enacted in 1912.
- In Australia the first set of regulations governing PQ came into force on 1909 following introduction of the Quarantine Act of 1908
- The German Government started to put ban on plants and plant products from USA in 1913

In India the first regulation legislative measures against crop pests and diseases was initiated under the Destructive Insects and pests Act of 1914 (DIP act) and it was passed by Governor General of India on 3^{rd} February, 1914. Under this Act, rules governing the import and movement of plants and plant materials, insects and fungi are framed. The Act provides

- It authorizes the Central Government to prohibit or regulate the import into India or any part there of any specific place therein, of any article of class of articles.

- It authorizes the officers of the Customs at every port to operate, as if the rules under the DIP Act are made under the Sea Customs Act.
- It authorizes the Central Government to prohibit or regulate the export from a State of the transport from one State to another State in India of any plants and plant materials, diseases or insects likely to cause or infestation. It also authorizes the control of transport and carriage and gives power to prescribe the nature of documents to accompany such plants and plant materials and articles.
- It authorizes the State Governments to make rules for the detention, inspection, disinfection or destruction of any insect or class of insects or of any article or class of articles, in respect of which the Central Government have issued notifications. It also authorizes the State governments for regulating the powers and duties of the officers whom it may appoint on this behalf.
- It provides penalty for persons who knowingly contravene the rules and regulations issued under the Act.
- It also protects the persons from any suit or prosecution or other legal proceedings for anything done in good faith or intended to be done under the Act. Consequent to Bengal famine 1943, a Central Plant Protection organization was established in 1946 under the then Ministry of Food and Agriculture. Often a new pest, disease or weed has accidentally entered a country where it did not exist before and has multiplied, spread and caused enormous damage to the crops of that country.

13.13 Plant Quarantine, 2003

Plant Quarantine (Regulation of Import into India) Order, 2003 (PQ Order, 2003): Government made this order to prohibiting and regulating the import into India of agricultural articles. This order notified under the DIP Act and came into force with effect from 1st January, 2004. This order contains seven chapters on different aspects such as Preliminary, General conditions for import, Special conditions of Import, Post-entry Quarantine, Appeal and

Revision, Power of Relaxation and Repeal and Savings. The PQ Order, 2003 replaces all the preceding Orders / notifications of plant quarantine regulations. PQ Order, 2003 was formulated on the scientific basis of Pest Risk Analysis (PRA). The commodities are categorized into various Schedules based on associated pest risk either through pathway or from countries where the pest is known to be reported. *In toto*, the order clearly spells out notified points of entry, list of prohibited, restricted, regulated commodities, quarantine weeds of concern to India, Inspection fee, authorities to issue import permits, to certify post entry quarantine facilities (PEQ) and the deposition of samples to gene bank of NBPGR.

13.14 Environmental Acts

Environment (Protection) Act, 1986: This act constituted after the decision taken at the United Nations Conference on the Human Environment held at Stockholm in June, 1972, in which India participated, to take appropriate steps for the protection and improvement of human environment and also abide to implement the decision aforesaid related to the protection and improvement of environment and the prevention of hazards to human beings, other living creatures, plants and property. This act was introduced on 23rd May, 1986 from Indian parliament and called the Environment Protection Act, 1986. Under this act the Central Government shall have the power to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environmental pollution. Some important provisions are mentioned below:

1. No person carrying on any industry, operation or process shall discharge or emit or permit to be discharged or emitted any environmental pollutant in excess of such standards as may be prescribed.
2. No person shall handle or cause to be handled any hazardous substance except in accordance with such procedure and after complying with such safeguards as may be prescribed.
3. Where the discharge of any environmental pollutant in excess of the prescribed standards occurs or is apprehended to occur due to any accident or other unforeseen act or event, the person responsible for such discharge and the person in charge of the place at which such discharge occurs or is apprehended to occur shall be bound to prevent or

mitigate the environmental pollution caused as a result of such discharge and shall also forth with:-

a. intimate the fact of such occurrence or apprehension of such occurrence; and
b. be bound, if called upon, to render all assistance, to such authorities or agencies as may be prescribed.

4. On receipt of information with respect to the fact or apprehension of any occurrence of the nature referred to in subsection1, whether through intimation under that sub-section or otherwise, the authorities or agencies referred to in sub-section 1 shall, as early as practicable, cause such remedial measures to be taken as are necessary to prevent or mitigate the environmental pollution.
5. The expenses, if any, incurred by any authority or agency with respect to the remedial measures referred to in sub-section 2, together with interest at such reasonable rate as the Government may, by order, fix from the date when a demand for the expenses is made until it is paid may be recovered by such authority or agency from the person concerned as arrears of land revenue or of public demand.
6. The Central Government or any officer empowered by it in this behalf, shall have power to take, for the purpose of analysis, samples of air, water, soil, or other substance from any factory, premises or other place in such manner as may be prescribed.
7. The Central Government may by notification in the Official Gazette, appoint or recognize such persons as it thinks fit and having the prescribed qualifications to be Government Analysts for the purpose of analysis of samples of air, water, soil or other substance sent for analysis to any environmental laboratory established or recognized under sub-section 1 of section 12.

13.15 Industrial registration

The Industries (Development and Regulation) Act, 1951: An Act to provide for the development and regulation of certain industries. It contains four chapters. Chapter I describes about different terms related to industries. Chapter II provides information related to the central advisory council and development councils (CAC&DC). (i) Central Advisory Council is made for purpose of advising to matters concerning the development and regulation of scheduled industries, The Advisory Council shall consist of a Chairman and 30 members appointed by the Central Government. This council advised to central government for making rules connected with the administration of this Act. It works for the interest of (a) owners of industrial undertakings (b) owners of industrial undertakings (c) consumers of goods manufactured or produced etc. (ii) Development Councils is made to provide in order to increase the efficiency or productivity of scheduled industries. It also functions for which the Development Council is established, to improve or develop the service that such industry or group of industries renders or could render to the community, or to enable such industry or group of industries to render such service more economically. A Development Council shall prepare and transmit to the Central Government and the Advisory Council, annually, a report setting out what has been done in the discharge of its functions during the financial year last completed. It also imposed cess on scheduled industries. Chapter III contains rules to regulate scheduled industries which registered viz., registration of existing industries, revocation of registration, License for new industries, licence for producing or manufacturing new articles, etc.

i. Registration of existing industrial undertakings C: The owner of every existing industrial should follow
   - The owner of every existing industrial undertaking, not being the Central Government, shall, within such period as the Central Government may, by notification in the Official Gazette, fix in this behalf with respect to industrial undertakings generally or with respect to any class of them, register the undertaking in the prescribed manner.
   - The Central Government shall also cause to be registered in the same manner every existing industrial undertaking of which it is the owner.
   - Where an industrial undertaking is registered under this section, there shall be issued to the owner of the undertaking or the Central Government, as the case may be, a certificate of registration containing the productive capacity of the industrial undertaking and such other particulars as may be prescribed.
   - The owner of every industrial undertaking to whom a certificate of registration has been issued under this section before the commencement of the Industries (Development and Regulation)

Amendment Act, 1973 (67 of 1973), shall, if the undertaking falls within such class of undertakings as the Central Government may, by notification in the Official Gazette, specify in this behalf, produce, within such period as may be specified in such notification, the certificate of registration for entering therein the productive capacity of the industrial undertaking and other prescribed particulars.

- In specifying the productive capacity in any certificate of registration issued under sub-section (3), the Central Government shall take into consideration the productive or installed capacity of the industrial undertaking as specified in the application for registration made under sub-section (1), the level of production immediately before the date on which the application for registration was made under sub-section (1), the level of the highest annual production during the three years immediately preceding the introduction in Parliament of the Industries (Development and Regulation) amendment Bill, 1973, the extent to which production during the said period was utilized for export and such other factors as the Central Government may consider relevant including the extent of under utilization of capacity, if any, during the relevant period due to any cause.

ii. Revocation of registration in certain cases C: If the Central Government is satisfied that the registration of any industrial undertaking has been obtained by misrepresentation as to an essential fact or that any industrial undertaking has ceased to be registrable under this Act by reason of any exemption granted under this Act becoming applicable thereto or that for any other reason the registration has become useless or ineffective and therefore requires to be revoked the Central Government may after giving an opportunity to the owner of the undertaking to be heard revoke the registration.

Chapter IIIa contains rules and regulations related to direct management or control of industries. Chapter IIIaa described the rules related to management or control of industrial undertakings owned by companies in liquidation. Chapter IIIab described power of central government to provide relief to certain industries undertakings. Chapter IIIac contains rules and regulation of liquidation or reconstruction of companies. Chapter IIIb described the rules and regulations for control of supply, distribution, price etc., of certain articles manufactured by registered industries. Chapter IV contains all miscellaneous rules viz., inspection of industries, and general prohibition of taking over management or control of industrial undertakings, to issue directions to Development Councils, penalties made on industries for contravenes or attempts to contravene or for false statements provided by industries, delegation of powers to Development Council, State Government or officer or authority subordinate to the Central Government etc. This act contains three schedules. The first schedule provides list of industries engaged in the manufacture or production of any of the articles viz., metallurgical industries, fuel, boilers and steam generating plants, transportations, industrial machinery & tools etc. The second schedule contains functions which assigned to Development Councils. The third schedule includes the Industrial Employment (Standing Orders) Act, 1946; the Industrial Disputes Act, 1947 and the Minimum Wages Act, 1948.

13.16 APEDA

APEDA: The Agricultural and Processed Food Products Export Development Authority (APEDA) was established by the Government of India under the Agricultural and Processed Food Products Export Development Authority Act passed by the Parliament in December, 1985. The Act (2 of 1986) came into effect from 13th February, 1986 by a notification issued in the Gazette of India: This Authority replaced the Processed Food Export Promotion Council (PFEPC).

13.16.1 Functions of APEDA: Following functions have been assigned to the Authority.

- Development of industries relating to the scheduled products for export by way of providing financial assistance or otherwise for undertaking surveys and feasibility studies, participation in enquiry capital through joint ventures and other reliefs and subsidy schemes;
- Registration of persons as exporters of the scheduled products on payment of such fees as may be prescribed;
- Fixing of standards and specifications for the scheduled products for the purpose of exports;
- Carrying out inspection of meat and meat products in slaughter houses, processing plants, storage premises, conveyances or other places where

such products are kept or handled for the purpose of ensuring the quality of such products;

- Improving of packaging of the Scheduled products;
- Improving of marketing of the Scheduled products outside India;
- Promotion of export oriented production and development of the Scheduled products;
- Collection of statistics from the owners of factories or establishments engaged in the production, processing, packaging, marketing or export of the scheduled products or from such other persons as may be prescribed on any matter relating to the scheduled products and publication of the statistics so collected or of any portions thereof or extracts there from;
- Training in various aspects of the industries connected with the scheduled products;
- Such other matters as may be prescribed.

13.16.2 Products monitored: APEDA is mandated with the responsibility of export promotion and development of the following scheduled products *viz*., fruits, vegetables and their products, meat and meat products, poultry and poultry products, dairy products, confectionery, biscuits and bakery products, honey, jaggery and sugar products, cocoa and its products, chocolates of all kinds, alcoholic and non-alcoholic beverages, cereal and cereal products, groundnuts and walnuts, pickles, papads and chutneys, guar gum, floriculture and floriculture products, herbal and medicinal plants. In addition to this, APEDA has been entrusted with the responsibility to monitor import of sugar.

13.16.3 Composition of the APEDA Authority: As prescribed by the statute, the APEDA Authority consists of a Chairman and 39 members (one member from Agricultural Marketing Advisor to the Government of India, ex-official; one member appointed by the Central Government representing the Planning Commission; three members of Parliament of whom two are elected by the House of People and one by the Council of States; eight members appointed by the Central Government representing respectively; the Ministries of the Central Govt. viz., Agriculture and Rural Development, Commerce, Finance, Industry, Food, Civil Supplies, Civil Aviation and Shipping and transport; five members appointed by the Central Government by rotation in the alphabetical order to represent the States and the Union Territories; seven members appointed by the Central Govt. each representing from Indian Council of Agricultural Research, National Horticultural Board, National Agricultural Cooperative Marketing Federation, Central Food Technological Research Institute, Indian Institute of Packaging, Spices Export Promotion Council and Cashew Export Promotion Council; twelve members appointed by the Central Government representing Fruit and Vegetable Products Industries, Meat, Poultry and Dairy Products Industries, Other Scheduled Products Industries and Packaging Industry and two members appointed by the Central Government from amongst specialists and scientists in the fields of agriculture, economics and marketing of the scheduled products).

13.17 Import and export of bio-control agents

Import and export of bio-control agents: International Standard for Phytosanitary Measures (ISPM No. 3) provides guidelines for risk management relating to the export, shipment, import and release of biological control agents and other beneficial organisms. The standard lists the related responsibilities of contracting parties to the International Plant Protection Convention (IPPC) ('contracting parties'), of National Plant Protection Organizations (NPPOs) or of other responsible authorities, importers and exporters. ISPM No. 3 addresses biological control agents capable of self-replication (including parasitoids, predators, parasites, nematodes, phytophagous organisms, and pathogens such as fungi, bacteria and viruses), sterile insects and other beneficial organisms (such as mycorrhizae and pollinators), including those packaged or formulated as commercial products. Provisions are also included for importation of non-indigenous biological control agents and other beneficial organisms for research in quarantine facilities. The final version of the standard was submitted to the seventh session of the ICPM (in April 2005) for consideration. After minor modifications it was adopted as ISPM No. 3 (FAO 2005a and 2005c). The Standard states that it is "*intended to facilitate the safe export, shipment, import and release of biological control agents and other beneficial organisms. Responsibilities relating to this are held by contracting parties, NPPOs or other responsible authorities, and by importers and exporters.*" However it does not include reference to living modified organisms, issues related to registration of bio-pesticides, or microbial agents intended for vertebrate pest control.

"Contracting parties, or their designated authorities, should consider and implement appropriate phytosanitary measures related to the export, shipment, import and release of biological control agents and other beneficial organisms and, when necessary, issue related import permits."

As described in this standard, NPPOs or other responsible authorities should:

- Carry out pest risk analysis of biological control agents and other beneficial organisms prior to import or prior to release;
- Ensure, when certifying exports, that the phytosanitary import requirements of importing contracting parties are complied with;
- Obtain, provide and assess documentation as appropriate, relevant to the export, shipment, import or release of biological control agents and other beneficial organisms;
- Ensure that biological control agents and other beneficial organisms are taken either directly to designated quarantine facilities or mass-rearing facilities or, if appropriate, passed directly for release into the environment;
- Encourage monitoring of release of biological control agents or beneficial organisms in order to assess impact on target and non target organisms.

*Responsibilities of, and recommendations for, exporters include ensuring that consignments of biological control agents and other beneficial organisms comply with phytosanitary import requirements of importing countries and relevant international agreements, packaging consignments securely, and providing appropriate documentation relating to biological control agents or other beneficial organisms.

*Responsibilities of, and recommendations for, importers include providing appropriate documentation relating to the target pest(s) and biological control agent or other beneficial organisms to the NPPO or other responsible authority of the importing country." In nut shell, in India following procedure is follows:

"The Accompanied documents in respect of Import of Live insects/ Fungi /Bio control agents shall be scrutinized to ensure the imports are covered by a special permit issued by the Plant Protection Advisor to the Government of India (PPA) and shall be allowed to be imported only through specified point of entry. Further the packages were inspected to ensure the seals are intact and not damaged during the transport and are cleared to the actual importer under intimation to the Plant Protection Advisor to the Government of India (PPA). In case of illegitimate imports the same shall be destroyed by incineration under intimation to the importer and the same brought to the notice of the Plant Protection Advisor to the Government of India (PPA)".

13.18 Physical methods for Pest management

Physical methods for pest management: Use of certain physical forces to minimize the pest populations are known as physical methods. This method involves manipulation of temperature, humidity, radio frequencies, infrared and use of radiant energies. Some of the important practices listed below:

- Male insects can be made sterile by exposing them to gamma radiation (source ^{60}CO) or by using chemicals. When sterile males are released in normal population they compete with normal males in copulation and to that extent reductive capacity of the population are reduced. By sterilizing the pupae of screwworm, livestock pest (*Cochliomyia hominivorax* Coquerel) with radiations, sterile males were obtained. They were released @ 400males /sq mile for 7 weeks. By this method total eradication was achieved in South East parts of America and in the Curacao islands in case of screwworm.
- Artificial heating and cooling of stored products will prevent insect damage. Usually high temperatures are more effective than low temperatures.
- Stored products can be exposed to 55 ^{0}C for 3 hours to avoid stored product pests.
- Kaolinic clay after successive activation with acid and heat can be mixed with stored grains. The clay minerals absorb the lipoid layer over the insect cuticle, and the insects lose their body moisture and die of desiccation.

- Steam sterilization of soil kills soil insects and nematodes.
- Oxygen stress and carbon dioxide high concentration: In air tight containers small volume of air is enclosed, the available oxygen is quickly utilized by insects and raise concentration of carbon dioxide. High concentration of carbon dioxide leads to death of stored products insects.
- An entoleter is used in flour mills to kill stored grain pests by centrifugal forces.
- Exposure of insects to ultrasonic waves of 400 kilocycles for 4 to 30 minutes at 500 watts found effective to kill insects.
- Vapour Heat Treatment (VHT): Heated air is saturated with water (>RH 90%) for specified period of 6 to 8 hours for raising pulp temperature to 43-44.5°C in case of mango against fruit flies.

13.19 Summary

An insect (or any other living being) whose population increases to such an extent as to cause economic losses to crops or a nuisance and health hazard to man and his belongings will be declared a pest. The population of pest never remains constant for long, but it tends to oscillate all the time about a theoretical optimum for the species. Several techniques available for controlling individual insect pests and are conveniently categorized in increasing order of complexity as - cultural, mechanical, physical, biological, genetical, regulatory and finally chemical. Pest management is an application of different plant protection technologies in a compatible manner to maintain the pest population below levels that causes economic damage and also help in the conservation of environmental qualities and are social accepted. Some culture, legal measures and chemical practices are used as prophylactic measures to keep away the pests from crops. These are effective especially in the case of certain pests which are known to occur in an area year after year or season after season. The pests associated with plants and seeds also moved along unnoticed into a new region, where they caused severe damage, not only to the plants with which they associated but also started to infect / infests many other plant types in the introduced region. Therefore, domestic restrictions regulate the inter-state movement of plants and plant materials in order to prevent the further spread of

destructive insects and diseases that have already entered the country and international restrictions regulates the imported plants and plant materials have to be thoroughly examined at the port of entry for the presence of any foreign insects or of their any other life stages. DPPQS are responsible for expansion of plant quarantine facilities, integrated pest management programmes, implementation of Insecticide Act, locust control and training in plant protection in India and NBPGR designated as the national nodal agency for issuing permission to public and private sector agencies for import of seeds and germplasm, transgenic planting material or genetically modified organisms (GMOs) for research and experimental purpose. APEDA is mandated with the responsibility of export promotion and development of the following scheduled products viz., fruits, vegetables and their products, meat and meat products etc. International Standard for Phytosanitary Measures (ISPM No. 3) provides guidelines for risk management relating to the export, shipment, import and release of biological control agents and other beneficial organisms.

13.20 Glossary

- **Epidemic pests:** Pests which come suddenly in a severe form in a region or locality at a particular season or time only are known epidemic pests.
- **Gradient outbreak**: An outbreak which is not self-driven and does not spread from local epicenters and is also entirely dependent on external environmental or internal genetic conditions.
- **Curative measures:** Those measures which are taken to kill the already existing pest population are called as curative measures.
- **Phytosanitary certificate: It is** a certificate issued in the model format prescribed under the International Plant Protection Convention of the Food & Agricultural Organization and issued by an authorized officer at the country of origin of consignment or re-export.
- **Quarantine Pest:** A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled.

13.21 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Insects which cause a loss more than 10 per cent in yield are known as _______________.
2. Vedalia beetle, *Rodolia cardinalis* was imported in India from ____________in year 1929.
3. NBPGR is situated at ________________.
4. First plant quarantine station was established at __________ in year 1949.
5. Who is plant protection advisor of Government of India?
6. APEDA stands for ___________________________________.
7. San Jose scale of apple was introduced in India from__________.

Section -B (Short Answer Type)

1. Define persistent pests?
2. What is monoculture?
3. Enlist important practices of cultural methods?
4. Write the functions of NBPGR?
5. Write a short note on domestic restrictions for movement of plant materials?
6. Explain the important provisions of Insecticide act 1968?

Section -C (Long Answer Type)

1. Write down about histories of exotic pests and diseases and their status?
2. Outline various practices applied in physical methods of pest management?
3. What are the Environment (Protection) Act, 1986 and their important provisions?
4. Explain plant quarantine and write down the objective and importance of Plant quarantine?
5. Write in detail about APEDA?

Answer Key of Section-A

1. Major pests
2. California
3. New Delhi

4. Mumbai
5. Dr. S. N. Sushil
6. Agricultural and Processed Food Products Export Development Authority
7. Italy

13.22 References

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Unit – 14

Biological control of crop pests and weeds – I

Structure of the Unit

14.1 Introduction

The use of natural enemies for reducing pest populations whether insects or weeds and their damage is known as biological control or biocontrol. The principle behind biological control is that all living entities whether insect or weeds have natural enemies, which when encouraged and multiplied can keep pest populations below economically damaging levels. Use of these living organisms for reducing pest insects and weeds is an integral part of Integrated Pest Management (IPM) and organic farming as it is an eco-friendly method, which does not have the harmful effects associated with chemical means of controlling insects.

These natural enemies of insect pests or biological control agents can be predators, parasites or pathogens. Biological control agents of weeds include insects and pathogens. Predators, are species which directly eat a large number of preys during their lifetime, eg ladybird beetles and lacewings. Parasitoids lay eggs on or inside host insects, where their immature stages feed and develop, ultimately killing the host. Pathogens are organisms, which cause disease in pest insects. Pathogens are microbial and include bacteria, fungi, and viruses. The host insect gets weakened or killed due to the disease caused by pathogens. Pathogens are relatively specific to certain insect groups. Introducing or encouraging natural enemies in a cropping system can reduce the population of pest organisms. Bio control can be either natural or applied. Applied biocontrol has three broad and somewhat overlapping approaches: conservation, classical and augmentation. In this chapter, history, principles, scope, approaches and types of biological control will be discussed.

14.2 History of biological control

Human beings have been using biological control for controlling pests since a long time. From the earlier primitive ways of bringing predator population closer to preys, to the present day commercial insectaries and air-freight delivery of natural enemies across the world, biological control has passed through several phases .

14.2.1 Early phase

During the early phase of biological control (approximately 200 A.D. to 1887 A.D.), the use of natural enemies was on a small scale, not very systematic and was done without any scientific studies. It is believed that the Chinese were first to use natural enemies to control insect pests. The ancient Chinese observed that ants were very effective predators of many citrus pests. They increased the populations of ants by taking their nests from surrounding habitats and placing them into their orchards. In 1200 A.D., ants were used in Yemen also for control of date palm pests. In 1762, the mynah bird, *Acridotheres tristis,* was successfully introduced from India to Mauritius for control of the red locust, *Nomadacris septemfasciata.* Egg parasites *Trichogramma* sp. were shipped from the U.S. to Canada for control of Lepidopterous pests in 1882.

14.2.2 Intermediate Phase.

During the intermediate phase (1888 to 1955) there was better planning and execution of biocontrol programs. The introduction of Vedalia beetle, *Rodolia cardinalis* Mulsant, for control of the cottony cushion scale in 1888 is one of the famous examples of the intermediate phase. The Cottony cushion scale, *Icerya purchasi* Maskell, was accidentally introduced into California (USA) in 1887. It spread rapidly and the citrus industry was in grave danger. After a lot of research, the natural enemies *Rodolia cardinalis* of this pest (the Vedalia beetle) were collected from Australia and released in California citrus orchards. The population of pest reduced drastically in a year.

Lantana camara an ornamental plant of central and south America, became a serious pest in Hawai. Dr albert koebele explored the jungles of Mexico to search for its natural enemies and sent 23 species of insects to Hawai in 1902. These insects were released on lantana plants directly without host specificity tests. Eight species of insects were reported established on this plant throughout Hawai island by 1905.

The Sugarcane leafhopper *Perkinsiella saccharicida* , caused significant losses in total yield of sugar in the Hawaiian Islands in 1903 . The natural enemies attacking it were searched from Queensland, Australia and a number of parasitoids were collected and released. An egg parasitoid, *Paranagrus optabilis* Perkins established and played a dominant role in the early reduction of leafhopper in Hawaii in 1905. Later it became widespread and abundant in 1906-1907, leading to significant reduction in leafhopper population. Another major mile stone of this phase was the discovery of *Bacillus thuringiensis* to be the causative agent of bacterial disease of the Mediterranean flour moth in 1911 by Berliner .

During 1930 to 1940 biological control gained popularity, followed by decline during the World War II. The use of synthetic pesticides became widespread after the discovery of many relatively cheap chemical pesticides. In 1947, the Commonwealth Bureau of Biological Control was established. In 1951 the name was changed to the Commonwealth Institute for Biological Control (CIBC) which currently has its Headquarters in Trinidad, West Indies. In 1955 the *Commission Internationale de Lutte Biologique contre les Enemis des Cultures* (CILB) was established in Zurich, Switzerland. This organization is now known as the International Organization for Biological Control (IOBC). From 1956, it started a journal known as “Entomophaga” devoted to biological control of arthropod pests and weed species.

14.2.3 The Modern Period

The modern phase (1957 to Present) of biological control is marked by more precise studies of natural enemies and better execution of bicontrol projects. The concept of economic threshold levels was started in 1959 by Vern Stern et al, which helped growers in making decision regarding when they needed to apply pesticides or other management tools, and therefore reduced the need for routine pesticide sprays in cropping systems . In 1962, Rachel Carson wrote a book “Silent Spring” which focussed on the deleterious effect of indiscriminate spraying of chemical pesticides on the ecology and environment. People and governments became aware of the harmful effect of chemical pesticides, consequently the concept of Integrated Pest Management (IPM) was developed in the late 1960’s. Biological control constituted an integral component of IPM. In 1964 a book titled “Biological Control of Insect Pests and Weeds” was published by Paul DeBach and Evert I. Schliner which was later known as *History of Biological Control* which is considered to be a major reference source for the workers and researchers of biological control. A landmark paper titled “Biological Control: Panacea or Pandora’s Box” published in 1983 by , Frank Howarth changed the way in which biological control was perceived. He had the opinion that classical biological control sometimes led to extinction of beneficial endemic species. Research on this aspect of biocontol found some impact but no species extinctions due to classical BC efforts have resulted from to date.

14.3 History of biological control in India

The history of biological control in India dates back to the seventeenth century and since then a great deal of success has been achieved in biological methods of pest control. In India, organized and systematic biological control research began with the establishment of the Indian station of Commonwealth Institute of Biological Control (CIBC) at Bangalore in 1957 with need based substations at 22 places in the country right from Srinagar (Jammu & Kashmir) to Palghat (Kerala). The advent of CIBC marked the beginning of organized and systematic biological control research in India. During this period, our knowledge of natural enemies of crop pests and weeds has increased manifold. The All-India Co-ordinated Research Project on Biological Control of Crop Pests and Weeds (AICRP) was established in 1977 with 10 centres under the aegis of the Indian Council of Agricultural Research (ICAR) for carrying out biological control research in different parts of the country. The AICRP was elevated to independent Project Directorate of Biological Control (PDBC) with its headquarters in Bangalore in 1993. PDBC was the nodal agency in the country that organized biological control research at the national level with 16 centres spread across the country. During XIth plan, PDBC was upgraded as National Bureau of Agriculturally Important Insects (NBAII) to act as a nodal agency for collection, characterization, documentation, conservation, exchange and utilization of agriculturally important insect resources (including mites and spiders) for sustainable agriculture. In the twelfth five year plan the Bureau is now re-named as National Bureau of Agricultural Insect Resources (NBAIR).

14.4 Principles of biological control

1. Most organisms have their enemies in nature, which reduce their population by either diseases, or predation. This phenomenon of *natural control* is utilised by human beings in biological control for suppressing the population of pest species.
2. The aim of biological control is to suppress insect pest populations to a level where they are not economically important, rather than their total eradication. Biological control works in a way where both pest and natural enemies remain in the agro-ecosystem at low densities. Biological control be self-perpetuating and can keep population of many important pests at low density for long periods.
3. All natural enemies need certain level of pest population for their own survival, development and sustenance. Natural enemies need to search the pest to consume (predators) or develop and multiply on them (parasites and pathogens). But after being established , biological control can provide relatively permanent control, if climatic factors or pesticides do not create unfavourable conditions for them.
4. The possibility of development of resistance to a control agent is negligible.
5. Keeping pest populations at an acceptable level may be achieved by combining the action of natural enemies with other means of control {Integrated pest management (IPM)}

6. As compared to chemical pesticides ,biocontrol agents may take time for achieving significant control.

7. The success of a biological control program depends on extensive preliminary studies for understanding the biology and ecology of the pest and natural enemies, the environments of their origin and the places where they are going to be released. Although this research is time consuming, but it is necessary. When all essential efficacy studies' are conducted, the chances of biocontrol programs success are better as compared to hasty release of biocontrol agents without proper evaluation. Research on development of new molecule as a potential pesticide and placing a product on the market also takes around 10 years time.

8. Efficacy of a program of pest control also depends on the cost effectiveness. Although initially the biocontrol programs seem expensive, many studies have proved that, in the long run natural enemies are more cost effective than pesticides.

14.5 Scope of biological control

Due to the growing awareness on the harmful impacts of pesticide use on the environment and human health, biocontrol has emerged as feasible and safe alternate approach to pest management has a bright future. In the present times, the opportunities and need for effective biological control are greater than ever because of problems such as resistance of insect pests to many pesticides, ban and withdrawal of many pesticides on environmental grounds without suitable replacements. As biological control methods do not show the quick results as shown by pesticides, convincing farmers to adopt more biocontrol measures for controlling pests is not an easy task. However the use of bio control methods is gradually gaining importance, especially for the management of pests that are difficult to control with insecticides like mealy bugs, scales etc. In the coming years, biological control is going to be an integral part of pest management programs because it is a safe and sustainable eco friendly way of dealing with pests

Presently more than 150 species of natural enemies are commercially available for augmentative biological control (van Lenteren 2003).Each pest species has tens to hundreds of associated natural enemy species (parasitoids, predators and pathogens), and thus thousands of natural enemies still await discovery, indicating great opportunities in research on bio control agents. Improved networking among the world's biological control community and construction of easily accessible databases containing information on all studied natural enemies (with appropriate evaluation) is required for increasing the rate of identification of new and efficient control agents.

Training of extension personnel and farmers is essential as farmers through self-learning and experimenting, are capable of quickly selecting the most appropriate pest management strategy for their crops, and will move away from chemicals to cultural methods and biological control. The trained farmers later become master trainers and pest control decision makers themselves, and pass their experience to their neighbors and relatives. Creating awareness regarding the benefits of sustainable and environmentally friendly pest management is necessary to avoid unnecessary use of chemicals by farmers.

Biological control is expected to account for a significantly increased proportion of all crop protection methods by the year 2050. Future pest management will depend strongly on biological control because it is the most sustainable, cheapest and environmentally safest system of pest management with additional benefits for growers and consumers.

The future of biological control depends on researchers, bureaucrats in government agencies and farmers. The reluctance in using biological control is mainly due to attitudinal barriers. A commitment towards encouraging increased implementation of this sustainable, biologically-based pest management and more support and funds for research in this field is needed from policy makers. There is also a need to popularize bio control methods through more trainings, information and education and publicize the environmental and social benefits of biological control through the mass media.

14.6 Important groups of parasitoids, predators and pathogens

Natural enemies of insects and mites can be grouped into three primary types i.e. predators parasites and pathogens. Most of the parasites and pathogens are often highly specialized and attack a limited number of closely related pest whereas predators may not always be specialized. Weeds are controlled using insect herbivores and pathogens. In the following sections different groups of natural enemies have been discussed in detail .

14.6.1 Predators

A predator is an animal that kills and consumes other insects or mites (the prey). Predators generally are larger than their prey and they kill or consume both immature and adult prey. Insect predators usually belong to the orders Coleoptera, Neuroptera, Hymenoptera, Diptera, Hemiptera and Odonata . Maximum number predators are beetles (Coleopterans) especially from the families Coccinelidae and Carabidae . Other arthropod natural enemies include predatory mites and spiders. Predator adults and immature stages are often generalists rather than specialists. Some adult predators feed on pollen if prey is not available. Most of the predators are extremely useful natural enemies of insect pests. Unfortunately, some prey on other beneficial insects as well as pests. Insect predators are frequently found in all agricultural and natural habitats. Some important arthropod predators are ladybird beetles lacewings , geocorid beetles, syrphid flies and spiders.

14.6.1.1 Lady Beetles (Coleoptera: Coccinellidae)

Ladybird beetles, Lady beetles or, ladybugs, are among the most visible and best known beneficial predatory insects. Ladybird beetles are usually red or orange with black markings. They have alligator-like larvae. The adults pass harsh climate in hibernation and females lay their bright yellow or orange eggs in clusters near aphid colonies during favourable cooler weather when population of aphids increase.

Most lady beetles are beneficial as both adults and larvae, feeding primarily on aphids. They also feed on mites, small insects, and insect eggs. Two coccinellids exceptions are the introduced Mexican bean beetle, *Epilachna varivestis*, and the squash beetle, *Epilachna borealis* , which feed on plants both as adults and larvae of both species. Most lady beetles found on crops and in gardens are aphid predators. Some prefer mite or scale species. If aphids are scarce, lady beetle adults and larvae may feed on the eggs of moths and beetles, and mites, thrips, and other small insects, as well as pollen and nectar. They may also be cannibalistic. Because of their ability to survive on other prey when aphids are in short supply, lady beetles are particularly valuable natural enemies.

Fig 1 Eggs larvae and adults of lady bird beetles.

14.6.1.2 Lacewings *(Neuroptera: Chrysopidae*)

Many lacewings are important predators of insect pests. The larvae of all lacewings are predaceous but in some species, adults may also be predaceous. Lacewing larvae prefer aphids as prey but also consume a range of other soft-bodied pests such as mites, thrips, jassids and mealybugs.The most abundant are the common green Lacewings (*Chrysopa carnea*). The adults are about 1/2 to 3/4 inch long, and are yellowish-green with golden eyes and large, delicate netted wings. The lacewing lays her eggs on foliage. The eggs are oval, pale green in color, and are attached to the end of a hair-like stem. In a few days they hatch. The tiny larvae that emerges has a voracious appetite and will feed on aphids, small worms, insect eggs, mites, thrips, immature whitefly, and other insects.

Fig 2 Eggs larvae and adults of lacewings

14.6.1.3 : Syrphid fly *Hover Flies (Diptera: Syrphidae)*

Syrphid flies are also known as flower flies and are most easily recognized by their typical hovering (helicopter like) flight above flowers or aphid-infested plants. Syrphid flies are important pollinators. Some species of syrphid flies look like a bee or wasps. Larvae are voracious predators of aphids and other small soft-bodied insects, particularly aphids some caterpillars and scale insects. Adult syrphid flies require sugar from flower nectar as source of energy for their flight and female flies feed on pollen as a source of protein before they can lay mature eggs. Their eggs are whitish and oblong shaped and laid among aphids. A maggot hatches from the egg in 2 or 3 days and begins to feed on aphids voraciously. A single larva can consume as many as 400 aphids during its development period. The larvae are greenish yellowish maggots tapered toward the head. The larval stage lasts for 7 to 14 days, depending on temperature, and the larva can consume as many as 400 aphids in its period of development. Pupa are shaped typically like a teardrop. Pupation occurs on plant parts near the aphid colony, or in the soil.

Fig 3 Syrphid Adult pupa and larva

14.6.1.4 Geocorid bugs (big eyed bugs)

Adults and nymphs have oval bodies and broad heads. Their most distinguishing characteristic is their large, bulging eyes. Bigeyed bugs walk with a distinctive "waggle" and omit a fowl odor when handled. Bigeyed bugs feed on a wide variety of prey smaller than themselves. They are among the most important natural enemies in cotton. They feed on eggs and small larvae of most lepidopteran pests (bollworm, pink bollworm, tobacco budworm), on the eggs and nymphs of plant bugs (e.g., *Lygus*), and on all life stages of whiteflies, mites and aphids.

Fig 4 : Geocorid bug

14.6.1.5 Spiders

Spiders are arachnids, not insects but they are important generalist predators of many insect groups like thrips, caterpillars, aphids, plant bugs, leaf hoppers, flies, etc. Spiders are abundant and widespread in all types of habitats. Their importance as pest control agents has been acknowledged by farmers from time immemorial and their presence is considered by many to be indicative of a healthy agroecosystem. In China people in villages take the number of spiders in a field as a measure of its potential agricultural productivity. Spiders comprise a very diverse group that can be broadly categorized by their hunting tactics to capture prey. Web building spiders use silk to trap their prey, other species are hunters that actively search for their food. Some spiders are highly cryptic 'sit and wait' predators, that hide in flowers attack pollinators All spiders produce a venom that is poisonous to their food source and once this venom is injected, it immobilizes their victim and then begins the digestion process. Conservation and augmentation of spiders in the fields is a simple, yet efficient method of pest control.

Fig 5 Spider

14.6.2 Parasites

A parasite is an organism that lives and feeds in or on another organism(host) ultimately killing it. Often only, the immature stage of the parasite feeds on the host. Adult parasitoids are generally free-living. However, adult females of some parasites (such as many wasps that attack scales and whiteflies) may be predaceous. The term "parasite" and parasitoid are often used synonymously but the distinction between them is that true parasites (eg. lice, ticks) do not typically kill their hosts but parasitoids kill the host. Most insect parasitoids only attack a particular life stage of one or several related species. The female searches for host and lays eggs in or on it. The immature parasitoid develops on or within a pest, feeding on body fluids and organs, eventually leaving the host to pupate or emerging as an adult. Pests attacked by parasitoids die slowly. Some hosts are paralyzed, while others may continue to feed or even lay eggs before succumbing to the attack. Parasitoids, often complete their life cycle more quickly and increase their numbers much faster than many predators. Parasitoids can be the dominant and most effective natural enemies of some pest insects, but their presence may not be obvious. Most beneficial insect parasitoids are wasps (Order Hymenoptera) or flies, (Order Diptera), although some beetles and other insects may have life stages that are parasitoids . Tachinid flies, ichneumonid wasps , braconid wasps and chalcid wasps are valuable insect parasites .

14.6.2.1 Ichneumonid wasps

These wasps include a large number of species and are very widely distributed. Most are somewhat wasp-like in appearance and many of the females have very long ovipositors, often longer than the body. Most of these wasps are internal parasites of the immature stages of the insect pest host. The parasite may complete its development in the host insect pest.

14.6.2.2 Braconid wasps

These wasps are another large group of parasitic insects. The adults are relatively small (rarely over 1.5 mm long) and a great many are stout-bodied. These wasps parasitize a wide range of insects but chiefly aphids and the larvae of moths, beetles, and flies. The habits of the braconids are similar to the ichneumonids except that many of them pupate in silken cocoons on the outside of the body of the insect host.

Fig.6 Adult and pupae of braconid wasp

14.6.2.3 Chalcid wasps

These wasps are usually quite small (2 mm) and in general are black, metallic blue or sometimes green. Many species live inside minute insects or the eggs of scale insects, aphids, caterpillars, and flies.

14.6.2.4 *Trichogramma* wasps

Trichogramma are extremely tiny wasps of family *Trichogrammatidae* and are very important parasitoids of insects. *Trichogramma* wasps occur naturally in almost every terrestrial habitat. They parasitize insect eggs, especially eggs of Lepidopterans. *Trichogramma* species are the most widely used insect natural enemy in the world partly because they are easy to rear in masses and they attack many important crop insect pests. Mass rearing of *Trichogramma* species as biological control agents began in early 1900s. *Trichogramma* are reared and released annually on an estimated 80 million acres of agricultural crops and forests in 30 countries to control some 28 different caterpillar pests attacking corn, rice, sugarcane, cotton, vegetables and fruit trees.

14.6.2.5 **Tachinid Flies:** Many species resemble an overgrown house fly. The fly is usually grayish, brownish, or black mottled with bristles. The adult flies rest on foliage or on flowers upon which they feed. Adults lay eggs glued to the host or laid on foliage where the host insect pest may ingest them. Hatched larvae are also deposited on or in the victim insect pests. Larvae feed on the contents of host insect pests.

Fig. 7 Tachinid fly

14.6.3 Pathogens

Diseases can be important natural controls of some insect pests. Insects and mites can be infected by disease-causing organisms such as bacteria, viruses, nematodes and fungi. Most pathogens are very small size organisms(microbes) , which can be viewed clearly with the help of microsope only . These micro organisms cause diseases in insects and ultimately result in the death of insects. Under some conditions, such as high humidity or high pest abundance, these naturally occurring organisms may multiply to cause disease outbreaks or epizootics that can drastically reduce an insect population. In comparison to conventional chemical pesticides, the organisms used in microbial insecticides are essentially nontoxic and non pathogenic to wildlife, humans, and other organisms. The safety offered by microbial insecticides is their greatest strength. Some pathogens have been mass produced and are available in commercial formulations for use in standard spray equipment. Formulations of the bacterium, *Bacillus thuringiensis* or Bt, for example, are widely used by gardeners and commercial growers.

Most insect pathogens are relatively specific to certain groups of insects and certain life stages. Unlike chemical insecticides, microbial insecticides may take longer to kill or debilitate the target pest. This may limit their use to crops that can sustain some insect damage. To be effective, most microbial insecticides must be applied to the correct life stage of the pest, and some understanding of the target pest's life cycle is required. Some microbial insecticides must be eaten by the insect to be effective. Good spray coverage is therefore important. Microbial insecticides are compatible with the use of predators and parasitoids, which may help to spread some pathogens through the pest population.

14.6.3.1 Bacillus

Bacillus thuringiensis (Bt) is an insecticide with unusual properties that make it useful for pest control in certain situations. Bt is a naturally occurring bacterium common in soils throughout the world. Several strains can infect and kill insects. Because of this property, Bt has been developed for insect control. At present, Bt is the only "microbial insecticide" in widespread use. These bacteria are the active ingredient in some insecticides. *Bacillus thuringiensis* Berliner (Bt) is a Gram-positive, spore-forming bacterium that forms parasporal crystals composed of proteins known as the insecticidal crystal (Cry) proteins and hemolytic toxins during sporulation. Various strains of Bt produce different parasporal inclusion proteins, which exhibit specific activity against larvae of Lepidoptera, Diptera, and Coleoptera .Bt insecticides are most commonly used against some leaf- caterpillars. Recently, strains have been produced that affect certain fly larvae, such as mosquitoes, and larvae of leaf beetles.

Bt is considered safe to people and nontarget species, such as wildlife. Some formulations can be used on essentially all food Crops. The insecticidal activity of Bt was first discovered in 1911. However, it was not commercially available until the 1950s. In recent years, there has been tremendous renewed interest in Bt. Several new products have been developed, largely because of the safety associated with Bt-based insecticides.

14.6.3.2 Virus

Insect-specific viruses can be highly effective natural controls of several caterpillar pests. Different strains of naturally occurring nuclear polyhedrosis virus (NPV) and granulosis virus are present at low levels in many insect populations. Epizootics can occasionally devastate populations of some pests, especially when insect numbers are high. Insect viruses need to be eaten by an insect to cause infection but may also spread from insect to insect during mating or egg laying. In some cases, for example while searching for suitable hosts for egg laying, beneficial insects such as parasitoids may physically spread a virus through the pest population. No threat to humans or wildlife is posed by insect viruses. Virus diseases of caterpillar pests may cause indirect mortality of some beneficial larval parasitoids if the host insects die before the parasitoids have completed development. Predators and adult parasitoids are not directly affected. Viruses can overwinter in the environment or in overwintering insects to re-establish infection in subsequent seasons.

The successful commercialization of insect-pathogenic viruses has been limited. Thus far, NPV strains have only been mass produced in living insects, a costly procedure. Viral insecticide development is further hindered by the fact that the viruses are specific to one species or genus, ensuring a relatively small market.

14.6.3.3 Entompathogenic Fungi

As the name suggests the fungi which cause diseases in insects are known as entomopathogenic fungi, *Metarhizium anisopliae, Beauveria bassiana, Verticillium leacenii* are some of the well known entomopathogenic fungi and are available as commercial products also. Some insect species, including many pests, are particularly susceptible to infection by naturally occurring, insect-pathogenic fungi. These fungi are very specific to insects, often to particular species, and do not infect animals or plants. Fungal growth is favored by moist conditions but fungi also have resistant stages that maintain infection potential under dry conditions. Fungi have considerable epizootic potential and can spread quickly through an insect population and cause its collapse. Because fungi penetrate the insect body, they can infect sucking insects such as aphids and whiteflies that are not susceptible to bacteria and viruses.

Fungi invade insects by penetrating their cuticle or "skin." Once inside the insect, the fungus rapidly multiplies throughout the body. Death is caused by tissue destruction and, occasionally, by toxins produced by the fungus. The fungus frequently emerges from the insect's body to produce spores that, when spread by wind, rain, or contact with other insects, can spread infection. Infected insects stop feeding and become lethargic. They may die relatively rapidly, sometimes in an upright position still attached to a leaf or stem, perhaps in an elevated location or concentrated near crop borders. The dead insect's body may be firm and "cheese-like" or an empty shell, often but not always with cream, green, red, or brown fungal growth, either enveloping the body or emerging from joints and body segments.

Insect-pathogenic fungi usually need moisture to enable infection, and natural epizootics are most common during wet or humid conditions. The effectiveness of these fungi against pest insects depends on having the correct fungal species and strain with the susceptible insect life stage, at the appropriate humidity, soil texture (to reach ground-dwelling pest species), and temperature. The fungal spores, which can be carried by wind or water, must contact the pest insect to cause infection. Naturally occurring fungal epizootics may considerably reduce aphid, caterpillar, leafhopper, and thrips populations.

14.7 Principles of classical biological control – importation, augmentation and conservation

Biological control may be natural or applied. All insect species are suppressed by naturally occurring organisms and environmental factors, with no human input. This is frequently referred to as *natural control.* Natural biological control thus occurs without “man’s intervention” whereas applied in Applied biological control there is human intervention in “the manipulation of natural enemies to control pests”

Three distinct approaches to biological control are recognized: importation (classical), augmentation and conservation of natural enemies. These approaches or strategies are different but also overlapping. These techniques are used according to the situation of the farming system either alone or in combination in a biological control program. Classical biological control is generally perceived to be the most important approach but now augmentative and conservation biological control are also receiving great deal of attention.

14.7.1 Classical biological control

Classical (importation), biological control involves importation and establishment of new natural enemies to an area, usually for exotic pests but sometimes also for native pests. During the introduction of new crop in a country, its insect pests may also be imported to the new country along with the seeds or planting material either accidentally or due to negligence. These non-native insects may sometimes become established in the new country. Once established, the introduced organisms might also achieve pest status due to the absence of their natural enemies in the new habitat to suppress their populations. Under such a situation the natural enemies of the insect pests are imported from the native countries, and released in the new habitat where they are highly effective. This Importation of natural enemies, is known as importation or classical biological control. This approach is used when a pest of exotic origin is the target of the biocontrol program. The country where the pest originated is first determined, thereafter explorations are conducted in the native region for search of promising natural enemies. In principle ,the search for suitable natural enemies (parasitoids, predators, pathogens) should include all organisms closely related to the target pest, with special consideration to those organisms that affect pest density and distribution. The identified natural enemies are evaluated for potential impact on the pest and also non target organisms in the new country before being cleared for release. Natural enemies imported into country must first be placed in quarantine for one or more generations so that no undesirable species are accidentally imported .

The most famous and early example of classical biological control dates back to the end of nineteenth century, when citrus orchards in California were suffering grave damage due the Australian scale, *Icerya purchasi*. The introduction of its natural enemy, the coccinellid ladybird, *Rodolia cardinalis* from Australia successfully controlled the scale. In Europe the woolly apple aphid, *Eriosoma lanigerum* was controlled through the introduction of its specific parasitoid *Aphelinus mali* .

Biological control of the alfalfa weevil, *Hypera postica* (Gyllenhall) in US is another example of a successful program using importation of natural enemies (Bryan et al. 1993). The alfalfa weevil, a native of Europe, was originally detected in the US in 1904 and gradually the weevil became a serious pest of alfalfa. A major program aimed at biological control of the weevil was initiated in 1957. In this program 12 parasitoid species were evaluated imported and released which became established reduced the population of weevils in the US.

14.7.2 Augmentative biological control

This type of biological control involves the supplemental release of natural enemies. Relatively few natural enemies may be released at a critical time of the season (inoculative release) or literally millions may be released (inundative release). Augmentation is be achieved by mass production and periodic release of natural enemies of the pest, and by genetic enhancement of the enemies to increase their effectiveness of control. An example of inoculative release occurs in greenhouse production of several crops. Periodic releases of the parasitoid, *Encarsia formosa* are used to control greenhouse whitefly, and the predaceous mite, *Phytoseiulus persimilis* is used for control of the two-spotted spider mite. Lady beetles, lacewings, or parasitoids such as *Trichogramma* are frequently released in large numbers (inundative release). Recommended release rates for *Trichogramma* in vegetable or field crops range from 5,000 to 200,000 per acre per week depending on level of pest infestation. Similarly, entomopathogenic nematodes are released at rates of millions and even billions per acre for control of certain soil-dwelling insect pests. Mass releases are made at special times when the pest is most susceptible and natural enemies are not yet present, or they can be released in such large numbers that few pests go untouched by their enemies. The augmentation method relies upon continual human management and does not provide a permanent solution, unlike the introduction or conservation approaches.

14.7.3 Conservation approach

'Modification of the environment or existing practices to protect and enhance specific natural enemies or other organisms to reduce the effect of pests' (Eilenberg et al., 2001)

Conservation biological control involves identification and modification of factors that limit the effectiveness of the natural enemies. In conservation approach needed resources are provided to preserve and enhance natural enemies.Slight modifications in farming practices and ecological planting schemes can create agro ecosystems more closely resembling natural ecosystems and promote field populations of voracious pest eating beneficials at no additional cost to farmers. Cotton field populations of dominant natural enemies are markedly high when cotton agro ecosystem biodiversity is increased as compared to monocultures. Intercropping with cowpea was found to increase coccinellids, and parasitism of spotted bollworm under south Indian conditions. *H. armigera* parasitism by hymenopterous parasitoids in central India was high when late variety redgram was grown as strip or border crop with cotton. Interplant maize and cowpea act as a source of predators against *H.armigera*. The refuge or source function of border maize or cowpea are attributed to the abundance of floral nectar and alternative prey (aphids), shelter, mating and oviposition sites harbored in the border crop compared with monoculture cotton having lesser biodiversity. By their very nature, pesticides decrease the biodiversity of a system, creating the potential for instability and future problems Pesticides, should be used with caution, since such pesticides may kill predators at the same time as killing the pests. Sometimes part of a crop area is left untreated so that natural enemies will survive and recolonise the treated areas. Erecting bird perches increases the visitation by the birds and hence their predation on insects. *Farmscaping* is a term coined to describe such efforts. Habitat enhancement for beneficial insects, for example, focuses on the establishment of flowering annual or perennial plants that provide pollen and nectar needed during certain parts of the insect life cycle. Other habitat features provided by farmscaping include water, alternative prey, perching sites, overwintering sites, and wind protection.

This approach has inherent advantages over either classical biological control or augmentative releases. Conservation relies on naturally occurring enemies that are well adapted to the target area. Natural enemies occur from the backyard garden to the commercial field. Therefore, conservation is probably the most important and readily available biological control practice available to growers. The method is generally simple and cost-effective. With relatively little effort the activity of these natural enemies can be observed. For example lacewings, lady beetles, hover fly larvae, and parasitised aphid mummies are almost always present in aphid colonies. Fungus-infected adult flies are often common following periods of high humidity. The usage of pesticides has a side-effect on natural enemies. When a pesticide kills the pest, the natural enemies disappear too. They migrate from the agroecosystem

or die. Certain cultural practices can also damage the natural enemies or their habitats, e.g. removal of uncultivated areas, field margins, weedy areas, roadsides, etc.; soil cultivation; crop establishment; fertilisation, growth regulators, or harvesting especially at the critical periods of beneficial organism's life cycle. To conserve natural enemies, pest management decisions must be carefully planned. Conservation involves planning a programme for the whole farm, including the non-farmed land, to enhance biodiversity and landscape features.

14.8 Glossary

- **Augmentation:** Biological control practices intended to increase the number or effectiveness of existing natural enemies.
- **Biological control or biocontrol**: The use of living organisms, such as predators, parasitoids, and pathogens, to control pest insects, weeds, or diseases. Typically involves some human activity.
- **Biorational:** Having a minimal disruptive influence upon the environment and its inhabitants (e.g., a biorational insecticide).
- **Bt:** The bacterium, *Bacillus thuringiensis.*
- **Chemical control:** Pest management practices which rely upon the application of synthetic or naturally-derived pesticides.
- **Classical biological control:** The importation of foreign natural enemies to control previously introduced, or native, pests.

- **Conservation:** Any biological control practice designed to protect and maintain populations of existing natural enemies.
- **Cultural control:** Pest management practices that rely upon manipulation of the cropping environment (e.g., cultivation of weeds harboring insect pests).
- **Density (insect populations):** The number of insects per unit of measure (e.g., beetles per square meter).
- **Ecology:** The study of an organism's interrelationship with its environment.
- **Economic threshold:** The pest density at which a control tactic must be implemented to avoid an economic loss.
- **Entomopathogenic:** Insect disease causing organism.
- **Exotic:** Introduced from another country or continent (e.g., introduced insect pest).
- **GV:** Granulosis virus.
- **Habitat manipulation:** Manipulation of agricultural areas and surrounding environment with the aim of conserving or augmenting populations of natural enemies (e.g., the planting of a refuge for natural enemies).
- **Honeydew:** The sugary liquid discharge from the anus of certain insects (Homoptera) such as aphids and scales.
- **Host:** The organism in or on which a parasitoid lives; a plant on which an insect feeds.
- **Host plant resistance:** The relative amount of heritable qualities possessed by a plant that reduces the degree of damage to the plant by a pest or pests.
- **Hyperparasite:** A parasite whose host is another parasite.
- **Indigenous:** Native to an area.

- **Inoculative release:** The release of relatively small numbers of natural enemies that are expected to colonize, reproduce, and spread naturally throughout an area.
- **Insect growth regulator (IGR):** A substance, natural or synthetic, that controls or modifies insect growth processes.
- **Insect resistant (plants):** Tolerant of, or resistant to, insect attack (as in plants).
- **Instar:** The stage of an insect's life between successive molts, for example the first instar is between hatching from the egg and the first molt.
- **Integrated pest management (IPM):** An approach to the management of pests in which all available control options, including physical, chemical, and biological controls, are evaluated and integrated into a unified program.
- **Introduction (classical biological control):** The importation of a natural enemy from a foreign country or continent, usually to control a pest also of foreign origin.
- **Inundative release:** The release of relatively large numbers of natural enemies to suppress pest populations, without the expectation that the natural enemies will colonize and spread throughout the area.
- **Life Cycle:** The sequence of events that occurs during the lifetime of an individual organism.
- **Mass-reared:** Produced in large numbers, as in natural enemies produced for release programs.
- **Microbial insecticide:** A preparation of microorganisms (e.g., viruses or bacteria) or their products used to suppress insect pest populations.
- **Native (insect or plant):** Of local origin, not intentionally or accidentally introduced.

- **Natural control:** The suppression of pest populations by naturally occurring biological and environmental agents.
- **Natural enemies:** Living organisms found in nature that kill, weaken, or reduce the reproductive potential of other organisms.
- **Nectar:** The sugary liquid secreted by many flowers.
- **NPV:** Nuclear polyhedrosis virus.
- **Parasite:** An organism that lives in or on another organism (the host) during some portion of its life cycle.
- **Parasitoid:** An animal that feeds in or on another living animal, consuming all or most of its tissues and eventually killing it.
- **Parthenogenesis:** Development of an insect, from egg to adult, without fertilization.
- **Pathogen:** A disease-causing organism.
- **Pest:** An organism that interferes with human activities, property, or health, or is objectionable.
- **Pesticide:** A substance that is used to kill, debilitate, or repel a pest.
- **Pest-resistant crops:** Crops that possess attributes which minimize damage by pests.
- **Phenology:** The seasonal life history of an insect population.
- **Pheromone:** A substance, such as a sex attractant, that is given off by one individual and causes a specific reaction in other individuals of the same species.
- **Population:** A group of individuals of the same species within a given space and time.
- **Predator:** An animal that attacks and feeds on other animals, normally killing several individuals during its life cycle.

- **Resurgence (pest):** The development of large populations of pests that had previously been suppressed.
- **Sampling:** Estimating the density of organisms (pests or natural enemies) or damage by examining a defined portion of the crop.
- **Septicemia:** Blood poisoning caused by pathogenic organisms.
- **Specialist:** A pest or natural enemy that utilizes a narrow range of species for its host or prey.
- **Trap crop**: A small area of a crop used to divert pests from a larger area of the same or another crop. The pests, once diverted to the trap crop, may be treated with an insecticide.

14.9 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. The use of living organisms, such as predators, parasitoids, and pathogens, to control pest insects, weeds, or diseases is known as --------
2. The importation of foreign natural enemies to control previously introduced, or native, pests is known as-----------
3. Organisms causing diseases in insects are known as -----------------------
4. A preparation of microorganisms (e.g., viruses or bacteria) or their products used to suppress insect pest populations is known as -------------
5. Biological control practices intended to increase the number existing natural enemies are called- -----------
6. Organisms that lives in or on another organism (the host) during some portion of its life cycle are called -------------
7. Full form of NBAIR is ----------------------------
8. Full form IOBC is --------------------
9. If you find pale green in oval eggs attached to the end of a hair-like stem on plants they indicate the presence of -------------------------
10. Alligator shaped larvae eating aphids in a crop indicate the presence of ------

Section -B (Short Answer Type)

1. What is meant by biological control ?
2. What are natural enemies and what are their different types.?

3. What is the difference between parasites and parasitoids?
4. What are pathogens? Give examples of commercially available entomopathogenic pesticides,
5. How was the problem of the Cottony cushion scale, *Icerya purchasi* Maskell, in California (USA) controlled?
6. Who wrote the book *Silent Spring*? What issues did this book raise?
7. What are syrphid flies? How do they help in biological control?
8. Which are the commonly used parasitoids in India, and yhey are used for the control of which pests?
9. What is farmscaping?

Section -C (Long Answer Type)

1. What are entomopathogenic fungi. How do they work? Give examples of some entomopathogenic fungi.
2. What are lady bird beetles, how are they helpful in biocontrol?
3. What are the three approaches of applied biological control. Which approach do you feel is better and why?
4. What is Bt, how is it used in insect pest management?
5. What are the limitations in bicontrol, what do you feel is the future scope of biological control?

Answer Key of Section-A

1. Biological control
2. Classical biological control
3. Entomopathogenic
4. Microbial insecticide
5. Augmentation
6. Parasites
7. National Bureau of Agriculturally Important Insects.
8. International Organization of Biological Control
9. Lacewing bugs/ *Chrysoperla*
10. Ladybird beetle

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Unit - 15

Biological control of crop pests and weeds – II

Structure of the Unit

15.1 Objective

After going through this unit you will be able to understand

- How some insects are beneficial in controlling unwanted plants/weeds?
- Different types of parasitism?

- Various other organism such as virus, nematodes, bacteria, fungi, protozoa which help to control insects.
- Different aspects of biological control
- Adaptations of predators and parasites of insects

15.2 Introduction

Biological control/ biocontrol/ biopesticides is an ancient way to control plant diseases and harmful insects. The biological controlling agents do not infest the crop or beneficial insect but only destroy the target species. These are naturally occurring farmer's friends in the field that we can multiply in the laboratory and release them in the fields, this is called **Biological Control**. Biological control is the older technique that is not so expensive as compared to means of other control such as chemical, genetical or microbial. It is considered as primary or first line of control method in the field from the very ancient time. It has gained a lot of success in Integrated Pest Management (IPM). These agents are virus, parasites, bacteria and fungi .

According to Baker and Cook (1983), biological control is the reduction of inoculum density or disease producing activities of a pathogen in its active or dormant state by one or more organisms. DeBach (1973) defined biological control as the study and utilization of parasite, predator and pathogens for the regulation (FIG 15.1) of pest population densities (Biological control of Insects Pest and Weeds, 1964).

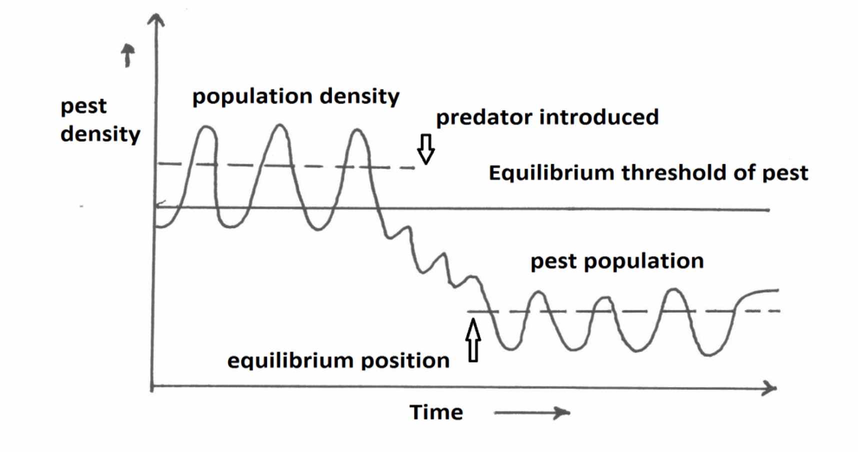

FIG 15.1: Biological control- Population density of pest reduced after introduction of predators

15.3 Biology, adaptation, host seeking behavior

Biocontrol may also be defined as the destruction of unwanted insects by the introduction and increase in the number their of natural enemies**.** With these entomopathogenic insects, insectivorous birds, reptiles, frog, spiders, centipedes crabs etc are also involved in and as agents of biological control.

Biology

Broadly bioagents which control insect pests can be divided into following categories:

1. **Obligate Bioagents:** These bioagents in nature are associated with a specific insect as they are obligatory and are difficult to culture in artificial media. E.g. *Bacillus popilliae* which causes milky diseases of white grubs.
2. **Spore Forming BioAgents**: The toxic protein crystals formed by these sporulating bio inoculants are highly toxic to the target agent. E.g. *Bacillus cereus* produces such toxins.
3. **Determinative Bioagents**: These bioagents are activated when they reach inside the host and then multiply in the haemocoel of insect and produce lethal septicemia. E.g. *Bacillus thuringenesis isrilensis* (Bti).
4. **Facultative Bioagents**: The host tissue is damaged by the invasion of these bioagent but they are not obligatory parasites.
5. **Predaceous Bioagents:** The bio agent either secretes a sticky substance or chemicals to kill the insect or feed upon them.

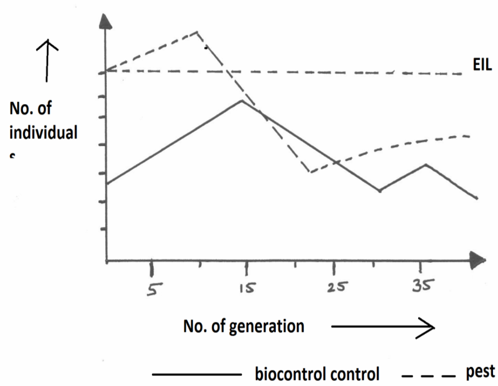

FIG 15.2: Effect of number of individual pest reduces below EIL on introducing biocontrol agents

Adaptation:

There are many **adaptations** and counter adaptation involves in parasites and hosts. Parasite induces some behavioral changes to increase the better of either the host or the parasite. For example, ant *Cephalotes atratus* when infected with a parasitic nematode are transformed to resemble a ripe fruit. Physical changes occur by behavioral changes that increase the ant conspicuousness to prey. Together with these changes the risk of predation by birds also increases. Ants are the intermediate host and birds are the definitive host, so that this predation allows the parasite to complete its life cycle. The nematode manipulates ant appearance and behavior thus confers fitness benefits onto the parasite.

Host seeking behavior:

Both predators and parasites have specific way to search or select their host. To parasitize or predate (FIG 15.3) host they should be efficient first in finding the host habitat where it lives. After finding host habitat it is necessary to find a suitable host which can accept the predator or parasite and suitable for infection. The parasite or predator found its host by tactile, olfactory senses and with this host color, size, shape, physiological conditions and contact are necessary stimulus to attack. Host may also change their own **behavior because of** the presence of parasites to defend themselves or tolerate impacts of infection. Any changes observed in hosts after infection of pathogen are assumed to be adaptive for either the parasite or the host. There are four criteria that characterize adaptation regarding parasite-induced behavioral changes.

1. **Fitness effects**- It is the most important criteria for adaptation as induced behavioral change increase fitness of either the host or the parasite.
2. There is strong correlation between the behavioral change that are induced and the benefit to the host or parasite is evidence for adaptation.
3. **Convergence** - Similar traits arising in different lineages experiencing similar selective pressures is considered evidence of adaptation.
4. **Complexity of the trait**- A trait that appears merely by chance or as a by-product of another selective force may be an adaptation.

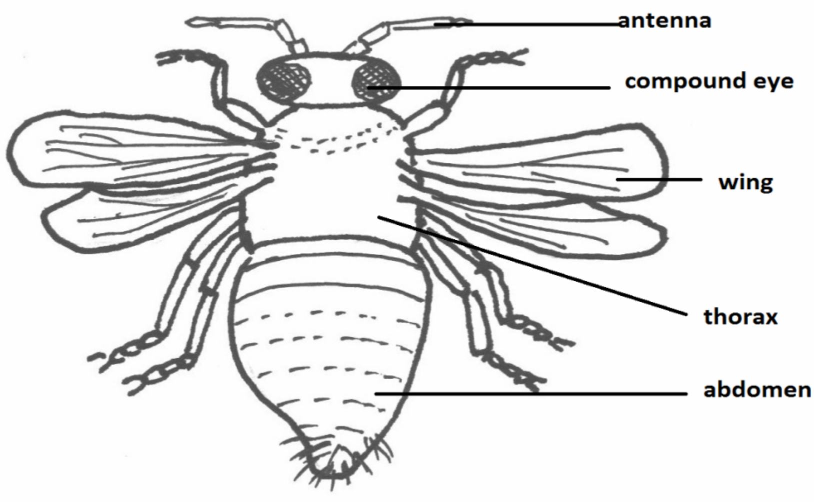

FIG 15.3: An aphid parsite, chalcid wasp *Aphlelinus mali*

A trait may be simple or complex or a trait whose expression appears simple may be mechanically complex.

Parasitic Manipulation of Host Behavior

Many parasites induce change in behaviors in their hosts that appear to confer fitness benefits. It include behaviors that enhance the likely hood of parasite transmission from host to host, changes in host preferences for habitat selection, parasite release at appropriate sites, and colonization by suitable mates for the parasite. The manipulation may be adaptive or produced by coincidental by products. The adaptive manipulation in which specific behavioral alterations induced in a host can be used by parasites to increase their fitness. For example, infection of the parasite *Pomphorhynchus laevis* leads to altered drifting behavior in *Grammarus pulex* as predation risk by *P. laevis*'s increases. The parasite induces behavioral alterations that are side effects of infection and no longer meet the criteria for adaptation and would be considered as coincidental by products. For example, when honeybees *Apis mellifera* are infected with the parasite *Nosema ceranae*, it exhibit a change in thermal preference.

The mechanism of the behavioral changes as temperature rises, the bees due to infection have poor thermoregulatory ability. The changes in behavior due to pathogen infection are stimulated by CNS and altered neurochemical communication.

Behavioral Adaptations for Parasite Resistance

Parasites have many deleterious effects on host fitness and adaptation of certain behavioral changes used by hosts may be characterized as adaptations. These behaviors such as behavioral fever, self-medication, compensatory behavior and suicidal behavior occurs due to parasite and predator attack. Self-medication of host when get infected is a complex behavior found in multiple animal taxa. Generally, compensatory behaviors are also seen where for example in case of female bush cricket infected with gut protozoa mate more frequently as compared to healthy females.Suicidal behavior is an example of pea aphid *Acyrthosiphon pisum* infected with braconid wasp *Aphidius ervi*. Here behavior of infected pea aphids becomes more risky that leads to death by a predator as compared to non-infected aphids.

15.4 Pathogenic nematodes

There are number of entomopathogenic/pathogenic nematode families as Mermithidae, Steinernematidae, Heterorhabditidae who contain species that are parasites of insects during their nematodes development. There are normally 4 moults in between the egg and adult stages known as juveniles. Most nematodes infect the insect during their infective stage juveniles. Their mode of entry may be through the host cuticle or the midgut, and after getting entry into the hemocoel, juvenile undergoes rapid growth. After enough growth it leaves the host and enters the soil to moult giving rise to the adult nematode. Mating and oviposition occurs external to the host in the Mermithidae family.

Mode of Action

Some species kill their hosts when they leave into soil. Some species kill the host by releasing symbiotic bacteria like *Acromebacter* when they enter the cavity of the host. The insect are killed due to bacterial septicemia. Most nematodes do not culture in artificial media except some obligatory endoparasitic nematodes of the genus *Steinernema/ Neoplectana*. They are fast acting which can kill the host within 24-48 hours. Generally the third stage juvenile is infective called **daner juvenile**(FIG 15.4)**.** The insect die due to protracted larval development, abnormal morphology or reduced fecundity, toxins released by nematode causes endocrine imbalance. Some of the examples are;

- *Neoplectana glaseri* is used against Japanese beetle observed first by Glaser.
- *Neoplectana feltiae* against immature stages of flies and crane flies.
- *Heterorhabiditis bacteriophora* against larvae of Lepidoptera and Coleoptera.
- *Heterorhabiditis megidis* against black wine weevil.
- Nematode DD-136 (*Neoplectana carpocapse* carries a pathogenic bacteria *Acromebacter nematophilus*) .It is used against many insect pest like beetles, cockroaches, grasshoppers, moths etc.

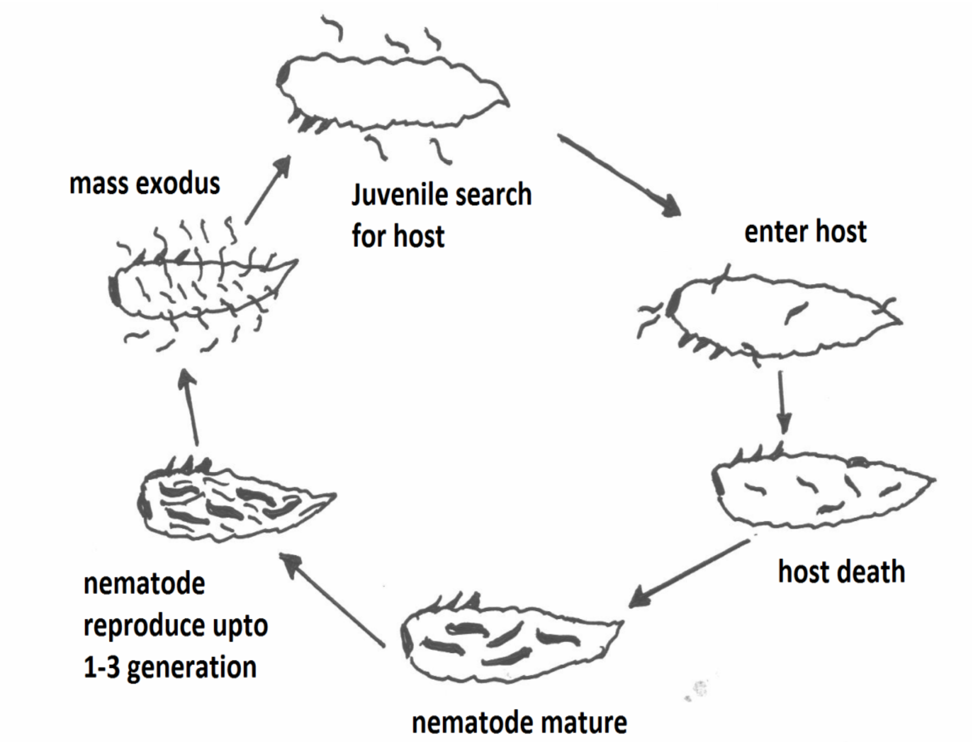

FIG 15.4: Nematode life cycle

The nematode entering in the host insect depends upon the quantity and quality of inoculum and their ability to establish it and multiply in large numbers, resulting in severe infection. The incubation period (time between the entrance of microorganisms into the body and the first symptom of infection) within the host varies from pathogen to pathogen and insect to insect. The mode of action to kill the insect may also be due to the production of endotoxins or exotoxins released by symbiotic bacteria.

Advantages

- They infest a wide range of host.
- Juveniles can be easily cultured and stored.
- Easily applicable in field.

15.5 Pathogenic viruses

Virus is submicroscopic, obligatory, intracellular and pathogenic organisms used to control insects . There are three categories of viruses ,spore forming cytoplasmic or nuclear polyhedral, granular and baculovirus.

Insect viruses fall into five major groups belonging to the family Baculoviridae on the basis of genetic material DNA or RNA. DNA is a genetic material in case of Nucleopolyhedrosis viruses (NPV), Granulosis virus (GV),`Non inclusion viruses (NIV) and Entomopox viruses (EPV) while RNA in Cytoplasmic polyhedrosis viruses (CPV).

Mode of action

There are more than 800 viruses found to control target arthropod insect pests. They are the obligate parasites and can be cultured only in living hosts in the laboratory. When they get mass multiplied it is sprayed in the field. The sprayed viral particles get attached to the plants and when the insect larvae feed and ingest the polyhedral inclusion bodies (PIB) they multiply inside the midgut. This causes death of the larvae. As these protein crystals are insoluble in water they can be reused to infect live insects. It can be stored for long storage outside the living tissue of plants. Virus are short lived outside the host except cabbage looper NPV that can persist for 9 years in soil.

Nuclear polyhedrosis viruses (NPV): It is the most frequently used viral agent in IPM. Virus particles are rod-shaped and enclosed in an outer envelope which may contain one or several viral rods. The viruses enclosed in the envelope are occluded (encased) in protein crystals called polyhedra. NPV is normally transmitted by oral ingestion of polyhedral that dissolves, releasing viral rods into the lumen of the insect host's midgut. For example, NPV controls *Helicoverpa armigera* (gram pod borer), *Spodoptera litura* (tabacoo caterpilllar). NPV infect nucleus of the midgut epithelium of the insect, may be seen with the following symptoms:

- larval skin darkens with yellow patches or appear oily
- Skin becomes fragile
- Hemolymph of the host becomes turbid
- infected larva usually climbs to highest peak available prior to death
- After death, integument ruptures and releases millions of polyhedral to the environment.

Cytoplasmic Polyhedrosis Viruses (CPV)

Particles are not enclosed in membranes like NPV's, but are occluded in protein crystals similar to those of NPV's. CPV infect the cytoplasm of the midgut epithelium of Lepidopterous larvae. Symptoms of CPV infected hosts include

- Time taken for the development of host larvae is longer
- Body of the infected larvae are small with their head large
- Body color may change from normal.

Granulosis Viruses (GV)

GV particles are surrounded by an envelope similar to NPV's envelope. Particles surrounded by these membranes are occluded in a proteinaceous capsule similar to the polyhedral protein that occludes NPV's. GV usually contains only one infectious virus particle called virion rather than many virion particles contained in Nuclear Polyhedrosis Viruses (NPV's) and Cytoplasmic Polyhedral Viruses (CPV's). It infects the fat body of Lepidopterous larvae primarly. GV's are transmitted orally and primarily through the egg. For example, GV controls *Achoea janata* (castor semilooper), *Chilo infuscatellus* (sugarcane borer). Symptoms of a GV infected host include

- The color of larvae becomes lighter
- Haemolymph turns turbid
- Host contains many capsules
- GV comes into action when epidermis is infected causing it to liquefy.

Baculovirus

In contrast to NPV and GV it does not contain protective protein coat or occlusion body. They are double stranded DNAs with non occluded virion. For example *Baculovirus oryctes* used to control rhinoceros beetle. It is strictly restricted to arthropods therefore it is safe to use that do not harm non target species. It causes wilting disease by entering gutwall and liquefies the tissue.

15.6 Pathogenic bacter

Infectious pathogenic bacteria include non spore-forming bacteria and spore forming bacteria. They are the potential pathogens live in digestive tracts of most insects. They enter in insect through haemocoel due to stress factors like temperature extremes, pathogen infestation, parasites and others. Because of these insects with sucking mouthparts like bug, butterflies, moths are hard to control. They can be stored in the form dried spores which later can be mixed with water and apply in the field. So it is available both in powder form or suspension form. First time the insecticidal activity of bacteria was discovered in 1920. The structure of Bti is given below (FIG 15.5).

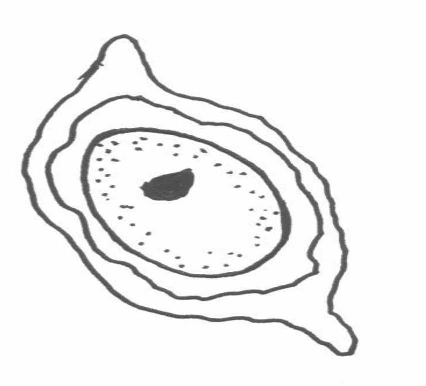

FIG 15.5: *Bacillus thuringiensis israelensis*

Mode of action:

It causes milky disease (*Bacillus popilliae*) in white grubs of scarab beetles such as the Japanese beetle. They can enter the insect through damaged integument. Or they come in action when they are ingestion, after which spores germinate and penetrate the alimentary canal. Invasion and destruction of midgut epithelium is the first step after ingested. They are found in blood after 30 hrs of initial invasion at 30 °C and 7 to 10 days later, about 2-5 billion spores/larva are determined. Larva's blood appears white milky due to number of spores. Larva dies due to septicemia as they multiply in host haemolymph and die due to starvation.

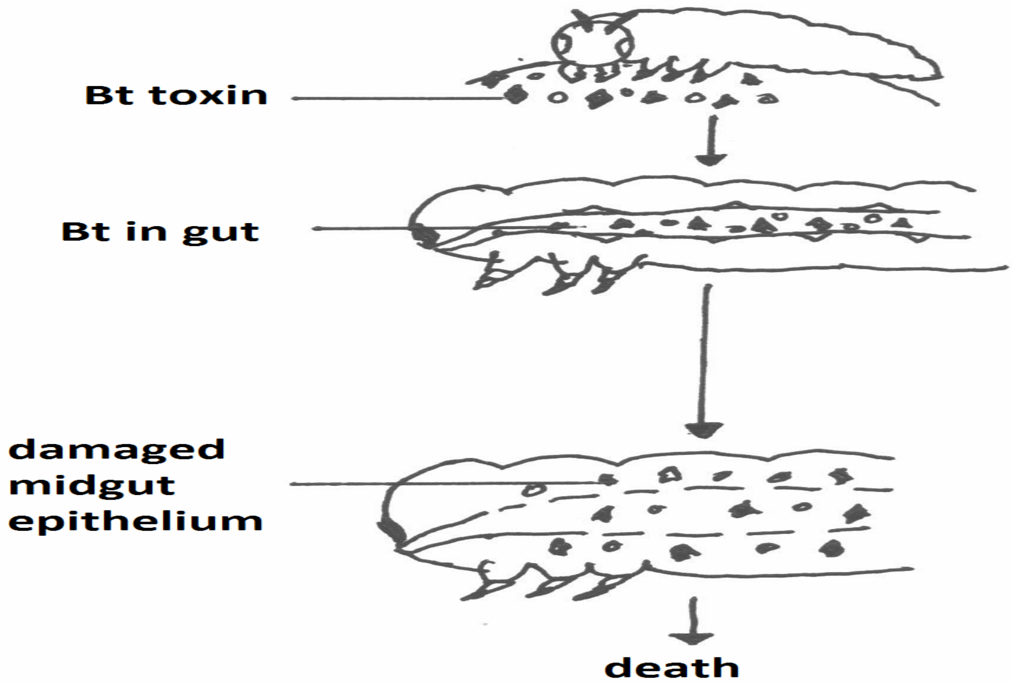

FIG 15.6: Mode of action of Bt

They are pathogenic to mainly lepidopterous larvae and immatures stages of other insects. It forms a toxic crystal (parasporal body) called delta endotoxin which is an alkaline activated crystalline protein (FIG 15.7). Parasporal body contains hyaluronidase and phospholipase that digest the cement holding substances of gut epithelium. Delta endotoxin reduces pH up to 6 and inhibits DNA dependent RNA polymerase by competing for ATP binding sites. Delta endotoxin is also called Insecticidal crystal protein (ICP) or cry proteins encoded by cry genes. Cry I are lepidopteran specific, Cry II for lepidopteran and dipteran, Cry III for coleopteran, Cry IV for dipteran and Cry V for coleopteran and lepidopteran (FIG 15.6). Endospores are also produced by alpha exotoxin which is heat labile lecithinase and beta exotoxin which is an ATP analog. Some are susceptible to action of either the crystal or the spore alone or some to both:

- Type I: develop a general paralysis and die within1 to 7 hrs after ingestion of bacillus;
- Type II: do not develop a general paralysis and die within 2 to 4 days after ingestion;

- Type III: susceptible to a combination of both crystals and spores;
- Type IV: some lepidoptera are not susceptible to both.

After ingestion of spores, first symptom in both Type I and II is that insect stops feeding. Activity of crystal is dependent on the pH of the larval foregut and proteolytic enzymes of the gut. *Pasteuria* bacteria used to control parasitic nematodes and decreases root knot nematode damage. *Bacillus spericus* for mosquito control and *Bacillus cereus* for army worms, cockroaches, codling moth and Indian meal moth. *Bacillus sotto* causes sotto disease in silkworm.

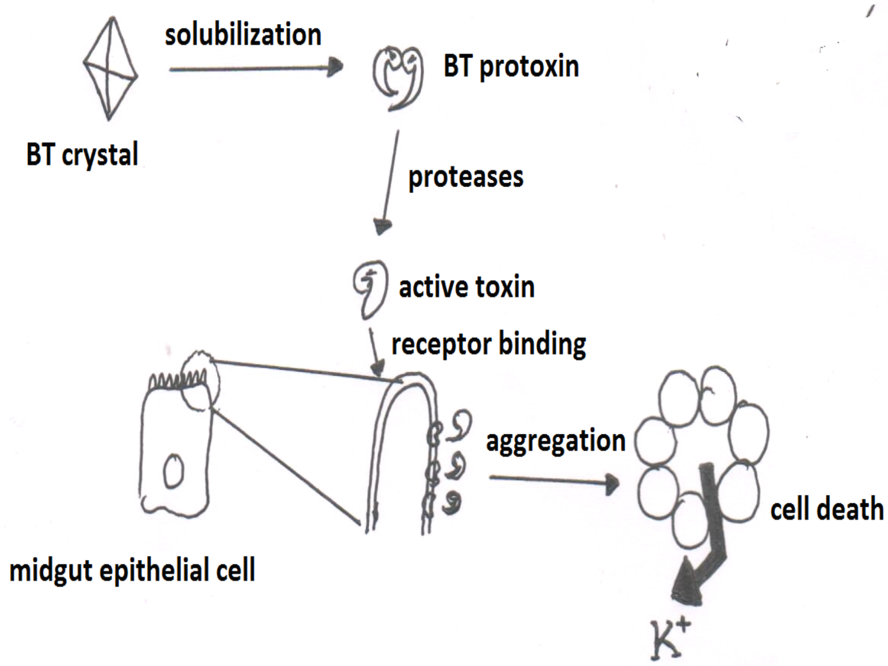

FIG 15.7: Mode of BT action

Non spore forming bacteria *Serratia marcescens* infect wide variety of insects and its presence in the host is determined by reddish color of the body. *Streptococcus pluton* is a causative agent of European foulbrood disease in larval honeybee.

Rickettsias:

Rickettsias also causes infestation in insect as in case of *Rickettsiella popilliae* against Japanese beetle.

Some of the important bacterial pathogens are:

Bacteria	**Trade name**	**Manufacturer**	**Used against**
B. popilliae Dutky and *B. lentimorbus* Dutky (bacteria)	Doom	Fairfex	Japanese beetle larvae (causes milky disease)
B. thuringiensis subsp. Ksurstaki (Btk) (bacteria)	Bactucide Bactospene Biobit Bt Condor Cutlass Delfin Dipel Javelin Larve Bt Sok Thuricide	Philips Duphar Novo Biokontrol Korea Exposives Ecogcn Biotechnology, Sandoz Inc. Abbott Labs Sandoz Inc. Knoll Ubs Nor- American Sandoz Inc.	Lepidopterous larvae of many agricultural crops, forests, ornamental plants and shade loving trees
B. thuringiensis subsp. galleria (bacteria)	Certan	Sandoz Inc.	Wax moth larvae in honey combs
B. thuringiensis subsp. kurstaki (Btk)	MVP	Mycogen Biotechnology	Lepidopterous larvae
B. thuringiensis subsp.	Muscabac	Formos	Flies

thuringiensis			
B. thuringiensis subsp. aizurai	Florback Centari	Novo Nordisk Abbot Labs	Diamond back moth

15.7 Pathogenic fungi

In Fungi, family Deuteromycetes and Entomopthora cause death in insects. They are still undergoing through research to find more and more use of it. They are in a new innovative approach to control insects and attack mostly members of the family Hemiptera, Lepidoptera and coleoptera. Fungi penetrates the body directly through integument and occupy in the softer tissues of insect body. Fungi infection can be seen in insects by a thick mycelial mat covering the entire body of it.

Fungi that infest insect and make them ill are called as entomopathogenic fungi. It includes at least 14 species that attack aphids only. A remarkable feature of some fungi is their effect on plant capay and its efficiency. Several members of fungi Chytridiomycota, *Synchytrium solstitiale* and Blastocladiomycota have been used to control yellow star thistle and mosquito.

Mode of action:

There are more than 36 different genera of fungi which are used in IPM to control pest. Fungi are transmitted from one insect to another by spore called conidium (FIG 15.8,9). Conidia germinate and form mycelia which penetrate the insect cuticle. Development of fungus infections is dependent on favorable conditions as high humidity, temperature and population densities. The important examples of fungi are:

- *Metarrhizium anisopliae* (green muscardine fungus) against locust, white grub, lepidopteran, *Pyrilla*
- *Beauveria bassiana* (white muscardine fungus) against Colorado patato beetle, Pyrilla, aphids, thrips, weevils.
- *Hirsutella thompsoni* against citrus red mite (Trade name: My car, by Abbot labs)

- *Entomophthora* spp. etc.
- *Paecilomyces fumusoroseus* against thrips, white flies, aphids
- *Lecanicillium* spp. against thrips, white flies, aphids
- *Cordyceps* spp. Infect wide range of insects.

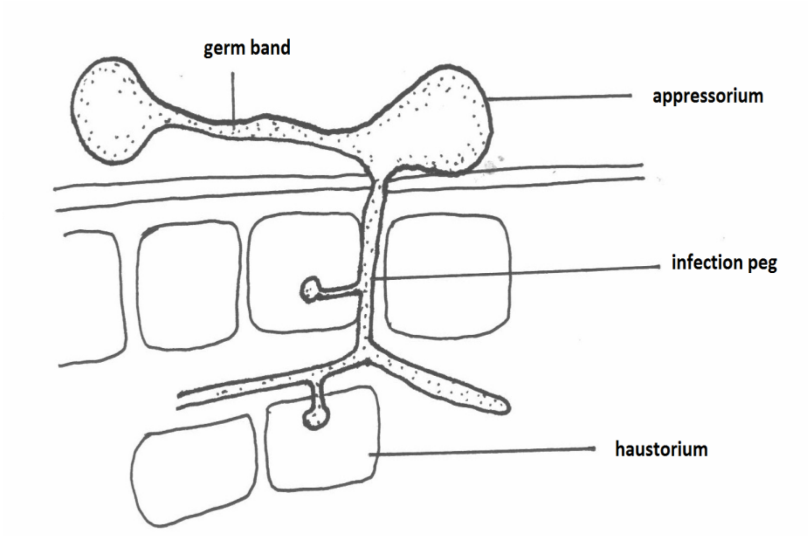

FIG 15.8: Mode of action of fungi

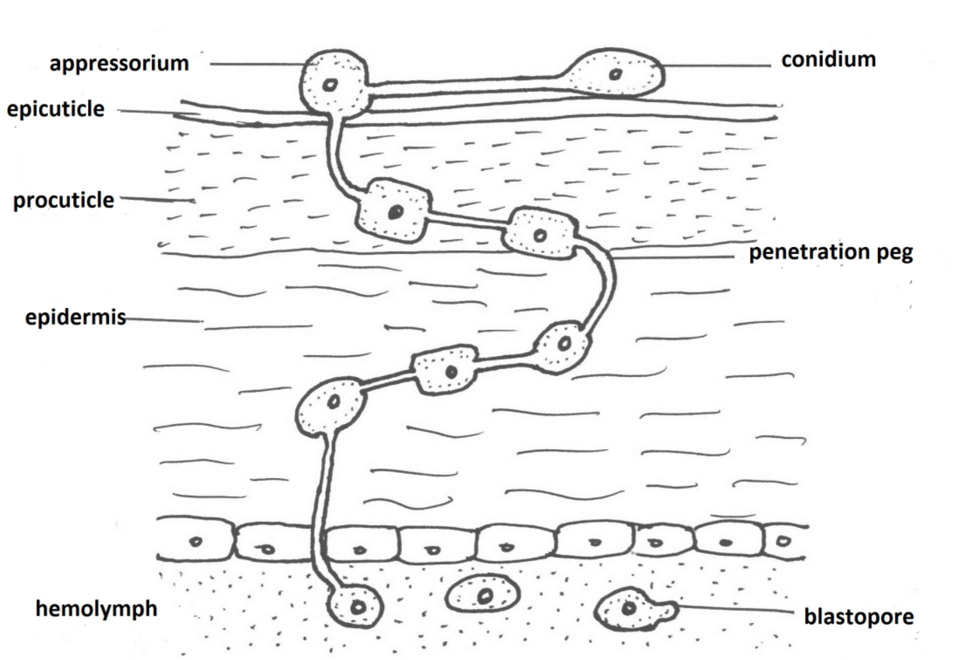

FIG 15.9: Conidia germinating and penetrating in insect cuticle

15.8 Pathogenic protozoa

Flagellates, coccidians, ciliates, amoebas and haplosporidians have pathogenic relationships with insects, but are considered as the least important groups. Neogregarines and microsporidians (FIG 15.10) are the most important entomopathogenic protozoa.

Mode of action

They are transmitted orally from one insect to another as their spores are resistant. They can be transmitted transovarial (from mother to developing egg/ova) from infected females to her progeny. They produce diseases in insects which range from very pathogenic to chronic debilitating infections. They can be important naturally occurring mortality factors. They are obligatory parasites which cannot complete their life cycles in external media. They firstly attack midgut epithelium in some insects and later to other tissue especially fat body. The insect die due to protozoa reproduction, toxin released or secondary invasion of bacteria or viruses. They produces spores or cyst which can live outside the host for quite long duration.

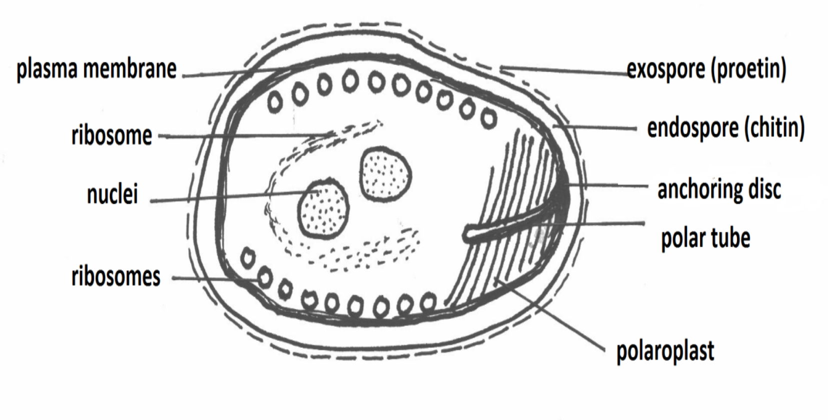

FIG 15.10: Generalized microsporidian spore

Pathogenic protozoans are:

- *Nosema locustae* used to control grasshoppers marketed in the trade name of noloc, Hopper, Stopper by the companies Sandoz Inc., Environment Technologies and Reuter Labs.
- *Perezia pyraustae* used against European corn borer in United states.
- *Nosema bombycis* causes pebrine diseases in silkmoth.

- *Nosema apis* in honey bees.
- *Nosema lymantriae* for gypsy moth *(Lymantria dispar)*
- *Nosema polyvora* to control cabbage worm *Pieris brassicae*

Pre-requisites of Microbial Inoculants

- Bio inoculants/ bio agents should be highly virulent to the target organism.
- It should be stable to sustain in nature.
- Virulence should be host specific.
- Should not damage crop, beneficial insects, micro flora and predators.
- Should be easily cultured in masses.
- Should be stable for a long period of time.

Advantages of Microbial Inoculants

- They are eco-friendly and leave behind no toxic residues.
- Most of them are host specific insect and in turn protect beneficial insects.
- Most inoculants are easily culture in the laboratory covering minimum space as they are microbes.
- They are not expensive to produce large quantities of inoculum.
- They take long time to develop resistance.
- They are efficient in controlling insect where chemical insecticides cannot reach.

Way of using microbial inoculants:

- **Short Term Control:** For a particular season in a year or by using highly virulent pathogens.
- **Long Term Control**: Generally used for perennial crops and less virulent pathogens are preferred.

Disadvantages of Microbial Inoculants

- It is beneficial only when it is applied at correct times.

- They have host specificity for most pathogens, so narrows down its uses are quite limited.
- It is very important to maintain a pathogen in a viable condition, until the contact with the insect is made.
- Difficulty in producing some obligate and facultative pathogens on a large scale.
- Requirement of favorable environmental conditions for the pathogen to act, multiply and execute its mode of action.
- Tendency of dead insects remaining attached to the host.

15.9 Biological control of weeds

Weeds are the unwanted plants that grow along with the crop grown and compete the field crop for food, space, niche, water and shelter. So there is a need to remove these unwanted plants for efficient yield of crop grown. They are physically eliminated from the farmers by hand picking but it is a tedious job which waste a lot of energy and time. Biological control of weeds is an alternative which involves the invasion of living organisms, such as insects, herbivorous fish, other animals, micro-organisms, and competitive plants to limit their infestations. Any biological control approach shall yield best results when it is integrated with a comprehensive Weed Management Programme (WMP).

Outstanding examples of classical Bio-control of Weeds:

- **Lantana (*Lantana camara* L.)**

Lantana, was the first typical exotic weed that was controlled successfully with insect bio-agents in Hawaii. This bushy exotic weed is a native of Central & North America and invaded Hawaii in large areas of rangelands that it was causing great concern. In 1902, Albert Koebele was first to visit Mexico and Central America to find insects destructive to Lantana. Perkins conducted tests with insects sent by Albert Koebele and finally selected eight species for release on lantana infestations. Of these, *Crocidosema lantana* Busck (a moth) was found in destroying flowers and seeds of lantana, which formed the chief organ for dispersal of this weed. The insect greatly curtailed the spread of lantana and thinned its existing infestations. Fifty years later, the entomologists in Hawaii made further attempts to find and introduce new insect species to destroy lantana; this time from areas other than the native land of the weed. They found seven more insects feeding on lantana. Of these, *Hypena jussalis* Guenoe was an excellent feeder of lantana leaves. It defoliated all sizes of lantana plants rapidly. Since then many other insects have been screened for the destruction of lantana in Hawaii, and the weed has been brought under control on its different islands. Biological control of lantana has also been adopted successfully in Australia and other places. In Australia, three highly successful insect biocontrol agents are; hispine beetles (*Octotoma scabripennis* Guerin), *Uroplata girardi* Pic.) and tingid or lantana bug (*Teleonemia scrupulosa* Stal, FIG 15.11 A). These insects are causing severe damage to the susceptible taxa of Lantana, which are receding fast there. In Andhra Pradesh (India), lantana has been successfully controlled with some of these insects, besides the lantana seedfly (*Ophiomya lantanaea*) (Thakur, 1992).


A) B)

Fig. 15.11: *Lantana* bush has been destroyed A) Defoliation of the weed with *Teleonemia scrupulosa* B) *Lantana* stem gridled by larvae of *Plgiohammus spinipennis*

- **Prickly pear (*Opuntia spp.*):** In Australia, biocontrol of *Opuntia inermis* with a moth, *Cactoblastis cactorum* (Berg, FIG 15.12) is used. At the present, in Australia only occasional plants and few patches of prickly pear are found. The recovered land has returned to a useful agriculture there. In Tamil Nadu and Maharashtra (India), 40,000 hactare of land infested with *Opuntia dillenii* was recovered from the weed by releasing *Dactyloplius tomentosus* Auct. 'cochineal scale insect' as its bioagent. Other species of Opuntia were not attacked by this insect. The primary damage to Opuntia with insects can be combined with secondary attacks by bacterial and fungal parasites for further eroding the weed. These secondary bioagents are *Cleosporium anatum* E & E, *Phyllosticta concava* Seav. and *Montegnella oppuntiorum* Speg.

Fig. 15.12: *Opuntia* all Over and *Opuntia* infested by *Cactoblastis cactorum* within 3 years (in Australia).

- Carrot grass (*Parthenium hysterophorus* L.): It is an exotic alien weed which is considered one of the most dreaded weeds of the world. Originally a native of tropical America and West Indies, it has spread in many countries, including India. Ever since its first appearance in India in 1956 at city Pune, it has spread alarmingly in almost every part of the country. It is primarily a weed of all possible neglected non-crop areas, including grazing grounds, where it has covered vast areas with devastating effects on health and environment. Carrot grass has now also spread to some agricultural lands, fallow fields, and orchards. *Parthenium* is poisonous and allergic in its effects on humans.

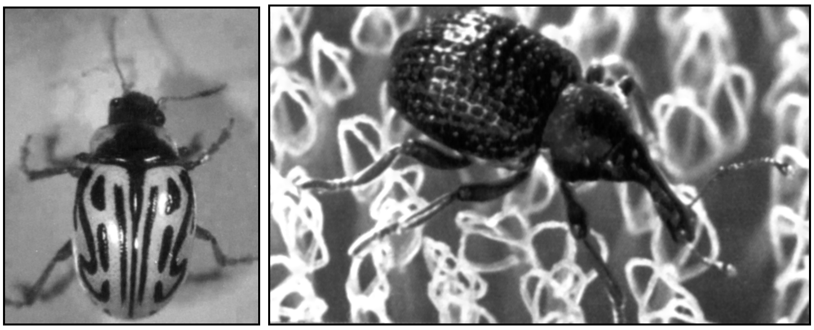

FIG 15.13: *Zygograma bicolorata* against *Parthenium hysterophorus* and *Cyrtobagous salviniae* against *Salvinia molesta*.

The biological control of *Parthenium* using a Mexican beetle, *Zygogramma bicolorata* (FIG 15.13), is found very promising. Large patches of land heavily infested with this menace have been cleared off by the beetle in several parts of the country. The number of insects released must be 50-100 beetles/plant of carrot grass. Management of *Parthenium* through biocontrol may be considered as the most preferred way as it is cost-effective and self-sustaining method.

- **Water hyacinth (*Eichhornia crassipes*):** Water hyacinth, a worldwide aquatic weed, infests transplanted rice fields in many countries, including India. Several attempts have been made on the biological control of this weed by pathogens and insects both. Most success in this respect has been met in Florida (USA) with a hyacinth moth, *Sameodes albiguttalis* B. Benner, which is a native of South America. The bioagent exhibits its rapid reproductive ability in field conditions. Its larvae feed upon young leaves and apical buds of water hyacinth, rather severely. With this hyacinth moth, two beetles, viz., *Neochetina eichhorniae (*Warne) and *N. bruchii (*Atustache)*,* are also damaging to water hyacinth, but these are not as fast acting in building their populations as the hyacinth moth do.

- **Salvinia (*Salvinia molesta*):** In Kerala (India), fresh water courses and paddy fields have been cleared of this noxious fern, using curculionid beetle (*Cytrobagous salviniae* Sands) as a very effective bioagent. The beetle is native of South America. It is released in waterways by collecting some beetle-infested *Salvinia* plants from either the beetle rearing ponds or some old infestations, and scattering these on the target, salvinia infestations. It takes 4-6 months for the salvinia mats to turn yellow, and another six months to sink, completely. The young larvae of the beetle damage the terminal buds, rhizomes, and petioles of salvinia. The biological control of salvinia has made lives of over 5 million people in Kerala more comfortable than before.

In addition to the above mentioned examples of outstanding achievements and wide interest in the biological control of weeds, there are many more successes on hand at various stages of research and field use.

Table 1: Some Additional Examples of Promising Bio-agents of Weeds

Weed	**Bio-agent**	**Reporting Country**	**Kind of bio-agent**
Chondrilla juncea	*Puccinia chondrillina*	Australia	Plant pathogen
Cirsium arvense	*Septoria cirsii*		Plant pathogen
Cyperus rotundus	*Bactra verutana*	India, Pakistan, USA	Shoot boring moth
Echinochloa spp. (In rice fields)	*i)Emmalocera spp.* *ii) Tripos spp.*		i) Stem boring moth ii) Shrimp
Eupatorium riparium	*Entyloma compositarum*	USA	Plant pathogen
Hydrilla verticillata	*Hydrellia pakistanae*	USA	Shoot fly
Orobanche cernua	*Sclerotinia sp.*	USA	Plant pathogen
Rumex spp.	*i) Uromyces rumicis* *ii) Gastrophysa viridula*	USA USA	Plant pathogen Beetle
Tribulus terrestris	*Microlarinus lareynii and M. lypriformis*	USA	Pod weevil

Biological Control Organization

The increasing importance of biological control has increased the interest of many countries in developing biological control stations and organizations to solve their pest control problems through natural enemies.

Table 2: Biological control stations in different countries

Country	Station/Organization
India	CIBC (Commonwealth Institute of Biological Control), Bangalore
Australia	CSIRO, Sydney
U.S.A.	CIBC, Fontana, California
Mauritius	FAC, of Agric. Kyushu University, Fukoda
France	USDA, ARC, Nanterre, Seine

CIBC is a unit of CAB (Commonwealth Agricultural Bureau). It came in existence in 1956 in Bangalore. It lists about 24 species of exotic natural enemies and about 68 species have been released.

15.10 Various aspects of biological control

The biological control includes all the agents which are living and its associated factors that can increase or decrease the population of biocontrol agents. There are various aspects that can maximize the effect of biological control.

15.10.1 Ecological aspects

The population of the insects has two major concerns as homeostasis and regulation. As the population density of insect is not constant and fluctuates in nature. Homeostasis refers to the stability of the population over a long period of time; they are more or less constant. This stability or equilibrium is achieved by regulation. The regulation of insect population comes in role as there are immigration and emigration of natural enemies which control insect number. Some predators and parasites are the natural agents that keep the population below a certain level. Food chain and food web has many interconnected trophic levels which includes predators and parasites. When the natural enemies are not living in an area where crop field are grown then these bioagents are trapped, augmented, transported and release to the field to control destructive insects.

15.10.2 Biological aspects

These include all the entomophagous insects and their aspects as nutrition, classification, behavior, mating and oviposition.

i) **Classification:** Biocontrol agents are classified into two types as true parasites and entomophagous insects. True parasites are the organisms other than insects and entomophagous insects which feed on other insect. Entomophagous insects are further subdivided into parasites or parasitoids. Parasites may be ectoparasite, endoparasite, solitary, facultative or obligatory. Parasites may attack any stage of life cycle of insect as egg, larva, pupa or adult.

ii) **Nutrition:** The female insect always needs a source of protein to develop their eggs. The source of protein may be nectar, honey dew or blood . If this protein requirement is not fulfilled by the female all the eggs get reabsorbed in the ovarioles.

iii) **Behavior:** It is the manner by which predators and parasites find their host and select them as per their requirement. Major steps are involved as host habitat finding, host finding, host acceptance and host suitability.

iv) **Mating:** Mating behavior is the way to meet male and female for copulation. Insects may be polygamous which mate several times as in case of most insects like grasshoppers, cockroaches or monogamous which mate only once in their life cycle as termite and honeybee queen.

v) **Oviposition:** And after mating to select the site of oviposition, host finding and where to lay egg on the host, in the host or away from the host. Eggs of the predators and parasites are laid singly or in groups and may or may not reach the host if laid away. In Diptera and hymenoptera there is specific way to parasitize the host as it first inject the venom through stinging and then have specific selected sites where they lay eggs. This specification is used as a useful taxonomic importance.

15.10.3 Taxonomic aspects

All the natural enemies should be identified well before they are used in biological control. Their behavior, life cycle, habitat, ecology, requirement and systematic position must be well known before application. For example genus *Circulifer tenellus* (beet leaf hopper) was place in genus *Eutettix* earlier which was found to be incorrect when the researchers were trying to locate it in Australia, Argentina, Mexico and was found in California which was its home place. Due to this incorrect placement of insects it is very difficult for the researchers to work on a correct path. Due to the biological control efforts new sibling species or cryptic species were discovered. Sibling species are those species which are morphological similar but they cannot cross. In case of genus *Aphytis* of the order Hymenoptera it was thought only one species exist but later on found seven sibling species of this genus. *Aphytis* is a effective biocontrol agent against red scale insect in California.

15.10.4 Economic aspects

Any other method used to control insect pest as chemical, physical, cultural etc needs a lot of energy and money to spend. But in case of biological control initial investment is needed but it is economical as it is effective in long run and do not need repeated application as it is self sustaining.

15.10.5 Legal aspects

When the biological control agents are not found in an area where it has to be applied, then we have to import the predators or parasites from other country. It is not an individual decision to import them as we have quarantine regulations and legislative laws decided by the government. These laws do a variety of jobs like;

i) It restricts the movement of organisms from one place to another.
ii) Inspection of organism by the committees is done at the port of entry.
iii) Testing and observation of imported organism in laboratory.

15.11 Types of parasitism

Parasite

Entomophagous parasite (Greek word means insect, eater of) is defined as an organism that feeds on another organism called host, mostly without killing the host. Certain insect species are the vectors of some of human most dreaded diseases, including malaria, typhus, and plague.

For example mosquitoes, are the most notorious carriers/vectors, of parasites or pathogens. Female mosquitoes need blood meal for production of their eggs. During the process of penetrating a host's skin with their long, sucking mouth parts, virus, protozoan, or helminth can be transferred directly into the blood stream of its host with its saliva. Among these pathogens are *Plasmodium* (protozoan) *W. bancrofti* (filarial worm), and *Flavivirus* (a virus). Flies also harbor many diseases that can be transmitted to humans and other mammals when they sit or feed to obtain a blood meal for themselves. For example, black flies can carry river blindness pathogen, sand flies can carry *Leishmania*, and tsetse flies carry the *Trypanosoma* that cause sleeping sickness. Fleas and lice are two of the most common and irritating parasitic insects of humans and our livestock. Lice commonly live among the hairs of their hosts, feeding on blood and are ectoparasitic in nature. Some species are carriers of the epidemic inducing typhus fever. Fleas usually infest birds and mammals, and can feed on humans when they are transferred from pets or livestock. Fleas are known to carry a variety of devastating diseases, including the plague. Some diseases are of veterinary importance but they get transferred to human beings when they come in contact with it.

Vector and Host Relationships

There are three important aspects to produce a disease as **pathogen** which is the root cause of disease, **vector** the agent that carry the pathogen and transfer them to host; and the **host** in which the pathogen passes its life cycle and causes diseases. Disease transmitted by insects depends on their behavior, life history and suitability of the vector to transmit disease. The parasites may be of many kinds:

- **Ectoparasites:** Species that live externally on the host. Example ticks.
- **Primary parasite:** These are the insects which attack phytophagous insects (feeding on plants).
- **Secondary parasite:** When primary parasite is attacked by another parasite considered as secondary/ hyperparasites.
- **Endoparasites:** These are internal parasites. Example, Dipteran larvae.

- **Obligatory Parasites:** If a parasite can only live on a given host species the relationship is called obligate, e.g., head lice are obligate ectoparasites of man.
- **Fluctuate Parasite*:*** If a parasite does not live exclusively on a given host species, then the relationship is said to fluctuate, e.g., cat fleas are facultative parasites of humans. Additionally, some parasites may be continuous on a host (like lice) but others may be temporary (like fleas).
- **Hyperparasite*:*** If a parasite live on other parasite. Hyperparasites are less restricted to their host selection. They are generally the ectoparasites and causes slow onset of death in host. It is being very rare that it causes castration as in case of parasitism by Strepsiptera. Example, chalcid *Perilampus* is a parasite of Ichneumonoid genera *Microgaster* and *Apanteles* which is further the parasite of Lepidoptera caterpillars. Female Aphilinidae is a primary pest of male of some other species which is a secondary pest of other insects. Similar to this case sometimes female becomes parasite of the same male species, the phenomenon is called **autoparasitism**. Genetic variation always occurs in **hyperparasites** so; are likely to produce new strains which are able to attack newly evolved resistant/virulent strains of the host pathogen. The hyperparasites are living agents which are able to adopt themselves to changes with the plants.
- **Brood parasitism/Cleptoparasitism*:*** Smuggling of eggs into the brood nest of another insects. Example, robber flies (*Miltogramma* sp.) and cuckoo wasp.
- **Multiparasitism:** If same host is attacked by different species of parasites. It is a rare phenomenon seen in certain circumstances as in *Autographa californica* which attributes to the partial host consumption. Multiparasitism is seen in case of larvae of moth *Ephestia serecarium* attackes by parasite *Horogenes chrysostictos* and *Nemeritis canescens*. Both the species lays eggs independent of each other and when the larva hatch at the same time they compete and attack each other either of them can win. But if the instars are of different ages then the older instars will win. So the factors effecting them are age of instars, environmental temperature, species and rate of development.

- **Superparasitism:** It is a kind of parasitism where many different individuals of same species attack same host. It generally can be seen in the larval stages as caterpillar which is attacked by number of parsitoids. For example, a social wasp named *Ropalidia romandi* is an endoparasite of Strepsiptera (females of family Stylopidae). The female Stylopid is an obligatory parasite of larva that makes their way through the cuticle. After entering the host it consumes almost 80% of the tissue in the abdomen and makes a sac around them to protect it from the host defenses. It causes sterility in larva because ovaries and spermatheca sometimes unrecognized due to its parasitism. They do not kill the host but they change the host behavior, morphology and normal life processing.
- **Social parasitism***:* Guest in the nest of various social insects. In case of ants certain species takes special form of nutrition called slavery. The slave driving ants capture the pupae so that they can breed their own brood. The ants *Anergates* cannot feed on their own so they invade nest of *Tetramorium*.

Vector and Pathogen Relationships

The ability of a pathogen to survive and remain infective in or on a vector species is a critical factor in disease transmission. The mechanisms of transmission are of two kinds:

1. **Direct contact:** These pathogens are actually inhabit the host as ectoparasite and majorly they cause disease primarily by their sucking blood, irritation, itching and excreta and secondarily causes diseases by carrying pathogens as in case of *Pediculus* spp. The two hosts are in direct contact with each other.
2. **Mechanical transmission:** It is the transfer of a pathogen from an infectious source to a susceptible host by a vector, without any reproduction or developmental changes in the pathogen. Generally, mechanical transmission is an inefficient mechanism for disease transmission. Many insects carry disease by clinging pathogens on their body parts, mouth parts, hairs, scales but relatively few are known to be associated with disease outbreaks. Such a transmission is usually non-persistent since the pathogen survives for only a short period, example aphids, housefly.

3. **Biological transmission/Circulatory transmission:** When the pathogen either reproduce, undergoes developmental changes, or both in the vector. Biological transmission is the most effective and significant mechanism for disease transmission by arthropods. It is also divided into three categories as:
   - **Cyclodevelopmental:** In this type of transmission the pathogen spends a part of its life cycle in a vector, grow and develop inside, can change their body form or shape but do not multiply in host. For example *Waucheria bancrofti* transmitted by *Culex* female mosquito and causes Filariasis or elephantitis in human.
   - **Cyclopropagative:** In this mode of transmission the pathogen undergoes cyclic changes and multiplication inside the vector. Malaria pathogen *Plasmodium* transmitted by female *Anophele*s mosquito.
   - **Propagative**: When the organism simply multiply and grows as in Plague causing pathogen*Yersinia pestis* transmitted by rat fleas.

The relationships between vectors, pathogens, and hosts are complex.

15.12 Summary

Biocontrol is a term which can include anything that can be used as insects, protozoa, nematode, virus, bacteria of biological origin to control weeds or harmful insects. In other words biocontrol means complete eradication or removal of the unwanted organism from the level of economic injury. The principals way for biocontrol are collection and use of biotic agents, their isolation and using microbial organisms containing bacteria, fungi, viruses, nematodes, protozoa etc. which are known as **microbial pesticide**. The microorganisms which are naturally occurring enemies used in biocontrol of infested plant diseases are termed as Bioagents or Antagonists.

Microbial insecticides are different with specific mode of action to kill the organism. Luck concluded that all are “to one degree or another inadequate”. He shows different processes associated with predation or parasitism.

15.13 Glossary

- **Ectoparasites:** Species that live on the host.

- **Endoparasites:** These are internal parasites.
- **Obligatory Parasites:** If a parasite can only live on a given host species.
- **Fluctuate Parasite*:*** If a parasite does not live exclusively on a given host species.
- **Social parasitism*:*** Guest in the nest of various social insects.
- **Superparasitism:** It is a kind of parasitism where many different individuals of same species attack same host.
- **Multiparasitism:** If same host is attacked by different species of parasites.
- **Cleptoparasitism*:*** Smuggling of eggs into the brood nest of another insects.
- **Biological transmission:** When the pathogen either reproduce, undergoes developmental changes, or both in the vector.
- **Mechanical transmission:** It is the transfer of a pathogen from an infectious source to a susceptible host by a vector.
- **Daner juvenile**: The third stage juvenile is infective called **daner juvenile.**
- **Biological control:** It is the study and utilization of parasite, predator and pathogens for the regulation of pest population densities.

15.14 Self Learning Exercise

Section -A (Very Short Answer Type):

1. Name one example of Rickettsia to control insect?
2. Write full form of CIBC?
3. Name example of direct contact transmission?
4. Write the trade name and manufacturer of *B. popilliae?*
5. What is the trade name of *B. thuringiensis subsp. thuringiensis* and used against which insect*?*
6. Give two example of nematode that control insect?
7. Which disease is caused by *Bacillus popilliae* in white grubs of Japanese beetle?

8. *Lantana camara* is controlled by which insects?

Section -B (Short Answer Type)

1. Define biocontrol agents?
2. Differentiate between multiparasitism, superparasitism and hyperparasitism?
3. Write short note on pathogenic nematode and its mode of action?
4. What are entomophagous pathogens?
5. Give in brief the role of protozoa in controlling insects?
6. How the fungi cause death in insects when infected?

Section -C (Long Answer Type)

1. What are various aspects of biological control?
2. Write different types of parasitism?
3. How the predators and parasites find their host and what changes occur in host?
4. Explain the mechanism of control of weeds biologically with examples?
5. Write about fungi bioagent, its mode of action and examples?

Answer Key of Section-A

1. *Rickettsiella popilliae* against Japanese beetle
2. Commonwealth Institute of Biological Control
3. *Pediculus*
4. Doom and Fairfex
5. Muscabac against houseflies
6. *Neoplectana glaseri* and *Heterorhabiditis bacteriophora*
7. milky disease
8. lantana bug (*Teleonemia scrupulosa)* and lantana seedfly (*Ophiomya lantanaea*)

15.15 References

- Cedric Gillot : Entomolgy
- Kachhwaha N.: Principles of Entomology-Basic and Applied

Unit - 16

Biological control of crop pests and weeds – III

Structure of the Unit:

16.1 Objectives

This unit is the third part of the biological control of crop pests and weeds , you have already gone through the first and second part in which you studied about the its history, principles and the scope . The various groups of parasitoids, predators and pathogens were described in the first part and the classical biological control principles were studied .The second part comprised of Biology, adaptation, host seeking behavior of predatory and parasitic group of insects . The role of insect pathogens, nematodes, viruses, bacteria, fungi, protozoa etc and their mode of action was studied .In the last part we dealt with biological control of weeds using insect.This Unit is a further advance of the previous units and will help learner understand how the mass production of quality agents takes place , the techniques involved in their formulations ,economics ,field release and evaluation. The unit also cites successful biological control projects in India ,trends and future possibilities of biological control. At the end importation of natural enemies and the legal constraints in it are described. The role of Biotechnology and Semiochemicals in biological control have been incorporated too.

16.2 Introduction

It should first of all be pointed out that biological control tends to have its strong supporters and vehement detractors; it tends to pass through alternate phases of popularity and loss of esteem. After 1945, biological control was, of course, somewhat eclipsed by the over optimistic hopes generated by DDT and other organic insecticides. We now recognize that insecticides offer no patent solution for all of our insect pest problems, and that indeed they generate considerable problems.

Since the mid 1960's, certain areas have received greater research emphasis: Insect pathology and biological weed control have developed rapidly as specialties within the field. Further research has been advanced in developing methods of evaluating the effectiveness of natural enemies. Also there have been significant advances in quantitative field population studies; inquiry into the extent of naturally occurring biological and research on the augmentation and conservation of natural enemies.

We may expect that much of the biological control work during the next decade will remain similarly uninfluenced. Biological control workers are dealing with problems of extreme complexity. They are carrying out field experiments involving an enormous number of unknowns. They are usually charged with solving several pest problems concurrently, and they usually operate with limited manpower and financial resources.

Although population dynamics has had little effect on biological control practice, it has created a new climate of opinion with regard to biological control. Increasing importance is being attached to biotic elements in pest control. Biological control, like chemical control, will increasingly come to be regarded as part of a comprehensive investigation of the total ecology of pests. The importance of one or more key factors in regulation is borne out by biological control, as the introduction of single species of natural enemies lowers the average density of a pest.

16.3 Mass production of Quality agents

The first major concern in commercial production systems involves the achievement of adequate growth of the biocontrol agent. In many cases biomass production of the antagonist is not easy owing to the specific requirement of nutritional and environmental conditions for the growth of organism. Mass production is achieved through solid and liquid fermentation techniques. The commercial success of biocontrol agents requires:

i) Consistent and broad spectrum action.

ii) Safety and stability.

iii) Longer shelf life.

iv) Low capital costs.

v) Easy availability of career materials.

vi) Economical and viable market demand.

16.3.1 Techniques

Biological control practices involve three major techniques:

1. Introduction
2. Conservation
3. Augmentation

1) Introduction

It is advisable to introduce an exotic species of a natural enemy either when there is an unoccupied a niche and is required to be displaced by a more efficient exotic species. The former is a common situation in newly introduced pest in a country. Foreign explorations for parasites and predators have been made primarily to introduce parasites from the place of origin of the pest and sometimes to introduce exotic natural enemies of the indigenous pest species.

Recently, many international organization have been established to facilitate the movement of beneficial species from one country to another and the largest of the organization is the 'International Institute of Biological Control' which has laboratories in Switzerland, Trinidad, Malaysia and Pakistan. About 40% of the introduced natural enemies have established in the introduced countries and provided partial to complete control of important insect pests at the global level. In India, since the launching of 'All India Coordinated Research Project on Biological Control of Crop Pests and Weeds' (AICRPBC) in 1977, 79 species on natural Enemies have been imported out of which 53 have successfully multiplied and 21 have been established in the field.

2) Conservation

Conservation means the avoidance of measures that destroy natural enemies and the use of measure that increase their longevity and reproduction of the attractiveness of an area to natural enemies. If the natural enemies are properly conserved the need for other control measures is greatly reduced. Various strategies of conservation as given below:

i) **Preservation of Inactive Stages :** This is most critical when there is small reservoir of natural enemies outside the cropped area e.g. Pupae of *Epipyrops* are found in large numbers on the trashes of sugarcane leaves at the time of harvesting. These are left around harvested fields to augment the supply of natural enemies in the pre-monsoon season against *Pyrilla*.

ii) **Avoidance of Harmful Cultural Practices :** Cultural practices like burning can be harmful to natural enemies e.g. burning of sugarcane trash destroy the resting stages of *Epipyrops*. Such practices can be modified to avoid harmful effects.

iii) **Maintenance of Diversity :** The concept more the diversity more is the stability holds true because diverse system may provide alternate hosts as source of food, ever wintering sites, refuges etc. e.g. mixed cropping, intercropping etc.

iv) **Natural Food, Artificial Food Supplements and Shelters :** Many parasitoids and predators require food frequently not available in monoculture. The availability of predatory mites was related to the availability of pollen. Artificial honey dew and pollen in the form of food sprays induced early ovipositor of *Chrysopera* spp**.**

v) **Protection from Pesticides :** All pesticides have adverse effects on natural enemies. The solution lies in the use of relatively resistant strains of natural enemies and selective use of pesticides.

3) Augmentation

Augmentation includes all activities designed to increase numbers or effect of existing natural enemies. These objectives may be achieved by releasing additional numbers of a natural enemy into a system or modifying the environment in such a way as to promote greater number or effectiveness. These releases differ from introduction of imported natural enemies in that these have to be repeated periodically. The periodic releases may be either Inoculative or Inundative.

i) **Inoculative Release :** Inoculative release may be made as infrequently as once a year to re-establish a species of natural which is periodically killed out in an area by unfavorable conditions part of a year.

ii) **Inundative Release :** Inundative release involves mass culture and release of natural enemies to suppress the pest population directly. These are most economical against pests that have only one or few discrete generations every year e.g. massive release of *Trichogramma spp.*

16.3.2. Formulations

Formulation is blending of active ingredients such as fungal spores with the inert material such as diluents and surfactants in order to alter the physical characteristics of to a more desirable form. A final formulation must:

i) Be easy to handle.

ii) Be stable over a range of -5 to 35°C.

iii) Have a minimum shelf-life of two years at room temperature.

Development of formulations with increased shelf life and broad spectrum of action with consistent performance under field conditions could pave the way for commercialization of the technology at a faster rate.

Major research on biocontrol is centered with the use of spores of quality agents directly to seed. Technologies become viable only when the research findings are transferred from the lab to field. As example, *Trichoderma* has a very good potential in the management of diseases, it could not be used as spore suspension under field conditions. Thus, the culture of *Trichoderma* should be immobilized in certain carriers and should be prepared as formulations for easy application, storage, commercialization, and field use.

Characteristics of an ideal formulation

i) Should have increased shelf life.

ii) Should not be phytotoxic to the crop plants.

iii) Should tolerate adverse environmental conditions.

iv) Should be cost effective and should give reliable control of plant diseases.

v) Should dissolve well in water.

vi) Carriers must be cheap and readily available for formulation development.

vii) Should be compatible with other agrochemicals.

Methods for the mass production of Formulation

Commercial application of quality agents either to increase crop health or to manage plant diseases depend on the development of commercial formulations with suitable carriers that support the survival of formulating species (eg. *Trichoderma)* for a considerable length of time. Various methos are described for development of formulation as follows:

1. **Talc based formulation:** In India, talc based formulations of *T. viride* was developed at Tamil Nadu Agricultural University, Coimbatore for seed treatment of pulse crops and *Trichoderma* is grown in the liquid medium is mixed with talc powder in the ratio of 1:2 and dried to 8% moisture under shade. The talc formulations of *Trichoderma* has shelf life of 3 to 4 months. It has become quite popular in India for

management of several soil-borne diseases of various crops through seed treatment at 4 to 5 g/kg seed. Several private industries produce large quantities of talc formulations in India for supply to the farmers. The annual requirement of *Trichoderma* has been estimated as 5,000 tones to cover 50 per cent area in India (Jeyarajan, 2006).

2. **Vermiculite-wheat bran based formulation:** *Trichoderma* is multiplied in molasses-yeast medium for 10 days. 100 g vermiculite and 33 g wheat bran are sterilized in an oven at 70°C for 3 days. Then, 20 g of fermentor biomass, 0.05 N medium and concentrated or entire biomass with HCl are added, mixed well and dried in shade.
3. **Alginate prills based formulation:** Sodium alginate is dissolved in one portion and distilled water (25 g/750 ml) and food base is suspended in another portion (50 g/250 ml). These preparations are autoclaved and when cool are blended together with biomass. The mixture is added drop wise into CaCl solution to form spherical beads, which are air-dried and stored at 5°C (Fravel et al., 1985).
4. **Press mud based formulation:** Press mud is available as a byproduct of the sugar factory and this can be used as a substrate for mass multiplication of *Trichoderma*. The method involved uniformly mixing of 9 days old culture of *T. viride* prepared in potato dextrose broth into 120 kg press mud. Water was sprinkled intermittently in to keep it moisten. This was covered by gunny bags to permit air movement and trap moisture under shade. Within 25 days, nucleus culture for further multiplication becomes ready. The same was added to 8 tons of press mud, mixed thoroughly and incubated for 8 days under shade condition before being applied in the field. By this we added 8000 times more inoculums in the soil than the recommended doses of biopesticides which rapidly get established showing rapid and visible effect. Similarly, other substances could also be effectively used for the multiplication of different bioagents at the mass level.
5. **Coffee huskbased formulation:** In Karnataka Sawant and Sawant (1996) developed a *Trichoderma* formulation based on coffee husk which is a waste from coffee curing industry. This product was very effective in managing *Phytophthora* foot rot of black pepper and is widely used in Karnataka and Kerala.

6. **Oil-based formulations:** They are prepared by mixing the conidia harvested from the solid state/liquid state fermentation with a combination of vegetable/mineral oils in stable emulsion formulation. In such formulations, microbial agents are suspended in a water immiscible solvent such as a petroleum fraction (diesel, mineral oils), and vegetable oils (groundnut etc.) with the aid of a surface active agent. This can be dispersed in water to form a stable emulsion. Emulsifiable concentrates require a high concentration of an oil soluble emulsifying agent, to give an instantaneous formation of a homogenous emulsion on dilution in water. The oils used should not have toxicity to the fungal spores, plants, humans and animals. Oil-based formulations are supposed to be suitable for foliar sprays under dry weather and to have prolonged shelf life. The spores can survive for longer time in the plant surface even during the dry weather as the spores are covered by oil that protects them 5°C from drying. Batta (2005) developed an emulsion formulation of *T. harzianum* for the control of post harvest decay of apple caused by *Botrytis cinerea*. Invert-emulsion formulation of *T. harzianum* with a shelf life of 8 months has been developed using indigenous constituents at the erstwhile Project Directorate of Biological Control (PDBC), in India and this his formulation has been and found to be effective against soil borne diseases of groundnut.

16.3.3 Economics

Abundant empirical evidence shows that biological control, as practiced by professionals is among the most cost effective methods of pest control. Because of its highly positive social and economic benefits, biological control should be among the first pest control tactics to be explored.

Biological control workers must not be indiscriminate in introducing exotic organisms, however. Biological control is a serious endeavor for professionals: it cannot become a panacea for enthusiasts having little of the formal training and understanding of the basis of this discipline. In pest control the rights of society and the environment are increasingly in conflict with private profit. Classical biological control and other forms of natural control, plus other environmentally and economically sound methods must fill the gap. Biological control has the best pest control record and remains a considerable untapped future resource

16.3.4 Field Release/Application

Where import of biological control agents or beneficial organisms are made for the first time, the Directorate of PPQS may grant permission for carrying out evaluation studies under confinement or in isolated fields. After evaluating the performance of limited/experimental trials, the Directorate of PPQS may grant permission for inundative release. PPA may consult the technical panel before granting permission for inundative release into fields.

16.3.5 Evaluation

The Directorate of PPQS shall ensure the monitoring of the release of biological control agents or beneficial organisms in order to assess the impact on the target and non-target organisms. Where appropriate, it should include a marking system to facilitate recognition of the biological control agent (e.g. sterile insects) or beneficial organism in contrast to the wild organism.

16.4 Successful Biological Control Projects in India

Classical biological control aims at introducing the exotic natural enemies of introduced alien organisms(which have become pests in the absence of natural checks in the new environment) in order to re-establish the balance between the pests and natural enemies. Introduction of host specific organisms from the country of origin of the pests offers some highly effective and environment friendly solutions to the problem of invading alien pests.

Introduction of Material; Methodologies /Approaches adopted:

Correct identification of the introduced exotic pest is determined .Literature is surveyed and information on the origin and distribution of the exotic pest determined. In fact complete dossiers are prepared on the pest and its natural enemies. Based on information collected ,the decision for introduction of suitable natural enemy (ies) is made. Letters are addressed to international and national institute of the country from where the natural enemy is intended to be imported. The terms and conditions and the time schedule are fixed .Once the consent and complete information from the exporter is received , application along with dossiers and full justification is sent to the Plant Protection Advisor to the Government of India for processing and grant of import permit. After obtaining the permit ,a copy of it is supplied to the exporter with necessary information for fast track receipt of natural enemy. The natural enemy on receipt is qurantified and multiplied for one or two generations and then evaluated in the net house and field. For non-specific pathogens , and weed killers elaborate host specificity tests are required to be conducted in the quarantine before the natural enemy is declared fit for field test. Even the field test are not conducted directly ; first these are evaluated in glass/net house and then in a specified area. Finally if it passes the entire set of tests it is permitted for field testing .This is just a brief out line of a detailed procedure. By and large similar procedure is followed in other countries with slight variation to meet the local needs.

In India of 166 exotic biological control agents introduced 33 could not be released in the field, 71 recovered after release, 6 providing excellent control, 7 substantial control and 4 partial control .Some of them are enlisted below :

A. Providing Excellent Control

1. Biological Control of Prickly pear ,*Opuntia elater ,O.stricta* and *O.vulgaris* by cochineal insect,*Dactylopius ceylonicus.*
2. Biological Control of Water fern, *Salvinia molesta* by the weevil, *Cyrtobagous salviniae.*
3. Biological Control of Water Hyacinth ,*Eichhornia crassipies* by hydrophic weevils- *Neochetina bruchi* and *N. eichhorniae* , and galumind mite *Orthogalumna terebrantis.*
4. Biological Control of Cottony Cushion Scale, *Icerya purchase* by coccinellid bettle ,*Rodolia cardinalis.*

B. Providing Substantial Control

1. Biological Control of Mealybugs by the coccinellid predator ,*Cryptolaemus montrouzieri.*
2. Biological Control of Common Mealybug, *Planococcus citri* by encytrid parasitoid *Leptomastix dactylopii.*
3. Biological Control of San Jose Scale ,*Quadraspidiotus perniciosus* by aphelinid parasitoid *Encarsia perniciosi.*

4. Biological Control of Spiralling Whitefly,*Aleurodicus dispersus* by *Encarsia guadeloupae.*

5. Biological Control of Subabul Psyllid ,*Heteropsylla cubana* by *Curinus coeruleus.*

6. Biological Control of Carrot weed, *Parthenium hysterophorus* by chrysomelid beetle *Zygogramma bicolorata.*

C. Providing Partial Control

1. Biological Control of *Lantana camara* by seedfly ,*Ophiomifia lantana.*
2. Biological Control of Siam weed ,*Chromolaena odorata* by *Pareuchaetes pseudoinsulata.*
3. Biological Control of Croftan weed, *Ageratina adenophora* by gallfly, *Procecidochares utilis.*
4. Biological Control of Submerged Aquatic Weed by grass carp *Ctenopharyngodon idella.*

16.5 Trends and Future Possibilities of Biological Control

One future goal for biological control will be to define the characteristics of a natural enemy that are required to control a given pest in a given area and to measure against these requirements the characteristics of the natural enemies available for this purpose in nature. At present this can be done only very crudely. To accomplish this we need to catalog and categorize the biological control potential of the various entomophagous insects attacking economic insects and their relatives throughout the world: the task has just begun, actually.

Biological control investigations should provide a stimulating source of ideas for studies of population dynamics and plant and animal ecology. Population dynamicists will probably profit more in the short run from the ideas and stimulus provided by contact with field workers, than biological control workers will benefit from laboratory studies of the population dynamicists. Although many of the procedures employed in biological control will largely remain empirical; that is, based on experience derived from trial and error; as more of the groundwork of population theory is adequately laid and is more broadly accepted, we can expect population theory to increasingly influence biological control practice and dictate areas requiring greater research emphasis.

The future undoubtedly will also see continued emphasis on foreign exploration and international exchange of beneficial organisms. We can expect the so-called "Amount of Effort" rule to hold. Increased political and financial support will be required (mixed signs of this already beginning to show). For example, the U. S. Department of Agriculture has been expanding in biological control. The World Health Organization supports biological control approaches to subdue pests of medical importance. The National Institutes of Health and National Science Foundation support research on biological control organisms.

Future of Integrated Control

Integrated control's future is very bright, especially with its new title "Integrated Pest Management," that is more generally understood by scientists and the public alike. There is no doubt expressed concerning the importance and value of the integrated control concept. But, much work remains to be done in order to implement integrated control on a wider scale. A broad interdisciplinary approach is needed, pooling talents of research teams. This also means incorporating economic considerations.

There are special difficulties of establishing integrated control in crops where excessive demands for eye appeal as a measure of quality, are great. There are also great difficulties in grower and extension personnel education. Integrated control programs will by necessity prove to be complicated and in some instances will require trained supervisors; and perhaps rely on computers for decision making. Governments can take a more active role in stimulating development of integrated control by instituting advisory services for promoting the merits of integrated control, supporting intensified research in ecology, systematics, population dynamics, and in the development of selective insecticides, attractants, repellents, etc. Governments should take over from the chemical industry the cost of the non-paying part of selective insecticide development. The conclusion is that we have a long way to go before integrated control gains widespread effective application.

Future of Insect Pathology

More must be learned about the role of disease among insects, the effect of disease on insect populations, how to accurately distinguish one disease from another, and the nature of the pathogens themselves: the basic nature of insect diseases. More must be learned about how to control and suppress diseases among insects beneficial to humans (e.g., in culture and mass-rearing). Also ways must be found to better use microorganisms to control insect pests: mass production, dissemination, and in combination with insecticides and with entomophagous insects.

Future of Biological Weed Control

Biological weed control's future is extremely optimistic if environmental groups concerned with endangered species can weigh the gains and detriments accurately. Pathogenic microorganisms have only been used in very limited situations, but they offer excellent possibilities, especially native pathogens to avoid the risk of importation. The combined use of disease organisms and insect vectors. For example, an introduced insect might serve to transport and inoculate a weed pathogen during its feeding or ovipositional activities. Insects incapable of causing adequate damage might be made more effective if artificially inoculated with a pathogen.

Since there are more than 1,000 introduced weed species in America, and only ca. 25 weeds are presently targets for the technique, there are still relatively unlimited opportunities for future efforts. As new weed species invade, new programs of biological weed control can develop. We have just begun to understand the diversity and roles of natural enemies of aquatic weeds. Since phytophagous insects are thought to be only secondarily and incompletely adapted to aquatic life, doubt has been expressed regarding their application as biological control agents in aquatic weed control. But, before any generalizations are made, however, further evaluation of the insect faunas of aquatic weeds is necessary. Natural enemies other than insects show more promise, however: aquatic snails, herbivorous fish and disease organisms.

Future of Biological Control of Medically Important Pests

Great possibilities exist, especially where chemicals are not practical to apply (Legner & Sjogren 1984. The prospects of importation of natural enemies have just begun to be explored. Where importation has been done, results were often spectacular. The problem of financing this research is great since economic losses are not neatly tied to the problem. Local financing is available, but rarely are there adequate funds for importing exotic beneficial organisms. The greatest successes are with predators and parasitoids; pathogens look excellent, but results in a practical sense have been poor to date.

16.6 Importation of Natural Enemies

16.6.1 Quarantine Regulation

The import of insects, microbial cultures including mushrooms and algae or biological control agents regulated by 'Plant Quarantine (Regulation of Import into India) Order, 2003 issued under

the Destructive Insects & Pests Act, 1914 and amendments issued thereunder. As per the provision of clause 7 (1) of the above said Order, no import of insects or microbial cultures including mushrooms and algae or biological control agents shall be permitted without a valid permit issued by the Plant Protection Adviser.

The Directorate of Plant Protection, Quarantine & Storage, on behalf of the NPPO, shall carry out pest risk analysis of intended import of biological control agents and beneficial organisms prior to allowing the import and before recommending for inundative release; ensure to hold them under containment facilities, while under quarantine testing before granting clearance for release into the environment; and maintain appropriate records relevant to import and release of biological control agents and beneficial organisms.

16.6.1.1 Responsibilities of Exporter

The exporter of biological control agents or other beneficial organisms should ensure that:

- All conditions specified in the regulations of the importing country or on the import permit are complied with consignments, upon export, are accompanied by appropriate documentation.
- Packaging is secure in order to prevent escape of the contents.

- The sterile insects have been irradiated with the required minimum absorbed dose suitable for sterile insect technique (SIT) purposes and appropriately marked to recognize from natural population.
- Exporters of biological control agents or other beneficia l organisms for commercial purpose or inundative release further should take all necessary steps to ensure that exported biological control agents or other beneficial organisms conform to import regulations specified and to relevant international agreements.
- Provide documentation on measures undertaken to ensure that acceptable levels of contaminating organism(s) are not exceeded.

16.6.1.2 Responsibilities of Importer

Prior to the first importation, the importer of biological control agents or other beneficial organisms for any purpose should prepare documentation for submission to the Directorate of PPQS, with the information on the targeted pest (s) to be controlled, including:

- Accurate identification of the target pest (s), its world distribution and probable origin, its known biology and ecology.
- Assessment of its economic importance and environmental impact.
- Consideration of possible benefits of the target and conflicting interests surrounding its use.
- Its known natural enemies, antagonists and other biological control agents or competitors already present or used in the proposed release area or in other parts of the world.

16.6.1.3 Inspection at the point of entry

All the consignments of biological control agents or other beneficial organisms upon import at the concerned point of entry should be referred for inspection at a specified quarantine facility.

16.6.1.4 Quarantine clearance

The PQ officer at concerned point of entry should allow certain biological control agents or beneficial organisms to be granted quarantine clearance directly for release, if appropriate and provided that all conditions have been complied with and required documentary evidence is made available.

16.6.1.5 Temporary holding in Quarantine

Where the import of biological control agents or beneficial organisms is made for the first time from the specified origin, the PQ officer should ensure that biological control agents or beneficial organisms are cultured in quarantine for at least one generation in appropriate post-entry quarantine facility established by the importer, to ensure free from natural enemies or hyper parasites or pathogens.

16.6.1.6 Notification of Non-compliance

The Directorate of PPQS shall promptly inform concerned/appropriate authority in the event of detection of presence of natural enemies or should the biological control agent or beneficial organism display unexpected adverse properties or contaminants exceeded the level of acceptance or the regulations of importing country not met with.

16.7 Biotechnology in Biological Control

Biotechnology could provide solutions to a number of basic and applied problems that limit the use of insect natural enemies as biological control agents. Mass rearing of insect natural enemies for classical or augmentative release is the main task of this insect control strategy. Maintaining quality in laboratory-reared insects is difficult due to possible genetic changes caused by accidental selection, inbreeding, genetic drift and founder effects.

Biotechnological techniques used in Biological control

New DNA-based methods for monitoring genetic variations are now available such as: mitochondrial DNA analysis, DNA sequencing, restriction fragment length polymorphism (RFLP), polymerase chain reaction (PCR), random amplified polymorphic DNA (RAPD)-PCR and ribosomal DNA analysis. Some of these methods are also of potential value for identifying and monitoring establishment and dispersal of specific biotypes of insect natural enemies.

Currently maintaining insect natural enemies is only by continuous rearing or holding specimens in diapause. The development of cryobiological method for preserving embryos of insects can significantly save the rearing costs, and the valuable collection of insect natural enemies could be maintained indefinitely.

Genetic improvement is a potential approach to increase the efficacy of insect natural enemies. Transgenic techniques provide the opportunity to introduce and express foreign genes and/or disrupt existing gene functions so that the desirable characteristics may be inherited by subsequent generations, thus reducing frequent mass releases.

Introduction of DNA into insect germ cells can be achieved by using physical means such as microinjection, biolistics and electroporation or by using biological means in which several transposable elements, Sindbis viruses and retrovirus are used as gene vectors. Microinjection is the best method for penetrating insect chorions and delivering vector DNA to the germ cells. Efforts have been most intense and successful with *Drosophila melanogaster*. Micro-injecting DNA carried in Plasmid-element vectors had been used for gene transfer in several insect species.

A technique called maternal microinjection in which the exogenous DNA microinjected through the cuticle of gravid females without the aid of any transposable-element vector, is developed for certain species of insect. The four transposable-element vectors, Minos element from *D. hydei*, Hermes element from the housefly, *Musca domestica*, MosI element from *D. mauritiana* and piggy Bac element from the cabbage looper, Trichoplusiani, have been developed for the generation of transgenic insects and for stable genetic transformation in non-drosophilid insect species.

The power of biotechnology on genetic manipulation of insect natural enemies is enormous, however, public concerns on the release of transgenic insect emphasized the need to assess the biological consequences of such a release; for example, the risk of any transgene being transferred to non target species. Releases of transgenic insect natural enemies into the environment should be planned and strictly following the appropriate regulatory oversight system set by responsible persons or institutes.

***Bacillus thuringiensis* and transgenic insect resistant plants**

Bacillus thuringiensis (Bt) is a ubiquitous, spore-forming, rod-shaped, Gram-positive bacterium that produces massive amounts of one or more proteins that crystallize intracellularly during sporulation stage. These proteins (Cry proteins) are toxic mainly to insect larvae in order Lepidoptera, Diptera, and Coleoptera, but isolates with toxicity toward Hymenoptera, Homoptera, Orthoptera and Mallophaga and against nematode, mites, lice and protozoa have been recently discovered (Lacey and Goettel, 1995).

The genes encoding the insecticidal proteins known as cry genes have been of particular interest. The genetic manipulation of cry genes in Bt offers promising means of improving the efficacy and cost effectiveness of Bt-based bioinsecticide products. In Asian countries, Bt products have been used almost exclusively as direct spray for the control of foliar-feeding lepidopteran insects.

Poor persistence under field condition and the dissemination of large amount of spores are two limitations of Bt for spray application. Cell Cap technology had been developed in which Bt toxin genes were cloned into a common plant-colonizing bacterium, *Pseudomanas fluorescens*. The bacteria were killed, resulting in encapsulated insecticidal proteins that had enhanced residual property in the field and had no Bt spores.

These novel formulations provide environmentally safe and stabilized Bt-based bioinsecticides. The gene encoding Cry1Ac protein has been engineered into the endophytic, xylem-inhabiting bacterium, *Clavibacter xyli*. The engineered bacterium was then introduced into corn, and damage caused by stem borer was significantly reduced. In this alternative approach, the endophytic microbe helps to enhance delivery of toxin to leaf and stem-feeding lepidopteran insects. Combining genes from different strains of Bt to increase the activity and broaden their host range is underway using nonrecombinant and recombinant technologies.

Recombinant Baculoviruses for Insect Control Entomopathogenic viruses have been employed as bioinsecticides for a wide range of situations from forest and field to food stores and greenhouses. Baculoviruses, particularly the nucleopolyhedroviruses (NPVs) are the most commonly used or considered for development as microbial insecticides mainly for the control of lepidopteran insects on field and vegetable crops. NPVs are formulated for application as sprays in the same fashion as chemical insecticide and Bt strains. However, only moderate success has been achieved due to several key limitations, which include a relatively slow speed of kill, a narrow spectrum of activity, less persistence in the field, and lack of a cost-effective system for mass production in vitro. Fermentation technology for their mass production on a large-scale commercial basis is extensively investigated to reduce the production cost.

Despite tremendous benefits of biotechnology in insect pest management, there are still questions that required answers especially in Asian countries where biotechnology could be most profitable. Specific examples are the uncertainty of the technology in terms of successful research and adoption by the end users; high start-up investment; public awareness and acceptance; national policies on bio-safety and intellectual property issues; technology dissemination and proper implementation; human resource and institutional development; and limited funding due to long-term and continuous nature of the research. Responsible national institutes and other affiliated research centers should engage in educational and training programs aimed at the general public for better understanding of the risks and benefits of biotechnology application.

16.8 Semiochemicals in Biological Control

Definition

Semiochemicals (literally, "signaling chemicals") are chemical compounds emitted by one organism that modify the behaviour of an organism receiving the signal.

Rodriguez and Niemeyer (2005) defined semiochemicals as molecules involved in chemical communication within and between insect species and employed for pest control.

Types of semiochemicals

These compounds can be classified in two groups considering whether they act as intraspecific i.e. within members of same species such chemical are known as pheromones and if they act as interspecific i.e. within the two different species known as allelochemicals mediators. Allelochemicals include allomones (emitting species benefits), kairomones (receptor species benefits) and synomones (both species benefit). However, a single chemical signal may act as both as pheromone and allelochemical.

There are different types of pheromones according to the response they induce on the perceiving individuals. The most common are presented hereafter

(Brossut, 1997; Cork, 2004): – Sex pheromones are generally produced by females of a species in order to attract males of the same species for mating.

Some exceptions exist where male butterflies (e.g. *Bicyclus anynana*) produce sex pheromones to seduce females during the courtship. Sex pheromones consist in individual molecules or specific blend of compounds in a given ratio.

The most studied, and used in IPM, sex pheromones are that emitted by Lepidoptera; – Aggregation pheromones are released by one gender of a species to attract individuals (both sexes) of the same species in order to exploit a specific resource (food, appropriate mating site, etc.).

They are mainly emitted by Coleopterous species; – Alarm pheromones alert conspecifics in case of threats. Generally the response behavior results in dispersion of congeners. These pheromones, characteristic of social or gregarious insects, occur in some important insect pests including Aphididae and Thripidae.

This class of pheromones has potential in IPM as:

- Trail pheromones are present in social colonies to indicate the trail to be followed when some scout insects locate food resource.
- Walking insects, like ants, typically produce these pheromones.
- Host marking pheromones reduce the competition between members of the same species, like it is observed in parasitoids that mark a host in which they have laid an egg.

Chemistry and properties of semiochemicals

Pheromones and semiochemicals in general, consist in a wide range of organic molecules which could be volatile or non-volatile. Non-volatile semiochemicals include cuticular hydrocarbons, acting in mate recognition or in cannibalism regulation of several insect species. Wilson et al. (1963) suggested that the volatile pheromones naturally exploited in insect communication have between 5 and 20 atoms of carbon with molecular weights ranging from 80 to 300. Those having a molecular weight above 300 are not sufficiently volatile to allow a communication at long distance. Cork (2004), in his Pheromone manual, cites the major pheromones identified in moths and butterflies according to their chemical classes.

IPM strategies using semiochemical

There are many benefits to formulate semiochemical substances in integrated pest management outline. These molecules are naturally occurring and are generally environmentally friendly.

Various strategies exist depending on the goals and scopes to achieve. Some of them are described hereafter:

1. **Monitoring:** Monitoring of insect populations has generally three purposes: to detect the presence of invasive pests; to estimate the relative density of a pest population at a specific site; to indicate the first emergence or peak flight activity of a pest species in a given area.
2. **Trapping:** Trapping with pheromone lures is a mechanical control action that consists in removing large number of pests in an area after monitoring step. The traps can be used simultaneously with a killing substance ("lure and kill" strategy) which has the benefit of not being in direct contact with the crop. This technique is also useful in stored-product pest control.
3. **Mating disruption**: The technique of mating disruption by using species-specific sex pheromones in large quantity is principally applied to control moth populations in orchards. In moth, females generally release sex pheromones to attract males, at relatively long distances (several kilometers), for reproduction. The females lay their eggs on orchard trees and larvae develop inside fruits which are then no more eatable.
4. **Push-pull strategy:** Also called stimulo-deterrent diversion, push-pull strategy is a more recent approach than the other described IPM practices. It consists in a combination of repellent and attractive stimuli modifying the behavior of insect pests and/or of their natural enemies. The insects are deterred or repelled away from the crops (push strategy).

Slow release of semiochemicals (Dispensers)

Major volatile semiochemicals being extremely unstable due to their chemical structure, it is necessary to formulate them so that they are protected from degradation by UV light and oxygen. Moreover, the formulation must ensure a controlled release of semiochemicals. To be efficient in IPM strategies, semiochemical slow-release devices must have particular specifications: the aerial concentration after release must be sufficiently high to be detected by insects; the release of semiochemicals must be effective during all the period of insect occurrence; the production of dispenser must be reproducible. The application of dispensers must be realized early in the season when the pest density is not too high, given that their release rates, for the majority of devices, decrease with time (Witzgall, 2001).

Several formulations and dispensers have been developed and commercialized with various slow release capacities. Some examples of dispensers are described hereafter. The majority of them involve mating disruption of moth. Three groups can be distinguished: solid matrix dispensers, liquid formulations to spray and reservoirs of formulations. On an historical point of view, the first related and the most commonly used pheromone dispenser is the natural rubber septum.

Significance of semiochemicals

The perspectives of semiochemicals use in IPM programs seem to be promising with the increasing worldwide biological agriculture. Slow release dispenser and formulation improvement will continue with the contribution of multiple scientific fields of research (entomology, chemistry, ecology, etc.) and the crop farmer skills.

16.9 Summary

Since the mid 1960's, certain areas have received greater research emphasis: Insect pathology and biological weed control have developed rapidly as specialties within the field. Further research has been advanced in developing methods of evaluating the effectiveness of natural enemies. Also there have been significant advances in quantitative field population studies; inquiry into the extent of naturally occurring biological and research on the augmentation and conservation of natural enemies.

Mass production systems involves the achievement of adequate growth of the biocontrol agent. Mass production is achieved through solid and liquid fermentation techniques. In many cases biomass production of the antagonist is not easy owing to the specific requirement of nutritional and environmental conditions for the growth of organism.

Introduction is techniques used to introduce an exotic species of a natural enemy either when there is an unoccupied a niche and is required to be displaced by a more efficient exotic species. Conservation means, the avoidance of measures that destroy natural enemies and the use of measure that increase their longevity and reproduction of the attractiveness of an area to natural enemies. Augmentation includes all activities designed to increase numbers or effect of existing natural enemies. Formulation is blending of active ingredients such as fungal spores with the inert material such as diluents and surfactants in order to alter the physical characteristics of to a more desirable form.

Economically biological control, as practiced by professionals is among the most cost effective methods of pest control. Because of its highly positive social and economic benefits, biological control should be among the first pest control tactics to be explored.

Biological control investigations should provide a stimulating source of ideas for studies of population dynamics and plant and animal ecology. Population dynamicists will probably profit more in the short run from the ideas and stimulus provided by contact with field workers, than biological control workers will benefit from laboratory studies of the population dynamicists. Although many of the procedures employed in biological control will largely remain empirical; that is, based on experience derived from trial and error; as more of the groundwork of population theory is adequately laid and is more broadly accepted, we can expect population theory to increasingly influence biological control practice and dictate areas requiring greater research emphasis.

Semiochemicals have great future prospective, they are uses in IPM programs seem to be promising with the increasing worldwide biological agriculture. Slow release dispenser and formulation improvement will continue with the contribution of multiple scientific fields of research (entomology, chemistry, ecology, etc.) and the crop farmer skills.

16.10 Self learning Exercise

Section -A (Very Short Answer Type)

1. What do you mean by mass production quality agents?
2. List out the techniques used in biological control.
3. Name any two formulative substances.
4. Give name of any two semiochemicals.
5. What are pheromones?
6. What is difference between pheromone and hormones?
7. Name any two biotechnological techniques used in biological control.
8. What do you mean by quarantine?

Section -B (Short Answer Type)

1. Write short notes on following.
   i) Formulation
   ii) Evolution
   iii) Field release
2. Explain the various methods for the mass production of formulation.
3. What are the quarantine regulations?
4. Explain importation of natural enemies.
5. What is *Bacillus thuringiensis* and its role in transgenic insect resistant plants?

Section -C (Long Answer Type)

1. Explain the role of biotechnology in biological control of pest.
2. Explain the quarantine regulation and process.
3. Write an essay on semiochemicals.

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Unit - 17

Pesticide Application Equipments

Structure of the Unit

17.1 Objectives

After reading this unit student will be able to:

- Describe the types of sprayers and dusters.
- Describe fog generators, smoke generators, soil injecting guns, seed treating drums and flame throwers.
- Know, describe and understand different types of nozzles and their uses.
- Know and describe the maintenance of pesticide appliances.
- Describe the role of Aerial adaptation of pesticides, principles of aerial application and factors affecting the effectiveness of aerial application. Advantages and disadvantages of aerial application.

17.2 Introduction

It might be said that the choice of equipment for pesticide applications is only as efficient as the knowledge of the person using that equipment. In other words, it is imperative that the pest control operator acquaint himself with the limitation of whatever device he chooses, so the ultimate in control can be accomplished. Ignoring this simple axiom causes, perhaps, more failure in the control of pests that any other factor.

In order that the information in this publication may be more intelligible, it is sometimes necessary to use trade names of the product or equipment rather than complicated descriptive or chemical identifications. However, no endorsment of named products is intended nor is criticism implied of similar products which are not mentioned.

Pesticide applicators utilize many methods in the application of pesticides. Most of these have been developed as the result of years of studying the most effective methods. Some of the methods, however, may result in problems such as over application, not reaching the pest habitat while using a minimum amount of pesticide, and depositing unsafe residues. Proper techniques of application not only aid in effectiveness but also ensure workers' safety, public protection, and protection of the environment.

17.3 Types of Appliances: Sprayers, dusters, fog generators, smoke generators, soil injecting guns, seed treating drums, flame throwers,

Competence in pest control includes basic knowledge of pests and pest problems, the ability to choose the right pesticide and equipment and equipment and a knowledge of proper methods of application. The proper technique of application probably plays a greater part in a successful job than all the others.

The applicator tends to take short cuts in application. He may use too much pressure in power spraying which creates voids in the spray pattern. He may fog when a careful needle point spray directed in the proper place would be more effective. Fancy fogging machines will not substitute for a thorough search of all cracks and hiding places and the application of just the right amount of pesticide with even a crude hand-held sprayer. A brief resume of the types of pesticide equipment and techniques of application is presented in the following section.

1. Sprayer

Most of the pesticides are applied as sprays. The liquid formulations of pesticide either diluted (with water, oil) or directly are applied in small drops to the crop by different types of sprayers. Usually the EC formulations, wettable powder formulations are diluted suitably with water which is a common carrier of pesticides. In some cases however, oil is used as 698diluents or carrier of pesticides.

Spraying is employed for a variety of purposes such as application of:

i. Herbicides in order to reduce competition from weeds,
ii. Protective fungicides to minimize the effects of fungal diseases,
iii. Insecticides to control various kinds of insects pests,
iv. Micro-nutrients such as manganese or boron,

The important factors for spray volume consideration are:

The volume of spray liquid required for certain area depends upon the spray type and coverage, total target area, size of spray droplet and number of spray droplets. It is obvious that if the spray droplets are coarse-size then the spray volume required will be larger than the small size spray droplets. Also if the thorough coverage (eg. Both the sides of leaves) is necessary then the spray volume requirement has to be more.

On the basis of volume of spray-mix the technique of spraying is classified as:

1. High volume spraying
2. Low volume spraying
3. Ultra low volume spraying

The range of volume of spray mix in each of the above case is arbitrary. Usually for

Field crop spraying the following spray volume ranges are taken as guide.

High Volume Spraying 300 – 500 L/ha

Low Volume Spraying 50 – 150 L/ha

Ultra Low Volume Spraying < 5 L/ha

The main function of a sprayer is to break the liquid into droplets of effective size and distribute them uniformly over the surface or space to be protected. Another function is to regulate the amount of insecticide to avoid excessive application that might prove harmful or wasteful.

1. High volume spraying

This is very common and popular method of pesticide spraying. The spray solution is prepared by mixing water with pesticide formulation in appropriate quantities. This diluted mixture is sprayed through hydraulic nozzles. The spraying is usually to the point of drip from foliage. In this method large volume of spray liquid is applied. Usually the spraying volume is 300-500 L/ha. The spray volume is not always rigid. The spray volume requirement depends on many factors e.g. sprayer capability, nozzle characteristics, stage of growth of crop, type of crop etc.

A variety of high volume sprayers are available in the market. Almost all types of high volume sprayers have some kind of pump to supply pressurised spray liquid to the hydraulic nozzle which breaks the liquid into spray droplets and throws the spray away from it. The high volume sprayers are both manually operated or power operated type.

Slide pump or hand sprayers

This is a simple sprayer. It creates hydraulic pressure by forcing spray solution to a nozzle by the direct action of hand pumping. The spray solution is filled in a plastic can (5-10 L) which is usually shoulder slung. A dip-tube draws liquid from the tank due to hand actuation of the plunger. Held by both the hands the piston pump is worked by sliding action. For want of a pressure chamber it is not possible to retain pressure and therefore the operator has to pump continuously without break. Due to constant engagement of both the hands it is difficult for the operator to ensure thorough coverage. Further due to pressure fluctuation the nozzle performance is not stable.

Fig. Slide pump or Hand sprayer

The discharge rate varies, spray angle changes and spray droplets size fluctuates. This sprayer is suitable for small scale application in nursery or kitchen gardens etc. It is not a good sprayer for large area treatment. The capacity of this sprayer is about 0.5 acre per day.

Stirrup pump sprayer

This is a simple hydraulic sprayer. It consists of hand operated hydraulic pump. The suction part of the pump is immersed in the spray solution kept on floor in a bucket. The pump is operated by hand by one person while the other person holding the delivery line, tigger cut-off device and lance nozzle sprays pesticide. In few models an air chamber is also provided in the pump system which helps continuous spraying. Also in some models provision of hydraulic agitation is made. This sprayer is used both for public health spraying and agricultural spraying purposes. The field capacity of the sprayer is 0.3 ha/day.

Fig. Stirrup pump sprayer

Compression sprayer

It comprises of a cylindrical metal tank for holding the spray liquid, a hand operated piston type air pump, a filler hole in the tank out let with delivery pipe, cut-off, lance and hydraulic nozzle. There is metal or plastic skirit as the base of the tank. A pair of adjustable shoulder straps is provided for mounting the sprayer on the back of the operator. The sprayers with tanks of different capacities are manufactured, but 18 litre capacity sprayers are commonly used for field spraying. The filtered spray solution is filled to 2/3 of the tank capacity. Then the air pump is operated by hand and air pressure (50-60 psi) is built up. The compressed air exerts pressure to move spray liquid to the nozzle via delivery pipe, cut-off device & lance system.

Fig. Compression sprayer

The spray design is strong and strudy. It is also easy to operate. The operater need not pump continuously so that he can divert his attention to better coverage. However, as the pressure cannot remain constant due to gradual decrease of pressure, the nozzle discharge rate changes so also angle of spray and droplet size. This sprayer is not recommended for herbicide spraying due to high initial pressure. The field capacity is 0.75 - 1.0 acre/day. The hand compression sprayer is used in kitchen gardens, nurseries, vegetable gardens, flower crops and field crops.

Foot operated sprayer

The pump of the sprayer is worked by operating a pedal lever by the foot of the operator. It requires two persons to work. The spray liquid is kept in bucket or container and it is sucked by a suction hose through a filter (strainer) due to piston movement.

Fig. Foot operated sprayer

A suitable ball valve is provided in the piston assembly to serve as suction valve. The liquid from the pump cylinder is then delivered into a pressure chamber where from the pressurized liquid reaches hydraulic nozzle. Minimum two person team is required to work on this machine. Hydraulic pressure of 10 kg/cm2 can be achieved which is necessary to project the jet of spray to tall trees simultaneously from two spray nozzles.

The foot operated sprayer is basically for orchard and tree spraying. The design is strong and sturdy. Hydraulic pressure of 10 kg/cm2 can be achieved which is necessary to project the jet of spray to tall trees simultaneously from two spray nozzles. An adjustable type hydraulic nozzle (Tripple Action Nozzle) is generally used which can generate different types of spray patterns viz., fine spray (hollow cone), medium spray and coarse spray (jet). The fine and medium spray are suited for low height orchards, jet spray are necessary for tree spraying. The spray jet can reach height of 15 - 20 feet. For spraying taller trees an extra extension like bamboo lance may be used to gain additional height by 8 - 10 feet. It is diffcult to treat field crops by foot sprayers because the sprayer is kept on ground and pesticide solution tank is also kept on ground separately and so movement of the long delivery hose becomes very difficult.

Rocker sprayer

It is very much similar to the foot sprayer. The main difference is the operation of pump. The pump actuation is done by hand of the operator. The rocker sprayer is a long lever high pressure sprayer designed for operation with one or two lances. The complete assembly is mounted on a wooden board, which is held to the ground by the foot of the operator. The sprayer consists of a single or double acting piston pump for developing high pressure, an air chamber, spray lance with shut off valve and strainer, 5 m suction line fitted with strainer and delivery line.

Fig. Rocker sprayer

The principal components are made from brass aIloy. The lance is fitted with gooseneck bend and nozzle and the length of lance may vary from 60 to 90 cm. The pump is operated with long lever to and fro in a rocking motion which suck the liquid from the inlet pipe submerged in the spray liquid. The other person holds the lance and directs the spray chemical to the target. If two lances are used, then it may require in all three persons for the spraying operation. The adjustable type hydraulic nozzle (Triple Action Nozzle) is normally used. With high jet spray gun or bamboo lance the spray chemical can be delivered to a height of up to 10m. For spraying on tall trees like coconut, areca nut, sugarcane, rubber plantations, orchards, vineyards and field crops, vegetable gardens, flower crops etc.

Lever operated knapsack sprayer

It is commonly known as knapsack sprayer. The sprayer is mounded on the back of operator with help of a pair of mounting straps. The pump of the sprayer is actuated by working a hand lever up and down by one hand of the operator and the other hand holds the cut off device for spraying purpose. This sprayer consists of liquid tank, hydraulic pump, operating lever, pressure chamber, agitator, delivery hose, spray lance and nozzle. A bean shaped plastic tank of 14-16 liters capacity is commonly used. It is necessary to operate the hand lever continuously at the rate of 15-20 strokes per minute. The normal working pressure is 40 psi.

Fig. Liver operated knapsack sprayer

High pressure power sprayer

These are high capacity power operated hydraulic sprayers. They are the high volume spraying machines good for large scale application in orchards and tree crops. The source of power is engine or electrical motor. A pressure regulator is used to control the pressure in the discharge lines and bye-pass from the pressure regulator is used for hydraulic agitation in spray tank. High pressure like 400 psi can be built up and large spray discharge rate like 30 L/min. can be obtained. The engine or electrical motors 3 - 5 H.P capacity power the sprayer.

Fig. High pressure power sprayer

2. Low volume spraying

The high volume spraying is labour intensive and time consuming. In water scarcity area it is difficult to practice high volume spraying. Also in situation where large area treatment in very short time is important, the high volume spraying has limitations. The low volume spraying methods essentially reduce quantity of spray solution. Spraying as against 300 to 500 L/ha in H.V. spraying technique is reduced to 50 to 150 L/ha in L.V. spraying technique.

Motorised knapsack sprayer, also called Mist blower is a L.V. sprayer in which gaseous energy nozzle is used for fine breakup of spray liquid. This type of nozzle is also called Air blast nozzle. The force of escaping air at high velocity is utilised to shear down the spray liquid into fine spray droplets. The size of spray droplets depends upon:

1. Air velocity and volume
2. Liquid flow rate
3. Properties of spray liquid

The spray droplets are then blown away from the nozzle outlet. The blast of air disperses the droplets over wide area and helps penetration of spray into the crop canopy. The gyrating movement of droplets in the canopy improves the underleaf depositing of the spray particles.

A two-stroke petrol engine (35 cc capacity) is used as prime mover to run a fan blower. The engine runs usually at 5000 - 6000 RPM and the blower emits at nozzle outlet about 5 m3 air per minute and at about 170 km/hr velocity. The spray droplets are about 150 - 220 micron VMD size. The nozzle flow rate can be adjusted by a regulator provided in the liquid line. The regulator can be a variable restrictor type or different size fixed aperture type. The later type is better because in the variable restrictor type regulator, it is difficult to achieve exact repeat application rates. The flow rate up to 2 L/min can be obtained.

While operating this sprayer the engine should be run at full throttle and the operator should take advantage of prevailing cross-wind for wider dispersal of the spray and also to keep away the spray from himself. The spray nozzle should be held and aimed at rows which are about one meter away from the the nozzle and the operator should try to create a little fluttering of leaves to improve coverage. In a day 2 - 3 hectare area treatment is possible with this machine. Since fine particles in concentrated form are sprayed out, the operator should wear adequate protective clothing and he should especially guard against inhalation hazards.

The motorized knapsack sprayer can be converted into power duster also. Then it is called motorised knapsack sprayer-cum-duster. In most of the machines the spray tank itself is used as dust hopper.

Fig. Motorised knapsack sprayer

In such a tank (dust hopper) suitable dust agitator attachment is fixed inside the hopper and dust-ejector tubes are fitted in the outlet of the discharge pipe. It is necessary to avoid compaction of pesticide dust while filling it in the hopper. The rate of flow of the dust from hopper to the discharge tube is controlled by variable restrictor aperture. In some models this is achieved by placing a butterfly type restrictor.

For low volume spraying the aircrafts are also used to spray pesticides at 20 - 25 L/ha. Tractor mounted air carrier sprayers are also used for low volume spraying in orchard and tree spraying. For tall tree spraying like Rubber plantation a mist blower type system run by 3 H.P engine and carried by two persons on stretcher poles is available, called turblow-sprayer.

3. Ultra low volume spraying technique

The ULV spraying is the method of pesticide application at minimum volume to achieve economic pest control. In this technique of pesticide application the volume applied per hectare is less than 5 liters which is extremely low as compared to the conventional High Volume and Low Volume spraying methods.

The spray droplets in ULV spraying methods are very fine in size. Therefore, the nozzles used in these methods are different. Various designs of rotory atomiser are used to generate droplets of 70 to 100 μ VMD. The vortex nozzles produce droplets in aerosol range i.e. 20 μ VMD. For large area ULV spraying as in the case of locust control exhaust nozzle sprayer which is mounted on a vehicle is used where thermal energy of the engine exhaust gases is used to atomise the pesticide liquid in droplets of 20–50 μ. The thermal foggers using pulse jet engines are used for indoor ULV application. The fogging machines are also used by public health personnels for mosquito control.

The rotary atomiser utilises centrifugal energy to break the pesticide liquid into droplets. The range of spray droplet diameter produced by centrifugal nozzle is generally narrow sprectrum. Therefore, this method of ULV spraying with the help of centrifugal energy nozzle is also called as Controlled Droplet Application (CDA).

The movement of extremely fine spray droplets depends upon natural air movement. These small particles usually take long time to settle and very much influenced due to prevailing wind. The spray therefore is not direct type but it is drift spraying. Obviously for small field treatment the pesticide spray may be drifted to outside the target. Thus the drift hazard is always present in this technique of spraying.

The spray droplets which are fine in size are also subjected to higher rate of evaporation due to increased surface area. Therefore, pesticide spraying diluted with water is not recommended for ULV technique. The rate of evaporation increases if the temperature is more. Also the relative humidity influences evaporation. Due to evaporation the effective aquoes droplet size which actually reaches the target becomes smaller and therefore concentrated pesticide droplets are deposited. The extremely fine size droplets may completely evaporate before landing and can cause pollution. It is, therefore, recommended to apply only special ULV formulation which is basically oil-bound and non-volatile. Some authors have reported use of sugar or mollases solution with the EC formulation to reduce the evaporation losses.

A hand held battery operated model of ULV sprayer is very simple and convenient. This sprayer consists of a spray head which includes an electric motor with a spraying disc and liquid container mounted on the spray head, a holding stick, source of battery power and off-on switch. The electrical motor is a 6 V or 12 V DC motor. The motor drives a directly fitted spinning disc usually plastic 2" to 3" diameter revolving at 6000 - 10000 RPM. The spinning disc is very light weight plastic disc flat or cup shaped having fine serrations cut on its periphery. In certain designs fine feeder channels are also provided on the disc such that the liquid is fed uniformly through these channels to the disc serrations. The pointed edge at the disc periphery serves as zero issue point so that uniform size spray droplets are released from the disc. The pesticide container is usually one liter capacity plastic bottle which is screwed on the spray head. The flow of pesticide from the container is simply due to gravity and depends upon the size of opening provided in the spray head. However, in certain models the rate of flow of liquid can be changed by replaceable orifice plates of different diameter or by changing liquid flow tubes of different size opening.

The dry cells (4 or 8 Numbers) or rechargeable storage battery supply 6 V or 12 V DC power to run the electric motor which rotates the plastic disc. The chemical moves by gravity to the spinning disc and due to centrifugal energy the liquid is broken into very fine spray droplets. The rate of flow of chemical liquid is from 50 to 100 ml/min. The ULV spraying is good in dry land areas where water is scare and therefore conventional high volume spraying is not feasible. This technique is also called waterless spraying due to special ULV formulations. But as the ULV formulations are not available, the advantage of this method is not being availed at present.

Electrostatic spraying

The conventional high volume spraying is labour intensive and time consuming process. The hydraulic nozzles produce wide spectrum of spray droplets and more than 40-60% of sprayed pesticide does not really deposit on the foliage. Neither the very small drops nor very big drops are useful due to drift and run off problems. The Controlled Droplet Application (CDA) method improves pesticide deposits and lower application volumes of less than 5 L/ha can be achieved. The ULV application method has serious problem of pesticide drift too.

The electrostatic spraying system reduces the application volume substantially and greatly improves pesticide deposites. The liquid atomisation is achieved by utilizing electrostatic forces. The spray particles of about 50 μm size having high electrostatic charge are issued from the nozzle. It is reported that the depositing increases by three times, or more.

This system has great potential. By imparting electrostatic charge to spray droplets of hydraulic nozzles and spinning disc nozzles also depositing improves much. There are following three systems of electrostatic charging of sprays:

1. Corona charging
2. Contact charging
3. Induction charging

A high voltage pointed electrode issues ions of similar polarity to the liquid droplets which become electrically charged. The sprays from hydraulic nozzle and rotary nozzle can be charged by these methods. The electrostatic application of paints industrially is also based on Corona charging.

In Contact charging system the high voltage potential is directly connected to the nozzle or to the spray liquid system. The electrical charge transfer occurs by conduction to spray liquid and finally to the spray droplets during disintegration. This system works well with the conductive liquids. The total system needs very good insulation.

In the Induction charging system the electrical field force is used to charge the spray droplets. This system needs good insulation between the conductive liquid and the charging electrodes. The Electrodyne sprayer (developed by ICI) is good for electrostatic charged spraying of pesticides. A high potential of 13 to 24 KV is applied to the spray head having pesticide bottle and electrodyn nozzle combination (called BOZZLE) resulting in dis-integration of spray in very fine charged droplets of 30-50 μm size. The application volume is drastically reduced to 0.5 to 1.0 L/ha besides much improved deposition of pesticide. The charged droplets leaving the nozzle repel each other owing to similar charge and thereby forming spray cloud. These charged droplets are readily deposited to foliage being earthed object. The power requirement is met by 6 V DC (4 torch cells) sources which are multiplied to 24 KV by a solid state electronic generator. The power consumption is very low. The collection of spray is so efficient that penetration into the canopy can be poor. The nozzle is held 40-50 cm above the crop canopy. Because of good depositing properties, the drift of pesticide is very minimum, so also the wastage.

Advantages of electrodyne spraying

1. Better deposit of pesticide
2. Minimum drift losses/wastage
3. Low power consumption
4. Narrow spectrum of droplet size
5. Labour and time saving
6. Minimum volume per hectare

Limitations of electrodyne sprayer

1. Top few leaves are deposited heavily but not the lower leaves.
2. Good for broad leaf crops and not so efficient for narrow-leaf crops like paddy.
3. Special Electrodyne formulations are suitable.
4. Electrodyne formulations of various Pesticides are not available.

2. Dusters and dust applications

The dusting powders are low concentration ready to use type, dry formulations containing 2 to 10% pesticide. The inert material or dry diluents is talc, soapstone, attapulgite, etc., and it is non toxic. The sulphur dust is not diluted with inert material.

The advantages of pesticide dusting application are:

1. Ready to use product reduces field tasks concentrate handling and further dilution (as in case of spraying)
2. In dry land agriculture where water is scare.

But the important disadvantage is pesticide drift. The fine dust particle cause serious drift problems and the operator and field labourer are exposed to dermal and inhalation hazards, besides pesticide being carried to neighbouring field/area and causing pollution. This is the main reason why the herbicides are not formulated as Dusting Powders. Precise metering and even distribution of dusting powders in field conditions is very difficult. The dusts are applied at 20 - 50 kg/ha. It should be noted that the application is done in highly concentrated form, as compared to high volume or low volume spraying technique. Therefore, adequate precautions must be taken in handling the dust and during the application in field. The dusters are available both manually operated and power operated models.

Manually operated dusters

Plunger duster

They are very simple, low cost machines and useful in a limited way. The field application capacity is low. They hold 200 to 400 g of dust in a chamber into which air is pushed by an adjoining piston type air pump operated by hand. The dust cloud is issued from the discharge outlet.

Fig. Plunger duster

Bellows type duster

This is also a simple design low cost dusting machine. A collapsible bellows pushes air into a dust hopper of 1-2 kg capacity and dust is discharged from the nozzle outlet.

Fig. Bellows type duster

Hand shake duster

This too is low cost very simple equipment which can be locally made by village artesian. It is particularly good for spot application of dust in rice crop and BPH control. These dusters are good for small scale application and spot treatment and they do not cause much drift problems, metering lacks in these equipment.

Hand rotary duster

This type of duster makes use of a fan or blower to flow large volume of air at high speed. The dust powder is fed into the stream of air and blown from the outlet tube. The fan or blower rotates at high speed by hand cranking handle, which is geared to it. The higher gear-ratio and better blower design provide easy cranking and good volume of air is emitted.

The dust hoppers are generally cylindrical and are provided with agitator, feeders and dust metering mechanism. Such rotary dusters are either shoulder slung type or belley mounted type. The shoulder-slung models are better balanced when the dust hoppers are filled. But it becomes inconvenient to operate in crops like sugarcane and cotton. The belley mounted type can be used in such situations. A hand rotary duster can discharge dust powder from 0 – 150 g/min and displace air about one m3/min at 35 RPM. Such machine can treat 1 to 1.5 ha /day.

Fig. Hand rotary duster

Power duster

These are bigger machines run with the help of engine or electrical motor. Some power dusters are tractor mounted type and are driven by tractor P.T.O. The equipment is mounted on iron frame (stretcher) and can be carried by 2-3 men. The engine/motor drives a centrifugal fan usually via V-belt drive. The engine is petrol/ diesel run and 3 - 5 H.P. The fan displaces 20 m3 air/min or more at 100-250 km/hr air velocity. These dusters are good for large area treatment and suitable for application on tall trees. In this type of duster design, usually the dust powder is not rotated in the fan-case but dust powder is aspirated in the delivery channel by air blast. The dust hopper capacity is 10-20 kg and dust can be discharged at a rate of 1 to 8 kg/min. A power duster can cover about 10 ha/day.

Fig. Power duster

Knapsack duster

The motorised knapsack sprayer can be converted to a duster by replacing some plastic fittings inside the hopper. Almost all mist blowers have provision of converting them from spraying unit to dusting unit. The two stroke petrol engine runs a blower fan and delivers the air through a hose pipe system. The dust is agitated and lifted by the blast of air in the hopper and it is fed into the main air hose or a long dusting hose (40-50 ft long polythene perforated hose) can also be attached to knapsack duster. Such an attachment is very good for large area treatment in less time. The dust output can be adjusted from 0 to 1.5 kg/min. The motorised knapsack sprayer-cum-duster unit is therefore useful for both low volume spraying and dusting operation.

Fig. Knapsack duster

Precautions

The dusting powers are very finely divided particles which can remain air-borne for long time and can drift far distances. The fine particles can very easily enter into body system by inhalation. Therefore, the operator should wear protective clothing. He must cover his nose and mouth in order to avoid inhalation of pesticide drift.The operator should never operate against the wind direction. Also if the wind velocity is more or wind turbulence exists, the dusting application should not be done.It is better to apply the dust power in early morning hours and in late evening hours, avoidind the mid-day and afternoons.

Maintenance

The dry and well sieved dust power should be loose filled in hopper. It should not be hand compacted. The dust powders often absorb atmospheric moisture and clods are formed, such clods should be crushed before filling into the hopper. After the completion of the work the dust powder should be removed from the hopper carefully. The dust materials which still remain in the hopper, feeders, discharge tube should also be removed by briskly cranking and blowing action. Finally, a dry brush should be used to dust off from inside the hopper, etc. The lubricating oil should be applied on moving parts e.g., gearbox, crank handle, agitator, fan bearing, etc.

3. Fog generators and Smoke generators

Fog generators

Power aerosol and fog generators break liquid pesticides into aerosol droplets. Reducing the liquid into droplets is done either mechanically (cold foggers) or by using heat (thermal foggers). Caution should always be taken to protect the applicator's respiratory system when these generators are used.

a) Cold foggers

Cold foggers break an insecticide into aerosolized droplets and propel them into the air in a light cloud or fog. Large, ultra low dosage (ULD) and ultra low volume (ULV) cold foggers are mounted on trucks and used in mosquito control programs, to control pests in large warehouses, and for fly control in some operations. Cold fog generators drive pesticidal fog over a relatively large area. Droplets fall on flying or resting mosquitoes or are deposited in very small amounts on plant leaves on which mosquitoes rest.

Fig. Cold foggers

Hand-held cold foggers are used inside buildings where they fill rooms, small warehouses, etc., with aerosol droplets. These floating droplets kill flying insects as well as exposed insects on horizontal surfaces. Fogs do not enter tight spaces or cracks and crevices. While some aerosol generators are used for crack and crevice applications, they also produce aerosol droplets that float in the air.

b) Thermal foggers

Thermal foggers use heat to vaporize oil in an oil-based insecticide formulation. Large truck-mounted thermal aerosol generators are used in mosquito control programs where the insecticide fog rolls across open spaces killing flying insects as air currents move it. Indoors, portable thermal foggers work like cold foggers except droplets are smaller.

Fig. Thermal foggers

Smoke generators

The fumigation of infested materials or building structures is a very specialized form of pest control, involving the use of a highly volatile gas having a great power of penetration. The insecticide diffused homogeneously. Smoke generators are used to treat air volumes to control flying insects and to treat surfaces (by deposition) to control crawling insects. Before use, a particular attention should be paid to the protection outside the building or structure to be treated.

Fig. Smoke generators

Smoke generators could be used in rooms with furniture, but sometimes it's preferred to move up some equipment. After treatment, a long ventilation period is recommended e.g. 4 to 8 hours in some cases.

4. **Soil injecting guns, Seed treating drums and Flame throwers**

   Soil injecting guns

Pesticides can be injected into the soil by pumping a pesticidal liquid through a metering orifice to a jet firmly attached to the rear of a tine on a cultivator so that the pesticide is delivered below the soil surface. This technique employs a long hollow, pointed probe connected to a spray rig and a shut-off valve at the top of the injector. It is useful in placing termiticides deep into the soil around the exterior foundation.This type of equipment has been used mainly for applying soil fumigants to control nematods and because of the volatility of the chemicals the soil surface should be covered immediately with a plastic sheet to reduce the lose of pesticide. The technique is expensive and many of the chemicals are no longer acceptable environmentally so preference is given to granule application if chemical control required.

Fig. Soil injecting guns

Seed treating drums

Seed treaters are used to coat seeds with a pesticides. The amount of pesticide the seed receive is important – too little will not control the pest but too much can injure the seed. There are three basic types of commercial seed treaters.

Dust treaters mix seed with a pesticide dust in a mechanical mixing chamber until every seed is thoroughly covered.

Slurry treaters coat seeds with wettable powder pesticide formulations in the form of a slurry. Only a small amount of water is used with the pesticide so that the seed does not start to germinate or deteriorate.

Fig. Seed treating drums

Liquid or direct treaters are designated to apply a small amount of pesticide solution to a large quantity of seeds.

Advantages

Allows more choice in the variety to be treated and in the pesticides to be used, treats only as many seeds as you need.

Disadvantages

Requires purchase of equipment instead of just buying pretreated seeds, pretreated seeds are easier to use, more chance of seed injury.

Seed treatment represents one of the most efficient means of targeted application of pesticides. Commercial bulk mechanisms include: spraying onto conveyer belts, rotating perforated drums, seed coating (pelleting) and fluidised bed coating. The pedal driven 'Rotosat' shown here is especially suitable for introducing the concept of seed treatment into remote areas.

The selective use of seed treatments can protect seeds from early-season disease and insect pests affecting crop emergence and growth. Occasionally, seed treatments can be used to stimulate production over a longer term, using biological agents such asbiopesticides and *Rhizobium* spp. (for nitrogen fixing).

Flame thrower

Compressed air type of sprayer filled with kerosene oil for producing flame. Lance modified to carry burner which is heated before allowing oil to flow through. It is commonly used for burning settled swarms of locusts.

Fig. Flame thrower

17.4 Types of nozzles and their uses

All types of sprayers generally speaking emit pesticide solution in very fine spray form. Spraying nozzle thus is a device for emitting spray liquid, breaking it up into small droplets and throwing the droplets away from the nozzle orifice. Different designs of nozzle are used to produce appropriate droplet size spectrum. In order to break the liquid into droplets energy is needed. The spray nozzles therefore are classified as:

1. Hydraulic energy nozzles
2. Adjustable nozzles
3. Gaseous energy nozzles
4. Centrifugal energy nozzles
5. Thermal energy nozzles

Almost all sprayers used for high volume spraying methods are fitted with hydraulic nozzles. The knapsack type low volume sprayers are generally worked with air blast nozzle or gaseous energy nozzle. The hand held battery operated sprayers also called CDA sprayers are fitted with spinning disc type nozzle which works on centrifugal energy. Thermal energy nozzle also called hot tube nozzles are used with fogging machines for ULV applications. Recently electrical energy has also been used to produce charged spray droplets for ULV application of pesticides.

1. Hydraulic energy nozzles

The hydraulic nozzles are most commonly used spray nozzles for pesticides application. Almost all the hydraulic sprayers use this type of nozzle. The following types of hydraulic nozzles are used for spraying pesticides:

a) Hollow cone type
b) Fan type
c) Impact type

a) Hollow cone nozzles

This is a very popular type of hydraulic snozzle for spraying insecticides and fungicide. It produces a hollow cone pattern of spray consisting of mixture of different sizes droplets. In its simplest design this type of nozzle is made of brass metal having orifice hole drilled in it and a rotral with tangential cut grooves provides swrill motion to spray liquid which breaks down into droplet when emerging from the nozzle under pressure. This simple brass nozzle is screwed onto a hand lance/ boom. There are different designs of hollow cone nozzle. Other designs of nozzles consist of a stainless steel disc with a central circular hole through which the spray emerges from a swirl chamber behind it. The disc and the swirl plate (core) are suitably fitted in the body of the nozzle which has threads for screwing (fitting) it to the lance/ boom. The normal working pressure of hollow cone nozzle is about 40 psi.

Hollow cone nozzles are good for treating complex targets because spray particles move in infinite angles and various planes providing better penetration of spray. These nozzles are generally not recommended for herbicide application due to possible drift of fine spray particles and difficulty in obtaining an even distribution of spray across the swath. The variation of liquid pressure can vary discharge rate, spray angle and also droplet size. The nozzles are made from brass, stainless steel and plastic materials. The nozzles tips wear due to chemical corrosion and abrasive action. The stainless steel tips or plastic tips are better wear resistant and help consistant spraying.

b) Fan nozzle

They are also called flat fan nozzles. The spray liquid is thrown from an orifice which is elliptical to give a flat shaped sheet of spray. These are used for band spraying. These nozzles are generally used on booms with propor distance in between and overlapping to give even distribution. The normal working pressure is about 40 psi. However these fan nozzles can also be used for herbicide application but the application is done at low pressure like 15 - 20 psi to avoid drift of fine droplets.

c) Impact nozzle

These nozzles are also known as deflector nozzles or floodjet nozzles. In these nozzles, the spray liquid emerging from a circular hole strikes an inclined smooth face and is deflected at an angle. The liquid thus spreads as a sheet in a wide angled fan pattern. These nozzles are used for herbicide spraying and are low pressure (15 - 25 psi). The spray pattern essentially consists of coarse droplets.

2. Adjustable nozzle

These are also called as tripple action nozzle. They are so called because of varying patterns of sprays that can be obtained by manipulating the swirl velocity of spray liquid in the eddy chamber. The hollow cone spray pattern consisting of fine spray particles, or a jet spray for orchard/ tree spraying and a medium coarse spray petterns can be obtained by simple adjustments. These nozzles are generally used with foot operated sprayers, rocking sprayers or high pressure hydraulic sprayers for spraying trees.

3. Gaseous energy nozzles

In this type of nozzle spray liquid is injected into a stream of high velocity air. The force of the air streches the liquid to form ligaments which ultimately break into fine spray droplets. The airstream further transports the droplets to the target. The liquid flow into the airstream is metered. Motorized knapsack sprayer or mist blower is fitted with this type of air blast nozzle. The spray droplet size depends upon the nozzle design. The positioning of liquid flow and air velocity is very important. By increasing the liquid flow rate the droplet size also increases. In larger models of sprayer’s hydraulic nozzle atomise the liquid first and then the droplets are further sheared by the air blast. Vertical nozzles also work on gaseous energy for ULV spraying.

4. Centrifugal energy nozzles

If liquid is fed on fast rotating disc, then it is carried by centrifugal force to the outermost edges of the disc and spray droplets are issued. Rotating cylindering cage of fine mesh also produce fine spray if liquid is fed into it. The revolving speed of the disc or cage is very important for size of droplets. The disc has serrated teeth on the periphery which make droplet spectrum narrow. The physical properties of the spray liquid are important for droplet size besides the speed of rotation. These types of nozzles are generally used for ULV spraying and for L.V spraying methods.

5. Thermal energy nozzles

Fogging machines work with thermal energy nozzles, also called hot tube nozzles. Spray liquid is injected into stream of hot gases (exhaust of engine) where it vaporises due to high temperature but then it condenses when issued out of the nozzle due to outside temperature and forms fog of fine droplets. Exhaust nozzle sprayers (vehicle mounted) are used for ULV application in locust control operation. Pulse jet engine models are used for pesticide fogging for public health purposes.

17.5 Maintenance of appliances

There are three important reasons for maintaining and cleaning equipment:

To save money

Proper maintenance of equipment will reduce the need for replacement parts. Good maintenance makes it easier to control the application of pesticides. Before any sprayer can be reliably calibrated, it must be in good mechanical condition. In fact, inspecting your equipment is the first step in calibration. If you mix a pesticide in equipment that has a residue of a different pesticide, you may damage your crops or injure your livestock. For these reasons, you should clean all pesticide equipment immediately after use.

To prevent pesticide poisoning

Pesticide application equipment will normally have some residual pesticide left in the tank, hoses and boom and on the surface of the equipment. This residue can harm humans, animals and crops. If someone comes into contact with this residue, it can result in serious poisoning. Well maintained equipment is less likely to have something go wrong that could put the applicator or others at risk of pesticide exposure.

To protect the environment

Pesticide residues in, on or released by application equipment can harm non target organisms and wildlife. Keeping equipment well maintained reduces the chance for a burst hose or other equipment failure resulting in a pesticide incident that may contaminate soil or water or crops.

General maintenance:

1. Clean outer surface with brush or cotton waste by using kerosene oil or plenty of water.
2. Oil the moving or rubbing surfaces of parts with lubricating oil (SAE 30) or grease, if needed.
3. Filter or strain the chemical solution/ fuel oil mixture while pouring into the tanks. Make the caps or lids leak-proof with gaskets.

4. Flush the equipment with clean water to wash inside parts of containers, tubes and nozzles to be free from chemicals.

Care and upkeep of hand sprayer & duster:

1. Dry and sieved dust should be used for dusters.
2. Grease the duster gear box once in a month.
3. Clean the duster after the work by removing all dust from the hopper.
4. Oil the cup washers and bucket washers of sprayer frequently.
5. Spray tank discharge lines and nozzles should be flushed with clean water after the day's work.
6. Lances and nozzles should not keep on the ground. Nozzle parts should be cleaned with a brush.

Care and upkeep of power sprayers and dusters:

1. Lubricating oil level should be checked and maintained in four stroke engines daily.
2. Mixture of engine oil and petrol in correct proportions should be used for two stroke engines, duly stirred and strained.
3. Clean the Air and Fuel filters with petrol frequently.
4. All the nuts and bolts should be tightened once in a week.
5. Check up the pressure gauges and safety valves frequently.
6. Drain the fuel tank after the day's work.
7. Stop two stroke engines by closing the petrol cock.
8. Belts should be kept tightened always, to be free from slip and slackness.
9. Keep proper inflated pressure in the tyred wheels of power sprayers.
10. Rubber tyre equipment should be rested on steel props when stationed.
11. Rubber hoses should not be bent at angles and dragged on the ground.
12. Equipment should be stored in clean, dry, cool store room.

Care and upkeep of pp equipment when not in use:

1. Plant Protection Equipments should be arranged properly in a store house. They should be protected from sunlight.
2. Equipment of one category should be kept at one place and not in a mixed up fashion i.e., do not dump the equipment.

3. Attachment like discharge lines, lances, and nozzles should not be kept attached to the equipment.
4. The equipment should be cleaned with cotton waste every day and polished once in a month.
5. The rubber/ plastic delivery hose should be coiled forming a big circle instead of small spool. Otherwise the hose pipes break or crack when they are straightened.
6. All nozzles should be kept neat and clean separately.
7. The moving parts and washers are to be oiled or greased well once in a week.
8. The equipment should be tested for its normal performance once a week. Even the engines should be run for a short while.
9. The equipment in store should be classified and labeled to indicate its conditions as:

   i) Working condition

   ii) Needs servicing & repairs

   iii) Needs parts & repairs

   iv) Not serviceable
10. Rubber tires should be inflated regularly or they should be jacked and propped.

Care and upkeep of pp equipment when taken to field:

1. Always carry tools required for attending to field troubles.
2. Carry some spares like washers, filters, gaskets & pins to the field.
3. Carry small quantity of kerosene, petrol, engine oil, grease, cotton waste, and containers.
4. Carry the Plant Protection Equipment properly and carefully.
5. Do not drop the equipment or attachments on the ground.
6. Clean the equipment before and after work is over.
7. Flush the equipment with clean water, after work is over.
8. Oil the moving parts and apply grease on gears and in grease cups.
9. Filter the chemical liquids and fuel oil mixtures before filling.

Care and upkeep of pp equipment in transportation:

1. All knapsack equipment should be carried on operator's back, for short distances.
2. All the rubber tiered equipments should be pulled on roads with full inflation in the tier.
3. For longer distances, the equipment should be packed in a crate or box. The accessories should be dismantled and packed separately before placing in the box/ crate.
4. Secure literature like parts catalogue, servicing manuals and special tools etc., for the equipment and keep them handy for ready reference.

17.6 Aerial adaptation of pesticides, principles of aerial application, factors affecting the effectiveness of aerial application. Advantages and disadvantages of aerial application

The first practical use of the airplane for insect control was in the application of lead arsenate dusts to control the catalpa sphinx, *Ceratomia catalpa*, in Ohio in 1921. The advantage of aircraft applications in rapidity, cheapness, and ease of treatment were readily apparent and the uses increased rapidly. During the next 20 years most aircraft operations employed dusts because of the difficulties in formulating suitable sprays with the water insoluble arsenicals.

Aircraft have been employed extensively for the control of locusts and grasshoppers by a variety of means. The aircraft operations have also made insecticidal applications possible in many areas which were previously inaccessible. These include swamps and marshes where mosquitoes and other biting insects breed, jungles and forests vast plains areas where grasshoppers and locusts are found and certain cultivated crops such as rice, sugarcane, mature corn, and cotton where ground treatment is impractical or destructive.

Physical principles of aircraft application

The use of the airplane or helicopter for the application of insecticides introduces an additional dimension of complexity into the operation that of the turbulences imparted to the air by the rotation of the propeller and the downdraft resulting from the flight of the aircraft. The influence of these factors on sprays and dusts has been given a great deal of study and the principles involved are well understood although they are often ignored in practice. A thorough appreciation of these factors is very important in designing and operating aircraft application equipment which will have the maximum effectiveness on the insects to be controlled and reduce hazardous or objectionable drift to a minimum.

Airflow about the aircraft

The lift of an aircraft in flight is obtained by imparting a downward motion to the air. This downwash or downdraft may amount to about 600 feet per minute for the ordinary biplane flying at 80 to 100 miles per hour and as much as 1100 feet per minute for the helicopter. The downdraft helps to carry the insecticidal discharge toward the ground and also moves foliage which aids in penetration and distribution of the insecticide. The lift is secured by the airfoil of the wing and results in a decreased air pressure area above the wing producing a rotary movement at each wing tip the trailing wing tip vortex, which may persist for several seconds after the passage of the aircraft. Superimposed on these forces is the rotary slipstream of the propeller, which displaces the airflow in a counter clockwise direction. The velocities of the downdraft and the wing tip vortices increase as the speed of the aircraft decreases since the downward displacement of the air must equal the lift required to support the aircraft.

With the helicopter the forces are very similar. Pronounced vortices with outward and upward components occur at the ends of the rotor, while the downdraft is most pronounced under the central section of the rotor. The strength of these forces is greatest when the helicopter is hovering and they are materially decreased under conditions of normal forward flight.

Effects of particle size of discharge

The air currents following in the wake of an aircraft largely determine the movement of particles released in spraying or dusting. Small particles of aerosol dimensions with their very slow settling velocities follow the airflow almost perfectly and when realised in the region of the wing tip vortices may be thrown upward to heights of several thousand feet and will travel vast distances in very low wind currents. Larger particles such as coarse sprays, pelletized or granular insecticides or baits respond much more directly to gravitational forces and have a high settling velocity. Nevertheless the distribution of these is also influenced by the flight turbulence.

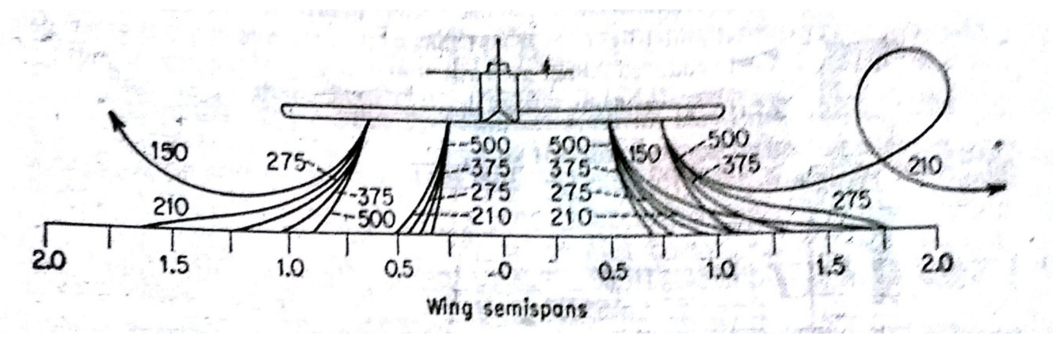

Fig. Theoretical path of various sixed spray droplets released by aircraft flying at 85 miles per hour and 10 foot altitude in still air.

The swath cross section

The practical assessment of the aircraft distribution of insecticides depends upon the dimensions of the swath of deposit. These are determined by such variables as the type, altitude and speed of the aircraft, the particle size spectrum of the discharge the nature of the venture, spray boom or other device for producing the discharge and by the meteorological conditions. The swath cross section is far from uniform, since the largest particles tend to fall most directly underneath the aircraft while the small ones are more readily deflected by air currents and are dispersed further in the lateral directions or may escape the treatment area altogether. Typically the resulting swath cross section is that of a bell shaped distribution curve skewed in the direction of the rotation of the propeller or where a long boom is employed more of a modified trapezoid. In some cases with airplane spraying using nozzles near the wing tips a bimodal or two peaked swath cross section results.

These curves are generally plotted as the averages of a number of determinations since the cross section is somewhat variable, especially because of corkscrew pattern produced by the rotation of the propeller and the presence of occasional large droplets in sprays. It will be noted that the total recovery of insecticide over a 50 to 200 feet swath, which represents the maximum treatment widths generally obtained in various operations is only a fraction of the total amount of material discharged. Many of the fine particles drift for relatively enormous distances as has been graphically demonstrated with 2,4-D herbicidal applications, which have severely damaged cotton fields more than a mile from the intended treatment area. With dusts, careful recovery studies have shown that only about 27 percent of a dust with a D_m of about 20 microns was recovered over a 200 foot swath, while increasing the particle size to a Dm of 30 to 40 microns increased the recovery to about 43 percent. Recoveries with oil based aerosols and sprays have ranged from 9 percent for an aerosol of D_m of 35 microns to about 32 percent for a spray of D_m of 200 microns based on a 200 foot swath. Even with water based sprays having a D_m of 300 microns the recovery over a 100 foot swath was only 50 percent.

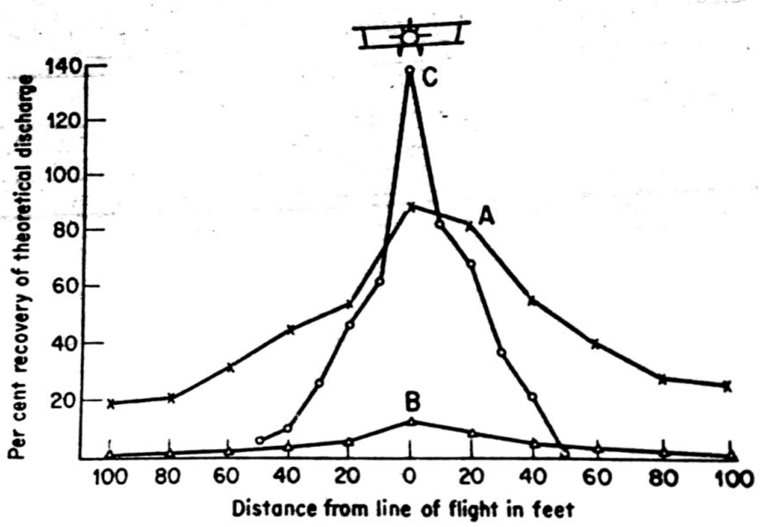

Fig. Swath cross sections from airplane applications of sprays and dusts, showing relation of particle size to percent recovery. A, dust with 88 percent in 20 to 50 micron range at 20 feet; B, oil aerosol with D_m of 35 microns at 20 feet; C, water spray with D_m of 300 microns at 5 feet above the ground.

From a consideration of the parameters of the swath cross section it is clear that for the successful application of any relatively uniform coverage of the treatment area it will be necessary to overlap the edges of the swaths so that the total deposits will everywhere exceed the minimum lethal dosage. Therefore the distance between swath centers (line of flight) must be gaged on the recovery pattern as shown in fig.

In as much as the dynamic catch of the dust or spray particles on vegetation will greatly influence the deposit this factor must be considered in gaging the rate of discharge. This factor acts in a positive or a negative way, depending upon whether the application is to form a residual deposit on vegetation or to penetrate through vegetation to kill flying insects or insect larvae breeding in water. The importance of the dynamic catch on dosage is shown by the fact that six times as much paris green dust was required in heavy plant cover to produce the same larvicidal effectiveness as occurred under light cover and that while 2 pounds of paris green per acre per 100 foot swath produced 90 percent kill of anopheline larvae over a width of 115 feet in light plant cover the same dosage in heavy cover produced no kill.

Width aircraft sprays a similar relationship exists: the recovery of a spray of D_m of 110 microns was approximately seven times the mass in the open of that recovered under heavy cover and the D_m of the material recovered under the heavy vegetation was 50 microns showing that the larger droplets were filtered out by the vegetation.

The swath dimensions are not materially affected by changes in air speed or height of flight in low level applications. As has been indicated the air currents around the plane are strongest at slow speeds and in practice the swath width in airplane spraying was about 10 feet wider at 50 miles per hour than at 80 miles per hour. An increase in height (to the wheels) from 1 to 10 feet did not appreciably change the swath width but the pattern was somewhat more regular at the higher altitude.

It should be noted that in most aircraft operations for the control of insect pests of field and vegetable crops, the maximum practical swath width is about 40 feet since the deposits achieves beyond the wing tips are not generally heavy and uniform enough to secure practical insect control. To complete the coverage of a treated field it is essential for the pilot to ‘dress out’ the ends by flying one or two swaths across the ends of the rows at right angles to the regular treatment swaths. For accurate work in large fields the use of flagman to indicate the desired line of flight is essenetial.

Equipment for aerial application

Equipment for aerial application of pesticides must be able to lift, transport and disperse pesticides safely and accurately to the target area. You need to understand how your equipment affects the application so that you can ensure effective treatment under any conditions you encounter.

Choice of aircraft

You can apply pesticides aerially using either a fixed wing airplane or a helicopter, although most applicators use airplanes. Airplanes are fast, manoeuvrable, and have a large payload capacity per dollar invested. Helicopters are even more manoeuvrable, can be operated over a range of speeds, and may be operated in almost any area because a regular landing strip isn't needed. However, helicopters are more expensive to operate per unit of flying time, so the pilot must minimize the time lost in turnarounds and refilling.

Weick has summed up the desirable characteristics of applicator airplanes as

- Ability to carry a spray or dust load of at least 35 to 40 percent of gross weight
- Ability to take off and climb to 50 feet within ¼ mile with full load
- Safe operating speed of 60 to 100 miles per hour and minimum safe flying speed of 45 miles per hour
- Easy handling controls with high maneuverability
- Excellent forward and lateral visibility
- Special design to protect the pilot in a slow speed crash
- Facilities for quick and easy loading and
- Simple rugged construction and simplicity in maintenance and repair.

Dust distribution

The components for aircraft dusting are as follows:

The hopper is sloping sided, holding from 200 to 2000 pounds (15 to 50 cubic feet) and should be constructed of aluminium or better of stainless steel or plastic reinforced with fibre glass for corrosion resistance. It should contain a large, easily accessible loading door with tight sealing gasket an air vent and a small window to serve as a gage for the pilot.

The agitator is located directly above the throat of the dust hopper and consists of a rotating reel to sweep the dust into the hopper throat, powered by a wind driven propeller through a gear box to reduce the speed by about 50:1. The agitator should be equipped with a brake operated from the cockpit. The rate of dust discharge is controlled by a sliding gate at the bottom of the hopper and operating from the cockpit. The gate should be made of aluminium to reduce the fire hazard from sulphur. A venture type distributor is commonly used to disperse the dust into the air stream. This employs the principle of the venture tube to produce increased air velocity and lower static pressure at the hopper throat which aids the flow of dust. An accurate metering device such as a variable auger or conveyer surface, although not generally used would be highly desirable to promote the even flow of dust from the hopper.

Spray distribution

The generalized components for aircraft spraying are as follows:

The spray tank which is made of aluminium , stainless steel or plastic impregnated with fiber glass and may have a capacity of 35 to 200 gallons. It should have a large, conveniently located filler opening with a screen, a large protected vent, a gage and sump and drain petcock. The spray pump is preferably of the centrifugal type and should be corrosion resistant with adequate seals and sufficient capacity to produce agitation by bypass action into the tank. Centrifugal pumps of suitable type operate at a maximum of about 70 pounds per square inch and at 3000 to 4000 revolutions per minute. Gear pumps are also satisfactory for emulsions and solutions but are badly worn by suspension of wettable powders. The simplest method for driving the pump is the wind driven propeller mounted in the airplane propeller slipstream and connected to the pump by a universal joint. The pump assembly should be equipped with a brake. Hydraulically driven spray pumps are also used in some installations.

The spray boom is usually a 5/8 to 1 ¼ inch diameter aluminium or steel tube and is best mounted about a foot below the lower wing or from 4 to 6 inches aft of the trailing edge of the wing. It should be approximately three quarters as long as the wing span to minimize the amount of spray entering the wing tip vortices. The type and position of the nozzles is of great importance in determining the particle size of the discharge and the swath cross section. A typical spray boom for agricultural spraying has from 20 to 30 nozzles.

These4 should be mounted progressively closer together toward the boom tips with a cluster of two to three at each tip. To compensate for the air currents from the counter clockwise rotation of the propeller ,which displace much of the spray from a distance of 1 to 4 feet right of center of the left of center, four or five nozzles should be massed close together 2 to 4 feet right of center of the boom and a corresponding reduction made by eliminating the nozzles in the 4 feet of space to left of center.

For insecticide distribution where sprays with a Dm of 50 to 200 microns are most desirable, hollow cone or flat spray nozzles are most desirable, operated at 30 to 40 pounds per square inch. The direction of nozzle placement with regard to the slip stream has an important effect on the degree of liquid breakup.

Other means of liquid breakup and distribution have been used in aircraft spraying. The rotating brush disk or drum uses a wind driven propeller to produce the centrifugal force necessary to break up the liquid which is fed by gravity. This equipment will distribute a wide variety of liquids including those containing a high degree of suspended matter.

The venture exhaust generator has been used to produce aerosols in the 10 to 100 micron range which have been used successfully for the control of adult and larval mosquitoes.

The most desirable particle sizes for aircraft spraying vary with the type of operation. In the control of adult mosquitoes, black flies or tsetse flies where jungle or forest canopy is to be penetrated an aerosol of 10 to 50 microns is most useful and this provides swath width up to 250 feet, but gives very low recoveries on vegetation and is highly sensitive to meteorological effects.

For the direct spraying of locust swarms s particle size range of 50 to 100 microns seems to be most suitable and will give swath widths up to 200 feet. For agricultural spraying for maximum deposit under conditions of low flight a range of 100 to 300 microns combines the best dynamic catch and the lest drift away from the treatment area but the effective swath width is only about 100 feet. Coarse sprays of 200 to 500 microns produce narrow swath widths of about 50 feet.

Meteorological effects

Wind and air currents appreciably affect the performance of aircraft in dusting and spraying operations. In general the most satisfactory results are obtained under conditions of very low wind velocity and when vertical currents or turbulence are at a minimum. These conditions usually occur from the early morning hours and again until about 1 hour before sunset. At these times the ground surface and the air immediately above it are cooler than the upper layers of air, and a stable condition of inversion, free from rising air currents exists. When the sun warms the ground so that the lower air level is warmer than the air above a condition of lapse results and the rising air currents or turbulence occurs. Inversion conditions can be measured by the difference of 1 to several degrees in temperature readings on two thermometers, one near ground level and the other at head height, or can be observed by the use of smoke, for everyone has seen the layering of smoke from bonfires or steam engines which commonly occurs at dawn and dusk. Because of the sensitivity of dust and spray clouds to distribution by turbulence most aircraft operations of this nature are carried out under inversion conditions.

Surface winds also play an important role and these are generally minimal under inversion conditions. An 8 year study in California showed that wind velocities in June to August were least from 3 to 7 am and that at sunrise, lulls of less than 2 miles per hour wind velocity occurred on approximately 15 days per month.

Aerial application of pesticides offers several advantages over ground application:

You can cover large areas quickly. You can treat crops or areas (such as mid-season corn or forest stands) for which ground equipment isn't suitable. The application cost per acre is comparatively low. To reap the full benefit of these advantages, you and your client must cooperate to develop a pest-control plan that will ensure a safe and effective operation. Your plan must be based on full knowledge of the pest-pesticide relationship, pesticide activity and restrictions, and the capabilities and limitations of your aircraft under prevailing conditions.

You must also be aware of hazards to people, livestock, other crops, and the environment.

Several factors limit the use of aerial application. These include weather conditions, fixed obstacles such as power lines, field size, and the distance from the landing strip to the target area. Your challenge is to know when and how you can overcome these limitations and, just as importantly, when these limitations make aerial application impractical.

17.7 Summary

- On the basis of volume of spray-mix the technique of spraying is classified as:
- High volume spraying, 2. Low volume spraying, 3. Ultra low volume spraying.
- High volume spraying is very common and popular method of pesticide spraying. The spray solution is prepared by mixing water with pesticide formulation in appropriate quantities. This diluted mixture is sprayed through hydraulic nozzles.
- The ULV spraying is the method of pesticide application at minimum volume to achieve economic pest control. In this technique of pesticide application the volume applied per hectare is less than 5 liters which is extremely low as compared to the conventional High Volume and Low Volume spraying methods.
- Power aerosol and fog generators break liquid pesticides into aerosol droplets. Reducing the liquid into droplets is done either mechanically (cold foggers) or by using heat (thermal foggers).
- Spraying nozzle thus is a device for emitting spray liquid, breaking it up into small droplets and throwing the droplets away from the nozzle orifice.

17.8 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Write any three characters of high volume sprayer.

2. Write the name of different types of sprayers.
3. Define cold foggers.
4. What is a soil injecting gun?
5. Write the name of different types of dusters.
6. Write the name of different types of nozzles.

Section -B (Short Answer Type)

1. Write short notes on hydraulic energy nozzles.
2. Describe fogg gneraters and soil treating drums.
3. Write short notes on:
    a) Rocker sprayer
    b) Knapsack duster
4. Write short notes on:
    a) Gaseous energy nozzles
    b) Foot operated sprayer
5. Describe low volume spraying in detail.

Section -C (Long Answer Type)

1. Describe various types of sprayers.
2. Give a detailed account on various types of nozzles and their uses.
3. Write short notes on :
    a) Fogg generators and smoke generators
    b) Maintenance of appliances
    c) Soil injecting guns
4. Give a detailed account on aerial application of pesticide.

17.9 References

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Unit – 18

Techniques in plant protection

Structure of the Unit

18.1 Objective

After going through this unit you will be able to answer the following question

- Why seed treatment is essential?
- What are different techniques for insect pest management?
- What is importance of electron microscopy?

- What are difference between Scanning electron microscopy and Transmission electron microscopy?
- How we use of computer application for pest prediction and forecasting?
- What is the importance of PAGE techniques?

18.2 Introduction

Several plant protection techniques are available for management of insect pests and diseases in various crops. These protection techniques are used in single or in combination for management of the pests in fields. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms". Various cultural practices viz., deep ploughing, soil solarisation, flooding etc. can be used as a primary tool in a successful Integrated Pest Management Program for sustainable agriculture since they target the pests and diseases and have no adverse effects on environment.

18.3 Seed treatment

Seed treatment: Seed quality is dependent on several environmental factors such as moisture, temperature, humidity and storage conditions. Seed quality may still be destroyed by insects and other pests or reduced by certain seed borne diseases, even though these factors are maintain properly. Several studies have shown that seed treatment is the most economical and efficient way to protect seed from pests and improve the seed quality. Since pesticides are hazardous, extra care and safety precautions must be taken when applying them and in handling seed after it has been treated. The term "treated" means "to give an application of a pesticide or subject seed to a process designed to reduce, control or repel disease organisms, insects, or other pests which attack the seed or seedlings."

18.3.1 Role of seed treatment

Diseases and pests affecting crops can have devastating consequences in agricultural and horticultural production if not properly managed. Breeding is an excellent tool to build resistances against pests and diseases in the plants. However, breeding alone does not address all of the agronomic challenges; therefore crop protection products are often needed and used for good crop management. These crop protection products can be applied during the growth of the crop but can also be added to the seed as a seed treatment. Seed treatments have played and are still playing a vital role in the history of mankind, in staving off hunger and starvation by improving the establishment of healthy crops.

18.3.2 History of seed treatments

Some of the first recorded seed treatments are the use of sap from onion (*Allium* sp.) and extract of Cypress in the Egyptian and Roman periods. Salt water treatments have been used since the mid-1600s and the first copper products were introduced in the mid-1700s. Other key milestones were the introduction of arsenic, used from 1740 until 1808 and the introduction of mercury, used from 1915 until 1982.

The first systemic fungicide product was launched in 1968. This systemic fungicide had not only seed surface activity but also moved into the plants protecting the young seedlings from airborne pathogens. Since the 1990s the crop protection and seed industries have developed and adopted new classes of fungicide, insecticide, and nematicides chemistry, expanding pest control while reducing user and environmental impact.

18.3.3 Seed Dressing/seed soaking

This is most common method of seed treatment. The seed is either dressed with a dry formulation or wet treated with a slurry or liquid formulation. Dressings are applied both on-farm or in specialised seed treatment facilities. Ex. Sorghum seeds are treated with chlorpyriphos 20 @ EC 4 ml/kg with 20 ml of water and shade dried to control shoot fly.

18.3.4 Seedling root dip

This method is used to control early stage pests (ex.) in rice to control sucking pests and stem borer in early transplanted crop. For this a shallow pit lined with polythene sheet is prepared in the field. And filled with 0.5 kg urea in 2.5 litre of water and 100 ml chlorpyriphos in 2.5 litre of water prepared separately are poured. The solution is made up to 5.0 lifters with water and the roots of seedlings in bundles are dipped for 20 min before transplanting.

18.3.5 Seed Coating

A special binder is used with a formulation to enhance adherence to the seed and begin to impact seed size and shape. Coatings require advanced treatment application technology.

18.3.6 Seed Pelleting

It is most sophisticated seed treatment technology, resulting in changing the physical shape of a seed to enhance plantability and handling. Pelleting requires specialised application machinery and techniques and is the most expensive of the applications.

18.3.7 Sett treatment

To protect sugarcane crop from scales pests, treat the sugarcane setts in 0.05% Malathion for 15 minutes, whereas for termites management, treat the sugarcane setts in 0.05% Imidacloprid 70 WS @ 175 g/ha or 7 g/l dipped for 16 minutes.

18.3.8 Soil drenching

In this method, chemical is diluted with water and the solution is used to drench in the soil to control certain subterranean pests. Ex. for management of root rot and wilt diseases in cumin, soil drenching with the solution of carbendazim @ 2 g/ litre of water is effective.

18.3.9 Seed treating equipment

There are three types of commercial seed treaters, generally, available in the market. These are dust treaters, slurry treaters and direct treaters. The Panogen and Mist-O-Matic treaters are examples of direct seed treaters. Seed treaters are designed to apply accurately measured quantities of pesticides to a given weight of seed.

18.4 Soil sterilisation

Soil sterilisation makes soil completely clean and free from harmful soil microorganism, insect pests and weeds. Sterilisation may be done through rising the soil temperature by steam or sun.

18.4.1 Steam Sterilization

Steam sterilization is used for management of insect pests and diseases in high-value horticultural crops. Soils and cultural composts contaminated with plant pathogens were sterilized by injecting steam (60-80ºC for 30 minutes). Plant diseases such as lily yellowing caused by *Fusarium oxysporium*, bacterial wilt caused by *Ralstonia solanacearum* and blight of ornamentals caused by *Athelia rolfsii* (Curzi) were controlled significantly by steam sterilization. The quality of ornamental products and weeds control were also improved by this method. Use of steam pipe line systems is further improving the efficiency of operation in fields and screen houses. This method is time consuming and labour-costly but reducing use of pesticides and their adverse impacts on the environment especially in the ornamental industry.

18.4.2 Soil solarization

It is a non-chemical disinfestation practice that may serve as a component of a sustainable IPM programme. Solarization effectively controls a wide range of soil-borne pathogens, insect pests and weeds. Soil solarization is based on the exploitation the solar energy for heating wet soil mulched with transparent PE sheets to 40–55ºC in the upper soil layer. The duration of soil mulching that is required for successful effect is usually four to six weeks, depending on the pest, soil characteristics, climatic conditions and the PE properties. Thermal killing is the major factor involved in the pest control process, but chemical and biological mechanisms are also involved. The efficacy of the thermal killing is determined by the values of the maximum soil temperature and amount of heat accumulated (duration x temperature). The use of organic amendments (manure, crop residues) together with soil solarization (bio-fumigation) elevates the soil temperature by 1–3ºC, and improves pest control due to a generation and accumulation of toxic volatiles. Although cheaper than most chemicals used as soil fumigants, not all crops can afford the PE prices, particularly in developing countries. Not all soil-borne pests and weeds are sufficiently controlled. Economical and eco- friendly accepted mulching technologies are needed before expanding the range of the controlled pests by solarization.

18.5 Deep ploughing

Cultural practice like deep ploughing influence directly the survival of soil inhabiting pests. This routine agricultural operation exposes soil inhabiting insect-pests and other arthropods and nematodes to harsh weather and to natural predators. Soil provides a protective habitat for pupation and diapausing of many insect-pests. Birds like the king crow, the myna, the starling, etc. pick up the exposed pupae following this cultural operation. Some insects e.g. grasshoppers, crickets, mole-crickets and borers lay their eggs in the upper layers of the soil. Their eggs are exposed during soil preparation and subsequently desiccate. Many insects like cutworms, grubs of the root borer and white grubs which feed on the root system of plants are also exposed to the vagaries of the elements during inter-culture operations. Deep ploughing carried out during winter helps in reducing the overwintering populations of several pests.

18.6 Flooding

Flooding with water in soil, affect larval diapausing, pupal survival and adult emergence. Flooding of the field at the time of pupation reduces the pupal survival, and thus leads to decreased population densities in the next generation and crop season. For example, when nursery beds of rice are flooded, the rice hispa float up and is killed in water. Though this is an effective method, it is not very efficient in terms of water use.

18.7 Techniques to check the spread of pests (Plant quarantine/Treated the materials before movement)

Man even in nomadic period carried with him the required seeds and plants wherever he moved. This practice is still continuing in the civilized settlements of mankind. As a consequence, many plant types have moved from their centres of origin, to an entirely new regions / continents, where they got well established and naturalized. The pests associated with plants and seeds also moved along unnoticed into a new region, where they caused severe damage, not only to the plants with which they associated but started to infect / infests many other plant types in the introduced region. The realization of the economic, social consequences happened due to indiscriminate and unscientific movement or trade of plants, seeds and plant materials, necessitated the countries or provinces to start regulating the movement of plants and plant material. Plant quarantine is effective method in which legal restriction of movement of plant materials between countries and between states within the country to prevent or limit introduction and spread of pests and diseases in areas where they do not exist. In addition to this, all the plant materials should be treated with chemical or and fumigated before movement from one place to another place to check the spreading of insect pests, diseases, nematodes and weeds.

18.8 Electron microscopy

Electron Microscopy (EM) can be defined as a specialized field of science that employs the electron microscope as a tool and uses a beam of electrons to form an image of a specimen. EM is operated in the vacuum and focuses the electron beam and magnifies images with the help of electromagnetic lenses. As we know that electrons are particulate constituents of atoms, circling the nucleus in a series of concentric orbits. Also in appropriate conditions electrons display wave properties. In other words they have some of the characteristics of other forms of wave motion such as visible light, ultraviolet light and X-rays. The orbiting electrons in the outermost orbit are known as Valence electrons which are loosely held by the attracting force of inner electrons. These valence electrons can be easily detached and these are used in the electron microscope.

The first functional transmission electron microscope was developed in the early 1930s by Ruska who constructed a two stage electron microscope with three magnetic lenses, condenser, objective, and projector. There are two types of electron microscopes, viz., transmission electron microscope (TEM) and the scanning electron microscope (SEM). The schematic structures of these microscopes are presented in figure1.

18.8.1 Light microscopy (LM)

which uses visible light as a source of illumination and optical (glass) lenses to magnify specimens in the range between approximately 10 to 1000 times from their original sizes.

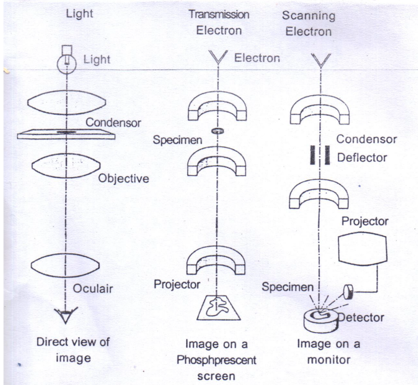

Figure 1. Scheme of a simple electron microscope

18.8.2 Scanning electron microscopy

Scanning Electron Microscopy (SEM) is an important technique for the investigation of surface structures of specimen. This technique provides a large depth of field *i.e.* the area of the sample that can be viewed in focus at the same time is actually quite large. SEM has also the advantage that the range of magnification is relatively wide allowing the investigator to easily focus in on an area of interest on a specimen that was initially scanned at a lower magnification. Furthermore, the three-dimensional appearing images may be more appealing to the human eye than the two-dimensional images obtained with a transmission electron microscope. Therefore, an investigator may find it easier to interpret SEM images. Finally, the number of steps involved for preparing specimens for SEM investigation is lower and thus the entire process is less time consuming than the preparation of samples for investigation with a transmission electron microscope. However, SEM specimen preparation harbours various risk factors that can easily distort the integrity and ultra structure of the specimen. The basic steps involved in SEM sample preparation include surface cleaning, stabilizing the sample with a fixative, rinsing, dehydrating, drying, mounting the specimen on a metal holder, and coating the sample with a layer of a material that is electrically conductive.

18.8.3 Transmission electron microscopy

Transmission Electron Microscopy (TEM) has added advantage over SEM that cellular structures of the specimen can be viewed at very high magnifications. However, TEM sample preparation for mollicutes is longer and more difficult than that for SEM and includes additional steps such as post-fixation, the embedding of mollicutes in a resin, the sectioning of samples, and the staining of semi-thin and ultra-thin sections. Bozzola and Russell emphasized that perhaps the least forgiving of all the steps in TEM is the sample processing that occurs prior to sectioning. In other words, a poorly prepared specimen is useless to the investigator, whereas problems during the sectioning can be relatively easily fixed by simply cutting and staining more sections.

Specimen preparation of mollicutes for TEM includes eight major steps *i.e.* cleaning, primary fixation, rinsing, secondary fixation, dehydration, infiltration with a transitional solvent, infiltration with resin and embedding, and sectioning with staining. The first two steps are essentially the same as those described for SEM specimen preparation.

18.9 Protein isolation from the pest and host plant and its quantification using spectrophotometer and molecular weight determination using SDS/PAGE

18.9.1 Spectrophotometer

The term “spectroscopy” comes from the word “spectrum” which originally referred to the multiple colours of light apparent in an analysis of white light using a prism. “Spectroscopy” therefore implies the use of multiple wavelengths of light. Spectrophotometry is an important analytical technique that can be applied in all areas of modern biology including entomology either for qualitative or quantitative analysis. This technique is based on the measurement of absorption and emission of electromagnetic radiation. It assumes many forms and most recognisable one is the light. The radiation obtained from single source consists of several waves which may be equal or unequal. Electromagnetic radiation having all the waves of single wave length is known as ‘monochromatic radiation’ *i.e.* one coloured whereas radiation with many wave lengths are called as ‘polychromatic radiation’. Spectrophotometers have the ability to specifically measure absorbance at specific wavelengths. The most commonly used method to allow this involves a “monochromator”, a device (either a prism, or more commonly, a diffraction grating) that splits the incident light into its component wavelengths, and permits only light of the desired wavelength to reach the sample. The ability to measure absorbance at different wavelengths is very useful, because the extinction coefficient of a compound varies with wavelength. In addition, the absorbance spectrum of a compound can vary dramatically depending on the chemical composition of the compound, and depending on the environment (such as the solvent) around the compound.

The Beer-Lambert law states that:

$$A = \square cl$$

Where A is the absorbance of the sample at a particular wavelength,□□ is the extinction coefficient for the compound at that wavelength in (M•cm)-1, *c* is the molar concentration of the absorbing species, and *l* is the path length of the solution in cm.

Thus, if the extinction coefficient of an absorbing species is known, the absorbance of the solution can be used to calculate the concentration of the absorbing species in solution. (This assumes that the species of interest is the only material that absorbs at the wavelength being measured.)

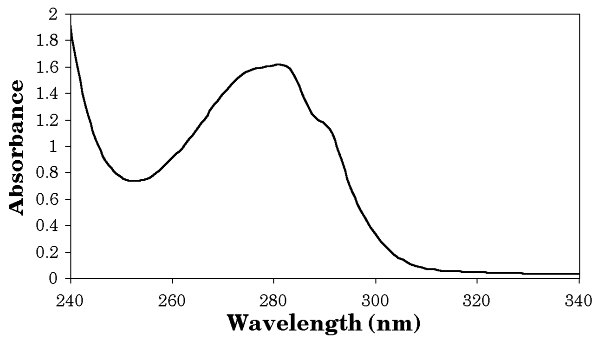

Figure 2. Absorbance spectrum of a protein

The protein has a strong absorbance peak near 280 nm, but exhibits very little absorbance at longer wavelengths. For this protein, the only chromophores (chemical groups within a compound that absorb light) are the aromatic amino acids tryptophan and tyrosine (Figure 2).

For many proteins, these two residues are the only chromophores; because tryptophan and tyrosine only absorb in the ultraviolet portion of the spectrum, such proteins are colourless molecules. Coloured proteins, such as hemoglobin, exhibit their colour due to chromophores (heme, in the case of hemoglobin) that absorb in the visible portion of the spectrum. The extinction coefficient of a molecule at a given wavelength can be calculated using the Beer-Lambert equation from absorbance measurements for solutions of known concentration.

Absorption spectrophotometry is a means for determining the concentration of a substance in solution. A dissolved substance will absorb light of specific wavelengths characteristic of that substance. When light of those wavelengths is passed through the sample, some of the light is absorbed by the solute, decreasing the amount of light that passes through the sample (Figure 3). A spectrophotometer is used to measure the difference in the amount of light entering and leaving the sample. The light that passes through the sample (not absorbed) is called transmitted light. This difference in the original and transmitted light is called the absorbance. Absorption spectrophotometry can be used to study the properties of many types of biological molecules, such as pigments, enzymes, DNA, and many small organic molecules.

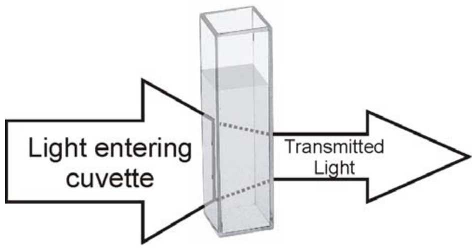

Figure 3. Absorption of light as it passes through a solution.

Protein concentration is typically measured by combining a small sample of the homogenate with a chemical reagent that changes colour in proportion to the amount of protein present. Several commercially prepared protein assay reagents are available.

18.9.2 Polyacrylamide gel electrophoresis (PAGE)

PAGE stands for Polyacrylamide gel electrophoresis. Basically it is used to analyse protein samples from any tissue in native as well as sub-unit forms. SDS PAGE allows assessment of purity of the preparation, estimation of approximate quantity of the protein, and measurement of the size of the protein. Acrylamide is used to make polyacrylamide gel with the help of other polymerising components.

18.9.2.1 Principles: Polyacrylamide gels are formed by polymerising acrylamide with a cross linking agent (bisacrylamide) in the presence of a catalyst (persulphate ion *i.e.* ammonium persulphate) and a chain initiator TEMED (N,N,N,N, tera methyl ethylene diamine). The porosity of the gel is determined by the relative proportions of acrylamide and bis acrylamide. SDS (anionic detergent) binds to most protein (hydrophobic interaction) in amount largely proportional to the molecular weight of the protein about one molecule of SDS for every two amino acid residue. The protein-SDS complex carries net negative charges hence move towards the anode and the separation is based on the protein size. Factors which affect the gel are percentage of gel ionic concentration of buffer, temperature and electric currents: voltage ratio.

18.9.2.2 Methodology:

18.9.2.2.1 Electrophoresis instruments: An instrument is made up of acrylic material with two separate reservoirs each having an electrode. There is a gasket to which two plates are sandwiched with the help of a spacer. To form wells in the gel, there is toothed plastic comb.

18.8.2.2.2 Reagents used in PAGE:

Running gel buffer		**Stacking gel buffer**		**Electrode buffer (x10)**		**Sample buffer (Loading dye)**	
Tris 1.5 (pH 8.8)	10.0 m	Acrylamide stock 30%	1.7 ml	Tris 2.0 M (pH 8.3)		Tris HCL buffer 1.0 M (pH 6.8)	5.0 ml
Acrylamide stock (30% w/v)	14.0 m	Tris 1.0 M (pH 6.8)	1.25 ml	Glycine 1.9 M		SDS	0.5 g
				Destaining Solution			
Distilled water	33.2 m	Distilled water	6.8 ml	Methanol	40 %	Sucrose	5.0 g
				Acetic acid	8%		
SDS 10%	0.4ml	APS 10%	0.1 ml	**Staining solution**		2- Mercapto-ethanol	0.25 ml
APS 10%	0.4 ml	SDS 10%	0.4ml	Coomassie Brilliant	1 %	Bromophenol blue (0.5%	1.0 ml

				blue R 250		w/v)	
TEMED	0.1 ml	TEMED	0.05 ml	Methannol	40 %	Distilled water	10.0 ml
Total	40.0 ml	**Total**	10.0 ml	Acetic acid	8%		

18.9.2.2.3 Protocol: PAGE is essential done as prescribed by Laemmli (1970). We first, clean the glass plates thoroughly. Now we place glass plate (rabbit eared) over the other sandwitching the spacer on the two sides. The assembly is held by bulldog clip. Now seal to lateral sides and the lower sides with cellotape without any gap. Use small amount of molten agar (1%) to seal the lower and lateral side.

Degas separating gel mix and add to the chamber by pouring over the top 2/3rd volume of the chamber (NB: degassing helps to remove oxygen which otherwise inhibits polymerization). Gently pour some water on the top of separating gel mixture. Water forms a thin layer over the separating gel. This prevents meniscus formation of the separating gel. Leave to set for one to two hours. Drain of water from the top of the polymerised gel and then add stacking gel carefully by pipetting. Insert the desired comb without delay. After the stacking gel gets polymerised, remove the comb carefully. (NB: Formed wells can be marked with glass marking pen, which will help in localising the well while loading the sample). After polymerising of stacking gel, remove the comb and flush the well with 1x electrode buffer to remove unpolymersied acrylic acid.

Assemble the plate to the electrophoresis set after removing the cellotape put at the bottom of the plate. Fill both upper and lower buffer chambers. Meanwhile prepare sample by mixing protein with sample buffer. The sample mixture is then placed in a microcetrifuge tube with a hole on the top and placed in boiling water for 5 minutes. Put the electrode buffer in the upper and lower tank. Remove boiled sample and cool. Give a quick spin and load the clear supernatant in the well. After loading the sample, adjust the current and electrophoreses till bromophenol blue dye reaches the bottom. Usually 20 mA constant current is used for 1.0 ml gel.

18.9.2.2.4 Staining and de-staining of gels:

Disassemble the plates which were sandwitched and remove gel carefully and keep in tray containing 100 ml stain. Allow gel to shake gently overnight in a rocking platform. Remove the gel next day and rinse briefly in distilled water and place in distaining solution. Allow the gel to destain on a rocking platform with several changes of destaining solution.

18.9.2.3 Uses/Application of PAGE in entomological research

1. Biodiversity analysis of insects.
2. Pest resistance management by studying isozyme/ enzyme profile.
3. Sex determination by differentiating protein component.
4. Understanding metabolic disorder when an insect carries some parasite such as and NPV.

18.10 Use of tissue culture techniques in plant protection

Tissue culture method reduces the pest/pathogen introduction risk in two ways:

(i) the size of the consignment is very much reduced since the introductions are represented by meristem tips, excised buds or embryos, and

(ii) the aseptic plantlet system has built-in pest/pathogen detection capability. All insects, mites, nematodes and most fungi can be eliminated. Symptoms on young seedlings, and growth of the organisms on the agar medium, if any, may be visible through the transparent culture tubes, and these could be discarded. However, certain systemically infecting pathogens like rusts, downy mildews, bacteria, viruses, viroids and MLOs, may still get transported.

18.11 Computer application for predicting/forecasting pest attack and identification

The techniques of image analysis are extensively applied to agricultural science, and it provides maximum protection to crops, which can ultimately lead to better crop management and production. Monitoring of pests infestation relies on manpower, however automatic monitoring has been advancing in order to minimize human efforts and errors.

Expert systems have developed from a branch of computer science known as artificial intelligence. Artificial intelligence is primarily concerned with knowledge representation, problem solving, learning, robotics, and the development of computers that can speak and understand human like languages. Thus, expert systems are computer programmes designed to mimic the thought and reasoning processes of human expert.

Expert system can be developed for many kinds of applications involving diagnosis, prediction, consultation, information retrieval, control, planning, interpretation and instruction. In USA, computer based diagnostic systems for diseases, insect-pests and physiological disorders are available. In citrus and selected tropical fruit crops, the TFRUIT. Xpert and CIT.Xpert computer based diagnostic programmes can quickly assist commercial producers, extension agents and home owners in the diagnosis of diseases, insect-pest problems and physiological disorders. The systems' methodology reproduces the diagnostic reasoning process of the experts. The diagnostic programme operates under Microsoft-Windows. Users can also refer to summary documents and retrieve management information from the University of Florida's Institute of Food and Agricultural Sciences extension publications through hypertext links. The programmes are available separately on CD-ROM and each contains over 150 digital colour images of symptoms.

18.11.1 Simulation models

These models can give some theoretical explanations of the effect of damages or competitive organism's *viz*., insect pests on crops. In general, computer models depend on a few known variables that influence plant growth, development and production. Plants respond, in reality, to damage or changes occur in the environment in a very complex manner. Therefore, such complexity cannot be incorporated into the models to simulate an actual situation. However, good simulations or computer models can improve the theoretical understanding of the major effects of injuries or damages of pests on plants and their yield.

18.11.2 Imaging Technologies

Improvements in existing technologies and development the new technologies the ways to view the object is changing. With the proliferation of mobile computing hardware and personal communications devices, for example, the possible development of portable imaging systems is becoming more realistic. These changes are not just taking place in the computing arena. Small, portable microscopes are now available that support digital photomicrography and are still capable of providing the same levels of magnification as their bench-top counterparts. When photographs or image recordings from a tower, balloon, plane, or satellite are available, they can give a useful indication of the area and intensity of dead or wilting plants or leaves and differences in crop yield caused by pest attack. Remote sensing techniques such as radar can automatically monitor the height, horizontal speed, direction, orientation, body mass and the shape of arthropods intercepting the radar beam. It can provide information of aerial migration of pests and natural enemies. It can be particularly useful for monitoring locust swarms. Radar entomology was first used in 1968 and since then comprehensive and intensive studies have been conducted in the UK, USA, Australia and China and it was predicted that fully automatic, season long and real time monitoring will be feasible with the vertical-looking radar (Zhai, 1999). Remote sensing technique relies on changes in the absorbance or reflectance of plants in response to pest attack. An instrument sensitive to specific wave lengths of radiation is used to detect such changes. Remote sensing in conjunction with '3S' technique can help in achieving three-dimensional real time visualization of insect pest populations (Wang et al. , 2003). Imagery provided by remote sensing satellites could be utilized in identifying pest affected areas and intensity of pest damage. This could be particularly useful for pests which produce visible symptoms of crop damage over large area for example hopper burn symptoms in paddy, blacking of cotton leaves caused by sooty moulds growing on honey dew secreted by aphid and whitefly, etc. Similarly, satellite data have also been used to identify areas of vegetation capable of supporting desert locusts. Further, such data can also find application in studying the effect of environmental changes on build-up, long distance migration and flight behaviour of air-borne pests.

18.11.3 Acoustic and other tools

Sensors which can detect the sounds of hidden insects like wood borers, termites, stored grains pests etc. are finding applications in the advanced countries. Similarly, portable X-Ray machines are being employed for detection of insects attacking forest trees.

18.11.4 Electronic nose

Electronic devices programmed for detecting particular odour or smell is being evaluated in Oregan state of USA. One of these devices, Cyranose 3201, a portable electronic nose, has shown good promise in determining stink bug damage by external properties. The volatile compounds given off by sink bugs were identified and E-nose was trained to identify stink bugs' (presence) smell prints. There was a strong correlation (R_2 = 0.95) between the number of stink bugs in a sample and the Cyranose sensor's response (Henderson *et al.*, 2006).

18.12 Summary

Seed treatment is a simplest and quicker method to manage pest and diseases of crops. Similarly, deep ploughing, soil sterilization, flooding etc. are also useful plant protection techniques for management of insect pests of crops without hampering the environment and compatible with other control techniques of IPM. Scanning Electron Microscopy (SEM) is useful technique for the investigation of surface structures of specimen whereas Transmission Electron Microscopy (TEM) techniques is useful for studies of cellular structures of the specimen at very high magnifications. Expert systems are computer programmes designed to mimic the thought and reasoning processes of human expert. SDS PAGE allows assessment of purity of the preparation, estimation of approximate quantity of the protein, and measurement of the size of the protein. PAGE is also used for studies of biodiversity analysis of insects, pest resistance studies, sex determination by differentiating protein component etc.

18.13 Glossary

- **Treated seed:** The term "treated" means "to give an application of a pesticide or subject seed to a process designed to reduce, control or repel disease organisms, insects, or other pests which attack the seed or seedlings."
- **Monochromatic radiation:** Electromagnetic radiation having all the waves of single wave length *i.e.* one coloured is known as 'monochromatic radiation'.

- **Electron Microscopy (EM)**: EM can be defined as a specialized field of science that employs the electron microscope as a tool and uses a beam of electrons to form an image of a specimen.
- **Plant quarantine**: It is a legal restriction of movement of plant materials between countries and between states within the country to prevent or to check introduction and spread of pests and diseases in areas where they do not exist.

18.14 Self Learning Exercise

Section –A (Very Short Answer Type)

1. ____________________makes soil completely clean and free from harmful soil microorganism, insect pests and weeds.
2. Legal restriction of movement of plant materials between countries and between states within the country to prevent or check introduction and spread of pests and diseases in areas where they do not exist is known as __________________.
3. Electron Microscope is operated in the vacuum and focuses the electron beam and magnifies images with the help of__________________________.
4. The first functional transmission electron microscope was developed in the early 1930s by __________________________.
5. ____________________have the ability to specifically measure absorbance at specific wavelengths.
6. PAGE stands for _____________________________.
7. Radar entomology was first used in year _______________.

Section –B (Short Answer Type)

1. Define seed treatment?
2. How flooding is useful in rice crop?
3. What are difference between TEM and SEM?
4. Explain Imaging Technologies?
5. Name the different content of running gel buffer?
6. What is the principle of PAGE?

7. What is electronic nose?

Section –C (Long Answer Type)

1. What are different techniques for insect pest management?
2. What is importance of seed treatment?
3. How cultural practices are useful for pest management?
4. How we use of computer application for pest prediction and forecasting?
5. How we use tissue culture techniques in plant protection?

Answer Key of Section-A

1. Soil sterilization
2. Plant quarantine
3. Electromagnetic lenses
4. Ruska
5. Spectrophotometers
6. Polyacrylamide gel electrophoresis
7. 1968

18.15 References

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Unit - 19

Innovative approaches in pest control

Structure of the Unit

19.1 Objective

After going through this unit you will be able to understand

- What are the innovative approaches to control pest population?
- Different types of methods used recently.
- All the methods are safer, biodegradable and eco-friendly.
- Advantages over pesticides.
- What are the problems regarding these techniques?

19.2 Introduction

There are many ways to control insect pest in Insect Pest Management like chemical control, mechanical control, physical control, cultural control, biological control and microbial control. With all these control methods stated above we are not in a condition to manage pest population below economic injury level. So, there is a need to grow more innovative approaches and techniques to fight against. Here in this unit several new methods are discussed which are now a day's included in Integrated Pest Management due to their species specificity, non hazardous techniques, non resistance properties and safe to human beings. Innovative approaches now formed foundation of modern insect control strategies.

19.3 Behavioral Control

19.3.1 Ethology is the study of animal behavior and how the animal reacts to specific stimulus.

Definition: Behavioral control is a method in which some chemicals are used to modify or stimulate the behavior of a pest and control them without harming or killing them.

19.3.2 Types of Behavior

Behaviors are of two type instinct and learned. Some common behavior seen in insects includes irritability (response to any stimulus), predatory, eusociality, mimicry, swarming, communicating behavior, parental care etc.

1. Mimicry

Mimicry is the close resemblance between one insect (the mimic) and another insect or a plant part (the model).

- Batesian mimicry (Bates, 1862): It is the palatable or harmless but is protected by virtue of its similarity to an unpalatable model, example Viceroy Butterfly (*Limenitis archippus*) which is a batesian mimic of monarch butterfly (*Danaus plexippus*).
- Mullerian mimicry (Müller, 1879): Mullerian mimicry differs from Batesian in that both mimic and model are un palatable.
- Wasmannian mimicry/Parasitic mimicry (Rettenmeyer, 1970): These insects live in close association with ants and closely resemble their host, example different types of ants that live together and are similar, and parasite resemble its host.

2. Crypsis

Crypsis refers to different form (Homotypism), color (Homochromism) and shape (Homomorphism) that make them resemble environment and not identified by predator. Example, industrial melanism (Kettlewell, 1959; Bishop and Cook, 1975) observed in the peppered moth, *Biston betularia* in England.

3. Aposematic / Warning Coloration

Blister beetles (Family: Meloidae) contains cantharidin in integuments that is a mucous member irritant which causes blisters. Bombardier beetle, *Brachinus* spp. secretes defensive secretion as explosive emission. The internal defensive reservoir contains hydroquinone and hydrogen peroxide. These chemicals when come in contact with cuticular chamber in presence of enzymes convert into quinine and oxygen which is visible as a cloud outside.

4. Epimeletic Behavior

Epimeletic behavioris is a behavior when an individual cares or helps another individual. Example bees, wasps.

Several species show a more advanced behavior of providing food resources as well as a **guarding behavior**. In the family Membracidae, females use aggressive guarding as well as an alarm pheromone that is emitted from an injured nymph. This communication from offspring to parent is another type of presocial behavior.

5. Social Behavior

Eusociality is a term used for social organization in social insects. The lowest level of social organization, presociality is classified using many related terms, including presocial, parasocial, subsocial, semisocial and quasisocial. Social insects, such as termites, ants, bees and wasps are the most common species of eusocial animal. They live together in large well organized colonies and genetically similar.

6. Swarm Behavior

In honey bee when a colony becomes overcrowded it is necessary to make more cells, therefore old queen with some workers move another place to make a new hive.

7. Orientation Behavior

Following are the common taxes:

- Geotaxis: Directed movement in respect to gravity, ants are positively geotaxic
- Anemotaxis: Movement in respect to wind direction or insects orienting to pheromones.
- Phototaxis: Many diurnal insects are positively phototactic
- Astrotaxis: Orienting towards sun or moon.
- Chemotaxis: Orientation towards taste or odor.
- Phonotaxis**:** Orientation in respect to sound.

8. Learning Behavior

Insect learns due to a region located in protocerebrum and in the *mushroom bodies.* In cockroach it is found in thoracic ganglia in cockroach and called ganglionic learning. Example, honeybees learn colors and various shapes, orientation flights, capture techniques.

9. Communication Behavior

The study of communications, between insects of same species for example, sounds of insects, language of honey bees, trails of ants, stinging behavior of bees. All these acts are called communication signals and are stereotyped. Most of the insects release an olfactory pheromone that are species specific and are received by olfactory organs.

19.3.3 Mode of action

No animal can live alone in planet as it requires specific responses, stimulus to act in a specific manner and behavior. Insects are also dependent upon each other for food, mating, reproduction and survival. It plays an important mechanism in an area wide control systems. Use of pheromones to confuse male and in trapping them is also a field of interest now a days. For example, *Pectinophora gossypiella, Cydia pomonella,* and *Eupocellis ambiquella* are controlled by this innovative approach. Along with pheromones, attractants, antifeedants, repellants are also used to alter or modify insect plant interactions.

Some insect's shows color preferences, volatile chemicals, auditory stimulus, olfactory stimulus and visual orientations. These behaviors are being successfully used to control insect pest population. Mostly females act only as signalers and the males as receivers. The chemical substance secreted by the female acts as olfactory stimuli for the male.

Automeris moth (peacock butterfly) beautifully shows its behavior called flash pattern in offense and defense. Its forewings have no eyespots but on hindwing large eyes like structure are present. When the moth is disturbed it readily expose its hindwing to protect itself (FIG 19.1).

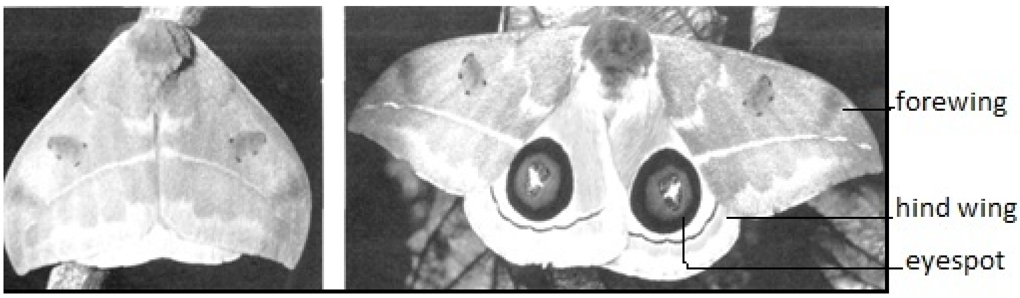

FIG19.1 : *Automeris* moth in resting position with and after being disturbed.

Aggregation pheromones are the chemicals which stimulates group of individuals to move together at the same place for food, defense in mass attack and overcoming host resistance. It can comprise one sex or both sexes on the basis of insect type. The stored grain pest weevils, *Sitophilus zeamais* (L.), *Sitophilus granaries* (L.) and *Sitophilus oryzae* (L.) infest a variety of food like corn, wheat, rice, sorghum etc. and releases aggregation pheromones to signal other individuals. So by mixing aggregation pheromones with bait weevils can be easily trapped. Likewise bean weevil, *Sitonia lineatus* (L.) secrete aggregation pheromone 4-methyl-3,5-heptanoid which has been utilized in mass trapping of weevils.

19.3.4 Advantages

1. Low dose is sufficient to trap the insect.
2. Species specific, ecofriendly.
3. New approach to control insect
4. Time saving technique.
5. It is commercially available

19.3.5 Disadvantages

1. The insect must respond effectively.
2. The behavior modifying agent must be fully identified.
3. It is expensive to made and need sophisticated understanding.
4. Must protect parasites and predators.

19.4 Pheromones

19.4.1 Definition

The term *pheromone* was introduced by Peter Karlson and Martin Lüscher (1959) and is based on the Greek word *pherein* (to transport or to carry) and *hormon* (to stimulate or to excite) is a chemical that triggers a natural behavioral response in another member of the same species. In other words Pheromones or ectohormones we can say that chemicals secreted into external environment by an insect or animal which elicit specific reaction in a receiving individual of the same species.

Their behavior among insects has been particularly well known, although many animals, chordates and plants also communicate using pheromones. Pheromones define a way that enables an insect to communicate with other members of its own species. Knipling and Viroza were first to identify, extracted, synthesized artificial pheromones. Among the insect orders it is observed in orthoptera, heteroptera, diptera, isoptera, neuroptera, siphonoptera, coleoptera, hymenoptera and Lepidoptera (FIG 19.2). Knipling observed in *Periplaneta americana* (cockroach), *Pectinophora gossypiella* (cotton pink boll worm), *Carpocaspa domorella* (codling moth), cucumber beetle, tobacco hornworm, cabbage hoppers etc.

19.4.2 Properties

1. They are called ectohormones as they are secreted by exocrine glands.
2. It may be volatile or non volatile.
3. They are species specific and also sex specific.
4. It can be artificially synthesized.

19.4.3 Types of Pheromones

There are alarm pheromones, food trail pheromones, sex pheromones, and many others that affect behavior or physiology.

a) Based on sense organ influenced it can be
   i. Olfactory acting pheromones
   ii. Orally acting pheromones
b) According to the response it can be categorized into
   i. Releaser substances: Those chemicals that produces an immediate change in the behavior of the recipient.
   ii. Primer substances: Those chemicals which trigger off a chain of physiological changes in recipient without any immediate change in behavior.
c) On the basis of biological functions:

i. Sex Pheromones (Aphrodisiaces)

In insects sex pheromones indicate the availability of the female for mating. Male insects may also secrete pheromones that convey signals or message to their partners. Many insect species release sex pheromones to attract a mate and many Lepidopterans can detect a potential mate from as far away as 10 km (6.2 miles). Pheromones can be used in gametes to trail the opposite sex's gametes for fertilization. Male and female communicate to locate each other. Sex attractants pheromones used to locate mate from a distance (eg. *Bombyx mori* secretes bombykol, musculure from *Musca domestica*) followed by courtship pheromones used before mating (male cockroach secretes seducin). It is retricted to one sex only mostly females but in Lepidopterans and Mecopterans males are the releasers. Butterfly *Danus gilippus* have several abdominal hairs that acts as pencils which produces pheromones ,dusted on antenna of male while both are flying. Female then folds her wings and allows copulation. This pheromone is named as danaidone which is a pyrrolizidine alkaloid.

ii. Trail Pheromones

These pheromones are common in social insects. For example, ants mark their paths with these pheromones to communicate their members for food finding which are basically non volatile hydrocarbons. *Dolichoderine* ants synthesize pheromones in their pavan's gland, *Solenopsis* fireants in dufour's gland and *Myrmicinae* ants in poison glands. In termites trail pheromone is secreted by sternal gland located on 5^{th} abdominal segment. Example *Zootermopsis* secretes caproic acid.

Some of the ants secretes initial trail of pheromones as they return to the nest with good quality of food. This trail attracts other members of ants and serves as a path to reach the goal. If the food source remains sufficient, the pheromone trail will be continually renewed because it evaporates quickly. When the supply of food declines, the trail making ceases.

In case of scout bees of *Melipona* species produces a series of droplets by mandibular secretion at specific intervals on pathway on vegetation.

iii. Alarm/Alerting Pheromones

Some individual of species release a volatile substance if attacked by a predator and trigger flight (in aphids) or aggression (in bees) in members of the same species. This behavior is commonly seen in Hymenoptera and Isoptera and appears to be chemical releasers for social behavior.

If the ant is disturbed, it releases a pheromone that can be detected by other members from several centimeters away. As they get nearer to their disturbed nest mate, their response changes to one of alarm. The higher concentration causes them to run about as they work to remedy the disturbance. It is provoked by the presence of predators as in *Pogonomyrmex badius* these pheromones behave as attractants in low concentration and as alarm pheromone in high concentration. Once the emergency is over, the ants return quietly to their previous work.

Honeybees also have an alarm pheromone eg. *Melipona* stingless bees and *Trigona* bees secrete citral pheromone and formicine ants secrete undecane. The workers of *Coromyrma pyramica* produces alarm pheromone 2-heptanone.

Honey bees' leaves traces of isoamyl acetate at sting region to induce other bees to sting on it.

iv. Queen Mandibular Pheromone

Honeybee queens show their presence to worker bees by secreting pheromone 9-hydroxy-decinoic acid or 9-oxodecenoic acid from her mandibular glands. The pheromone is a mixture of alcohols and organic acids. The pheromone is essential for

- inducing the workers to feed and groom her;
- maintains colony by realizing the presence of queen;
- prevent the workers from building large queen cells and rearing new queens;
- Suppresses ovary development in the workers.

v. Aggregation Pheromones

The chemicals are secreted by conspecific insects of both sexes to secure themselves from predators, maximum utilization of food source, and attraction of social insects and to mate. They are produced by one or the other sex; these pheromones attract individuals of both sexes. Examples bark beetles and *Ambrosia* beetle (Scotylinae).

vi. Territorial Pheromones (Area Making Pheromone)

These pheromones are laid down in the environment and mark the boundaries of an organism's territory. In dogs, these hormones are present in the urine, which they deposit on landmarks serving to mark the perimeter of the claimed territory. Example male bumble bee secretes 2, 3-dihydro-6-trans farnesol by its mandibular gland to mark their territory sites.

vii. Epideictic Pheromones

These pheromones are not so common in insects but they are not confused with territory pheromones. According to Fabre, those females who lay their eggs in these fruits deposit these mysterious substances in the vicinity of their clutch to signal to other females of the same species so that they will clutch elsewhere.

viii. Spacing pheromones

These are produced by some immature and adults that may be tactile or olfactory, may release to oviposition. *Rhagoletis pomonella* (apple maggot fly) females produces these chemicals to deter oviposition by other females. *Oecophylla longinoda* (African weaver ant) secretes for even dispersal of colonies. *Pieris brassica* larva secretes to inhibit egg laying of adult females in same place.

ix. Caste regulating pheromone

Several caste differentiations is regulated by corpora allata/ Juvenile hormone that acts as pheromones in termites.

d) On the basis of advantages or disadvantages

   i. **Semiochemicals:** The word is derived from a Greek word *simeon* = signal given by Law and Regnier (1971). These are chemicals communicating between individuals of the same species, example pheromones.

   ii. **Allelochemicals:** The word is given by Whittaker (1970). These are chemicals communicating between individuals of the different species.

- **Allomones (+, 0):** A compound released by one organism which evokes a reaction in an individual of a different species that is favorable to the emitter and not to the receiver, example chemicals produced by a plant to prove itself distasteful, repellants, antifeedants, toxicants comes under this category.
- **Kairomones (0, +):** A compound released by one organism which evokes a response beneficial to a member of another species but not to the emitter, example *Ponderosa* pine tree produces myrecene when damaged by Western pine beetle which acts as a synergist with aggregation pheromone to attracts more beetles. Also Dead elm tree weakened by fungus *Ceratocystis ulmi* produces α-cubebene and attracts elm bark beetle (*Scolytus* spp.). Attractants, arrestants, excitants and stimulants comes under this division.

- **Synomones (+, +):** A substance released by organisms which benefits both, the sender and receiver, example, α-pinene and myrecene produced by damaged pine for beetle to attract parasitoid pteromalid hymneopteran. Alpha-cubebene produced by Dutch elm fungus is synomone for braconid hymenopteran parasitoid of elm bark beetle.
- **Antimones (-, -):** A substance produced by an organism when it contacts an individual of another species in the natural context evokes in the receiver a behavioural or physiological reaction that is maladaptive to both the emitter and the receiver. Example, trichome of some wild *Nicotiana* species contains nicotine, nicotine alkaloid known to be toxic to a variety of insects including parasitoids of tobacco herbivores.
- **Apneumones:** A chemical released by nonliving substance that is beneficial to the receiver but detrimental to other organism in the substance.

19.4.4 Insect control

1. Pheromones can be used in Insect Control Programmes for survey work, to study behavior, distribution, abundance of pest.
2. Sexual behavior may be stimulated or completely inhibited.
3. Pheromones traps are made to catch insect and are useful in population peaks or egg hatching times applied in codling moth, pink bollworm, black cutworm.
4. Pheromones may bring insects at a place where they may be killed by odorless insecticides mostly applied on field crops, forest crops.
5. Main reproductive forms can be attracted with synthetic pheromones and population bring below injury level. Example, sex pheromone of pink bollworm named gossyplure (10-propyl-trans-5,9,tridecadinel acetate) used to control its population.

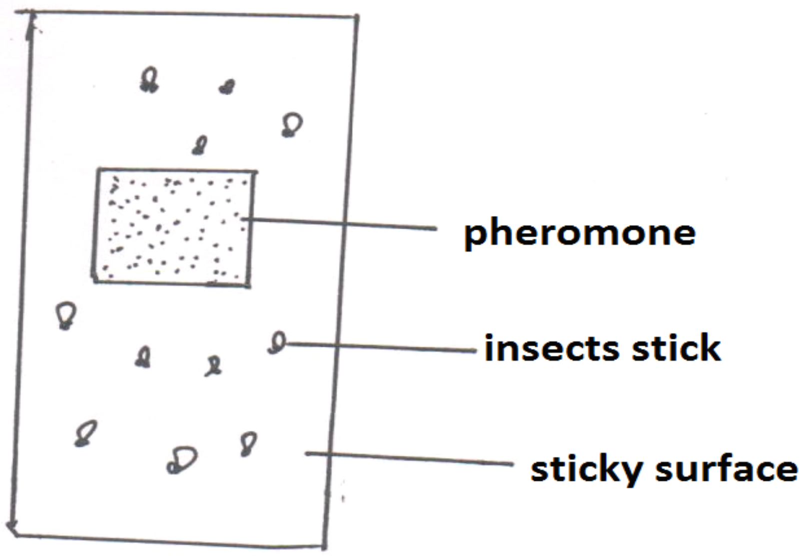

FIG 19.2: Pheromonal control

19.4.5 Advantages:

1. There is no residual effect.
2. Do not affect non target species.
3. No health hazards and no development of resistance.
4. It is highly specific.
5. They are effective in low concentration.

19.4.6 Disadvantages:

1. In some cases like alarm pheromones are required in large amount.
2. Effective in short distances.
3. They are short lived and disappear with time.
4. Sometimes several correlated species shows cross specificity.

19.5 Hormonal control

19.5.1 Definition

The word hormone was given by C. M. Williams and it is also called third generation pesticide/ Insect Growth Regulators (IGR). These are the chemicals which are secreted by endocrine glands and its function is to regulate internal environment of body.

19.5.2 Types of insect hormones and their associated glands

1. Brain Hormone and Neurosecretory cells

Neurosecretory cells of the brain and ganglions (pars intercerebralis of protocerebum) secrete hormone called brain hormone peptide in nature and are stored in neuro-haemal organs and bind to the protein molecules (carrier) named neurophysin. Neuro-haemal organs on stimulation releases neurohormone which diffuses into the blood, and activate other endocrine gland. Brain hormones directly or indirectly control all the life processes of insect. Brain hormone stimulates feeding in blood sucking bug *Rhodnius* and stretch receptor in pharyngeal wall in grasshopper and locust.

2. Prothoracicotropic Hormone (PTTH)/ Ecdysone and Ecdysial gland/ Prothoracic gland

Moulting a process when the cuticle is shed and larva converts into next larval satge and pupation a process when last larval stage pepare itself for next stage pupa. Both the moulting and pupation require the hormone, PTTH, secreted by a two prothoracic glands. These two prothoracic glands/ecdysial gland are ectodermal in origin and are located in the ventrolateral areas of prothorax. It is also associated with lateral longitudinal tracheal trunks and absent in apterygotes (wingless insects). Under the influence of PTTH, they secrete the steroid hormone ecdysone also known as moulting hormone. Moulting hormones are of two types : α-ecdysone and β-ecdysone (FIG 19.4). PTTH trigger every moult, larva to larva as well as pupa to adult. It maintains the changes during metamorphosis.

If these glands are cut out in a full grown larva, pupation does not takes place. And if transplanted somewhere else in the larval body, pupation occurs normally. PTTH is a homo-dimer of two polypeptides of 109 amino acids originated from protocerebrum targeted to ecdysial gland for ecdysone production. PTTH does not drive pupation directly but, as its name suggests, acts on the prothoracic glands. Ecdysone secreted by ecdysial gland target to epidermis for shedding the cuticle (FIG 19.3).

Insects have rigid exoskeleton and can grow only by periodically shedding their exoskeleton called moulting. Moulting occurs repeatedly during larval development. At the final moult, the adult emerges or in some insects via pupa adults emerges. In several insect orders, the adult looks entirely different from the larval and pupal stages.

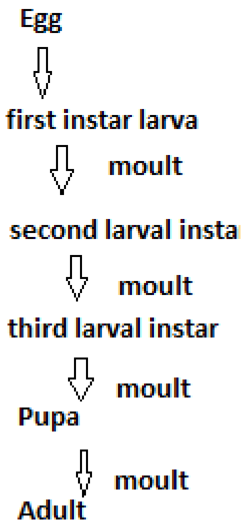

FIG. 19.3 : Moulting hormone in insect.

This marked conversion of larva and larva to pupa is called metamorphosis.

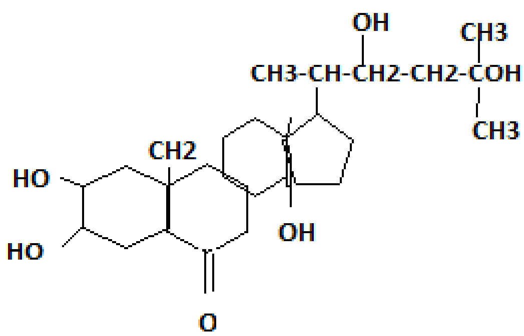

FIG 19.4: Molecular structure of ecdysone

3. Juvenile Hormone (JH)/ Neotenin and corpora allata

Juvenile hormone (FIG 19.5) is secreted by two small glandular bodies named corpora allata present on either side of corpora cardiac on sides of the esophagus. They are non sterolic compound generally terpenoid. These are mostly paired but they are single in Dermeptera and Heteroptera order.

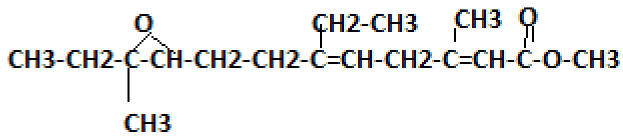

FIG 19.5 : Molecular structure of juvenile hormone.

JH target fat body, accessory reproductive glands and follicle cells. Its function to control metamorphosis that it maintains larval stages. It is responsible for yolk deposition of in eggs, egg maturation, vitellogenin production and tanning of cuticle. They are also involved in green brown polymorphism in locust. And sometimes it is noted that mating behavior in social insects are due to neotenin. As long as there is much amount of JH, ecdysone promotes larva to larva molts. As the amounts lowers, ecdysone promotes pupation. Complete absence of JH results in formation of the adult. Therefore, if the corpora allata are removed from an immature silkworm, it immediately spins a cocoon and becomes a small pupa. A miniature adult eventually emerges. On the contrary, if the corpora allata of a young silkworm are place in the body of a fully mature larva, metamorphosis does not occur. The next molt produces an extra large caterpillar.

4. Corpora cardiaca gland

It acts as a neurohaemal organ lying behind the brain on dorsal part of foregut associated with cephalic aorta. It is absent in Collembola. It regulates the heart beat, oxygen consumption and affects respiratory metabolism. In male cockroach copulation movement depends upon this gland and its secretion.

5. Weismann's Ring/ Ring gland

Endocrine glands like corpus cardiacum, corpora allata, prothoracic gland and hypocerebral galglion form a ring like structure in maggot stages of house fly, flesh fly, blow fly.

6. **Other hormones**

- Bursicon/ tanning hormone: secreted by brain of moths target to abdominal ganglion and regulate synchronization of eclosion with photoperiod.
- Diuretic hormone: secreted by thoracic glands target to malphigian tubules and regulates diuresis.

- Mating inhibition hormone: originated from accessory reproductive gland of males target to brain and prevents remating.
- Oviposition inhibiting hormone: originated from accessory reproductive gland of females target to oviduct and initiate oviposition.
- Cardioaccelerator hormone: secreted by brain or corpora cardiaca target to myocardium and regulate muscle contraction.
- Proctolin: secreted by corpora cardiaca target to hindgut, heart, oviduct and regulate muscle contraction, defecation, oviposition and heart beat.
- Eclosion hormone: originated from median neurosecretory cells (MNSC) in several moths causes ecdysis/ eclosion of pupa to adult.

19.5.3 Insect Growth Regulators (Igrs)/ Hormone Mimics

Definition: Insect Growth Regulators (IGR) are the chemicals which can be synthesized and mimics to natural hormones. These are also known as third generation pesticides. They can interrupt the life cycle of insect by our own will.

First of all Wigglesworth performed experiment to control insect growth by using hormones. Williams (1956) suggested that juvenile hormones could be accurately identified, then synthesized and used as insecticides. His prospects have been achieved since several commercial compounds called insect growth regulators or IGRs, have been used in insect pest control for more than 25 years. Slama and William discover "paper factor" named juvabion extracted from North American trees such as balsam fir, *Abies balsamea*. This plant is usually used to prepare paper therefore named paper factor. Now it is also being used to control insect as its components mimic's juvenile hormones. These insecticides of the third generation appeared after the first generation pesticides including arsenates like inorganic compounds and the second generation pesticides of organic synthetic compounds such as DDT.

19.5.4 Mode of Action

Insect Growth Regulators (IGRs) are one of the fastest growing chemical groups of insecticides in the past few years. They are considered a reduced risk pesticide because they are soft on beneficial insects and primarily are target specific for juvenile stages. This product does not affect insect nervous system like other insecticides, therefore more eco-friendly and have minimal exposure to dermal inhalation. They can be foliar, mixed with soil and used alone or in combination with adulticide. The mode of action of IGRs is quite simple as they are not stomach poisons and only disturb moulting process in larva. If the insect do not reach its adulthood it is incapable to reproduce. This can control the infestation made by adult insects. The IGRs may be hormonal, enzymatic and chitin synthesis inhibitor. It inhibits metamorphosis by blocking the maturation of imaginal disc which is a primordial of many integumentary structures in holometabolous insects. Imaginal disc occurs in larva as tiny sacs of epithelial cells that directly come from embryo. Example In Lepidoptera imaginal wing disc present in larva gives pupal and adult wings. As the concentration of JH reduces rapid morphogenesis of imaginal disc occurs and wings develop. JHA prevents this morphogenesis and cuticle synthesis of disc.

For an insect to develop and moult into next stage, the correct ratio of juvenile hormone and ecdysone is required is important. If the dose of 0.001 mg of JHA is applied to last instar larva it inhibits to metamorphose into adult in *Pyrrhocoris apterous*. One gram of crude extract of balsam fir tree is sufficient to kill 100 million bugs, 0.1 mg of JHA act as ovicide and sterilize the adult female.

Ecdysone is a moulting hormone that is necessary for insects to develop from the larval to pupal stage. It affects the insect at all stages from newly hatched to adult. Beta ecdysone in 25 gm dose converts pupa into pupa stage and adult is not formed. It can be applied as solvent as it penetrate the skin and as fumigant.

Phytoecdysone, Bracken fern, Cyastrone, Piperonyl butaoxide (PBO) are ecdysone analogue that causes diapause in many insects. The dose of 0.2 microgram of cyastrone causes diapause in *Cynthia* (moth) pupa and 10 microgram leads to death of pupa. These ecdysone activity substances are found in many vascular plants account for 1% dry weight of certain plant tissue

IGRs	Mechanism	Positive	Negative	common name/trade name	Insect control
JH mimics/	interferes moulting	Decreases no. of	correct timing is	Methoprene/altosid,	Flies, mosquito,be

analogues	process, deformed wings and reproductive parts,. produce infertile eggs	generations so compatible with beneficials.	essential to affect juvenile insects, unstabile in UV light	Kinoprene/ enstar, Hydroprene/ Gencor, Juvabione, Juvadecene	etle, moth, bugs Aphids, whiteflies, cockroach
JH antagonist/ inhibitor	Precocious metamorphosis of immature stages, female sterilization,	Shortens the life cycle	Effective only when endogenous JH of insect is low	Precocene -I and precocene-II, compactin	Milkweed bug
Ecdysone mimics/ analogues	Hormonal imbalance, results in moulting promotion and death	Several sps. Of pteridophytes, gymnospermae, angiospermae posssess ecdysone mimics	-	Cyasterone, PBO, Phytoecdysone (Berken fern), ecdysterone	*Cynthia* moth, *Plodia interpunctella*
Ecdysone inhibitor	Blocks ecdysone which signals the insect to molt. This causes	More broad spectrum than JHM,affect both larvae and pupae, also deters	May require the addition of horticultural oil	Azatin- azadirachtin Ornazin- azadirachtin Ajugarin plant, plumbagin	thrips, aphids, scales, whitefly, fungus gnats, shore

	pupae to die	feeding in some insects.	to be most efficient		flies, mealybugs,
Chitin synthesis inhibitor	Inhibit chitin synthesis, larva die due to malformation of cuticle	Most stable compound	Can negatively affect predaceous insects as well as arthropods and some fish.	Diflubenzuron / Dimilin, Citation-cyromazine	thrips, gypsy moth whitefly, boll weaver, cotton strainer, caterpillars, leafminers gnats Citation-leafminers

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- *Precocene- It is the newly discovered compound and also called IV generation insecticide. Precocene I and Precocene II are 7-methoxy,2,2-dimethyl chromene and 6,7-dimethoxy,2,2-dimethyl chromene.*
- Brain hormone mimics- proctolin against cockroach, isolated by Starratt and Brown.
- Novel non steroidal IGR is RH 5849 rich in ecdysone mimics in Lepidoptera.
- Sclerotization disruptors- DDC against blowfly, cyromazine against housefly, *Leucilia*.
- Sterol utilization inhibitors- β-sitosterol, azasterols.

19.5.5 Advantages

1. It is specific, non polluting and has no residual effect.
2. It can be used as fumigants as well as solvents as it can penetrate into cuticle.

3. It acts directly on target cell and widespread as found in plant sources.
4. It does not require mediation of any specialized organ.
5. Has a significant role in embryonic development of the insect.
6. Can terminate diapauses when host is not available.
7. It can brought development in wrong season thus committing ecological suicide.

19.5.6 *Disadvantages*

1. It is time consuming.
2. The proper life cycle and time of application must be known well.

19.6 Insect repellants

19.6.1 Definition

An insect repellent are probably the substance or chemicals that can be applied to skin, clothing, or other any other surfaces which discourages the insects from landing or climbing on that surface. In short the chemical substances that repel away the insects.

19.6.2 Properties

1. The repellent exhibits the nature of negative chemotropism.
2. They must be volatile in nature.
3. It depends upon where it is applied and if applied to skin whether it is diluted or not by perspiration, to be oxidized, hydrolyzed or removal by abrasion. Thus the skin is protected from the insects for few hours.
4. It depends on whether the clothing may retain these repellants for few hours, days or weeks.
5. Mostly these are used against blood sucking insects, crawling insects, egg laying insects.
6. They must not be confused with anti-feedants as it causes directed movements away from the source.
7. It works by stimulating chemo-receptors, olfactory receptors or gustatory receptors.

19.6.3 Types of repellants

1. Physical repellants: It can be simply by water barriers, oil bands around tree trunks.
2. Chemical repellants: That is being chemically synthesized.
3. Natural repellants: there are some plants that repel insects naturally.

4. Synthetic repellants: Those which can be made of chemicals, botanicals, or mixture of products.

There are also insect repellent products which are based on sound production, particularly the ultrasounds that means that high frequency sounds which is inaudible to insects. These electronic devices have been shown to have no effect as a mosquito repellent by studies done by many researchers and scientists. Insect repellants help prevent and control the outbreak of insect-borne diseases such as malaria, chikunguinya, Lyme disease, Dengue fever, yellow fever, bubonic plague, kala azar, West Nile fever etc. Pest animals commonly serving as vectors for disease include the insect's flea, fly, mosquito, arachnid tick, mites, louse and many more.

19.6.4 The common insect repellants include:

1. DEET (*N*, *N*-diethyl-*m*-toluamide). It is most widely used and considered to be the best repellent having LD50 2000mg/kg of rat. It is a most effective repellants against mosquitoes, ticks and other biting insects. It is used by USDA and US military soldiers.
2. Essential oil of citronella (extracted from *Andropogon sps.*), the lemon leaves, eucalyptus (*Corymbia citriodora*), peppermint, lavender, cedar wood oil etc are commercially used to prepare repellants.

   Insect Repellants from Natural Sources: There are many botanicals from which naturally occurring sources are extracted that act as a repellent to certain insects. Some of these act as insecticides while others are only repellent.

- *Achillea alpina* , Carvacrol , alpha-terpinene of some plants, Castor oil (*Ricinus communis*), Catnip oil (*Nepeta* species), Celery extract (*Apium graveolens*)- an extract of celery was demonstrated to be at least equally effective to 25% DEET, Clove oil, Fennel oil (*Foeniculum vulgare*), Peppermint (*Mentha*x *piperita*), Rosemary (*Rosmarinus officinalis*) are used against mosquitoes.
- Camphor, Cedar oil against mosquitoes, moths.
- Eucalyptus oil /cineol against mosquitoes, flies, dust mites.
- Garlic (*Allium sativum*) against rice weevil, wheat flour beetle or other stored grain insects.

- Geranium oil (*Pelargonium graveolens*), Lavender, Lemongrass oil (*Cymbopogon* species), Marigolds (*Tagetes* species) against many insects.
- Marjoram against spider mites *Tetranychus urticae* and *Eutetranychus orientalis*.
- Neem oil (*Azadirachta indica*) which has many properties is also a natural repellent.
- Oleic acid repels bees and ants by simulating the "Smell of death" produced by their decomposing corpses. It is a 400 million years old natural mechanism helping to sanitize the hives or to escape predators.
- Pennyroyal (*Mentha pulegium*) against fleas but it is very much toxic to pets.
- Pyrethrum (*Chrysanthemum* species, particularly *C. cinerariifolium* and *C. coccineum*) which actually causes the knock down effect in mosquitoes.
- Spanish Flag *Lantana camara* against Tea Mosquito Bug, *Helopeltis theivora*.

3. Bordeaux mixture: It is the first synthetic chemical repellent which is made by the combination of 2.5 kg $CuSO_4$,+2.5 kg hydrated lime+250 L water. It is used against fleas, beetles and leaf hoppers. The sprayed plants become distasteful, can be acts stomach poison for chewing insects.
4. MGK-326 is found to be best for repelling flies, gnats and is needed only in small amount.
5. MGK-11 is repellent against cockroaches and house hold insects.
6. PDB/ paradichlorobenzene and napthalene against cloth moths.
7. Pentaflurophenol against termites.
8. Coal tar/ creosote/ 4,6- Dinitro-O- cresol it's a derivative of napthalene and carbolic acid repels cloth moth, bugs, flies, beetles, termites.
9. Tetramethylthiurea disulphide against foliage beetles.
10. Mixture of benzyl benzoate, butylacetanilide, 2-butyl-2-ethyl-1,3-propanediol against mosquitoes, fleas, ticks, chiggers.
11. Butoxy polypropylene glycol is a suitable repellent for livestock protection.

19.6.5 Groups of repellants:

1. For crawling insects: usually consist of repellent barrier between insect and food. For example creosote against chinch bugs.
2. For feeding insects: it repel insect from feeding by blocking the attractants to which pest species responds. Ex. -DEET
3. For egg laying insects: Like pine tar oil and diphenyl amine used to repel screw worm flies to lay eggs.

19.6.6 Effectiveness of Repellent

Synthetic repellants are comparatively to be more effective, longer lasting than botanicals as repellants. In comparative studies, IR3535 was as better as and more efficient than DEET in protection against mosquitoes. Essential oils are actually short-lived in their effectiveness as essential oils are volatile in nature. All the commercially synthesized products gave almost 100% repellency for the first 2 hours, whereas the natural repellent products were most effective for the first 30-60 minutes, and required to apply again and again.

Permethrin is recommended for clothing, gear, or bed nets. On the contrary oil of lemon eucalyptus is more effective than other plant-based treatments, with a similar effectiveness to low concentrations of DEET. Neem oil is best mosquito repellent for up to 12 hours since years ago.

Anyway several repellent products are used by people but, it is recommended that the label is read before use and directions are carefully followed. Usage instructions for repellants vary from country to country. Some insect repellants are not recommended for use on younger children.

19.6.7 Advantages

1. It is safe to use.
2. It is non-toxic to man.
3. It is not unpleasant to use.
4. It can be used as spray by making synergist with pyrethrins.
5. Insects do not eat and die due to starvation.
6. It can be safely used on skin and most fabrics.
7. It is economic and not time consuming.

19.6.8 Disadvantages

1. Its efficiency depends on ability to deter greatest number of species from feeding for longest period.
2. All kinds of insects cannot be repelled by the same chemical.
3. It does not kill the insect if it is required.
4. Insects able to return to their normal activities if repellent is lost as the repellants are active only for a short period.
5. They are required in large amount like 20-40mg/cm2 of skin.
6. They are oily in nature and have disagreeable odor.
7. They may damage plastics and painted surface.

19.7 Insect attractants

19.7.1 Definition

These are the chemicals towards which the insect makes oriented movements. Thuron Industry made poison bait containing a fly attractant Muscemone which is the first insecticidal product that has attractant component.

19.7.2 Properties

1. The attractants influence the insect from a distance therefore these are also volatile.
2. Insect attractants and traps are useful asset to monitor insect populations to determine the need for control.
3. These substances are olfactory stimulus.
4. The nature of attractants can be chemical, pheromonal, sound waves, visual or light waves.
5. The insect responds to attractants because of reasons like if there is a need of searching the food, for oviposition, for mating and locating the opposite sex.
6. It must be sticky material.
7. Mostly males are attracted towards the attractants.
8. All these attractants are mixed with food to make poison baits, trap baits or specially designed traps.

In some instances, attractants and traps are the direct way to control insect population by trapping the insect in mass population or mating disruption. It can also improve the effectiveness of insecticide applications as we can find out the population left after the controlling measure and sometimes it proves that the present controlling practice is of less use and reduce the use of broad-spectrum, more toxic compounds.

Because these attractants are eco-friendly as they do not injure other animals or humans or result in residues on foods or feeds, they can be used in environmentally non disturbing agents in Integrated Pest Management (IPM) programs. The effective use of attractants and traps requires knowledge of basic biological principles and the pest- or crop-specific details involved in individual applications. The substances possess attractants are sugar molasses, yeast extracts, singlure (sec-butyl-6-methyl-3-cyclohexane-1-carboxylate), amyl acetate, trimedlure (t-butyl-4-chloro-2-methyl cyclohexane carboxylate), ethyl alcohol and Q-lure.

19.7.3 Types of Atttractants:

1. **Chemical Attractants**

Insects use many different semio-chemicals which are the chemicals that convey messages between organisms. (The Greek word *semeio* = sign.) Chemicals that act as attractants or carry other messages across distances are quick to evaporate i.e volatile compounds. When chemical attractants get released into the air, they can be detected by insects (those receptive to a specific compound) a few inches to hundreds of yards away. Chemicals that carry messages over considerable distances are most often used in pest management.

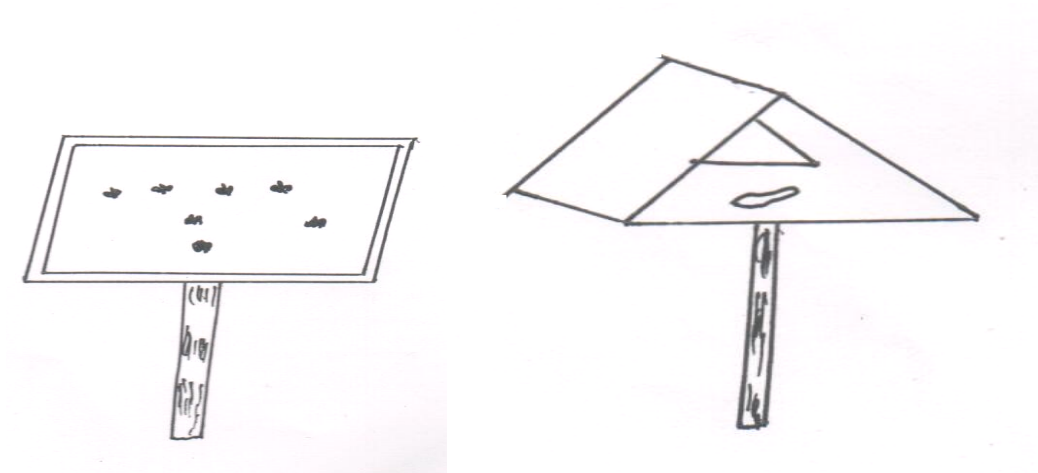
Practical use of pheromones or feeding attractants for pest management usually requires that specific active chemicals be isolated, identified, and produced synthetically. The synthetic attractants usually copies of sex or aggregation pheromones or feeding attractants are used in any of four ways previously described as a lure in traps used to monitor pest populations; as a lure in traps designed to trap out a pest population; as a broadcast signal intended to disrupt insect mating; or as an attractant in a bait containing an insecticide.

2. **Attractant Baited Traps**

The most common use of attractants is in traps to monitor insect populations. Although not all of the compounds used in this manner are pheromones, many publications refer to all attractant baited traps as pheromone traps. In monitoring or surveillance chemical attractants usually are impregnated/

encased/ covered in a rubber or plastic lure that slowly releases the active component(s) over a period of several days or weeks. Traps containing these lures are constructed of paper, plastic, or other materials. Most traps use an adhesive coated surface or a funnel-shaped entrance to capture the target insect so that once captured don't fly outside.

Attractant baited traps are used instead of other sampling methods because of two major reasons. Firstly, these traps are very sensitive and may capture pest that are present at very low density to detect. It is used as an important technique if we have to detect foreign or exotic pests (an immigrant pest that's not previously known to inhabit a region, state or country) as soon as they enter in an area so that control measures can be started immediately. Secondly, traps baited with chemical attractants capture only targeted species or a narrow range of species (FIG 19.6). Sensitivity and specificity make these attractant baited traps more efficient and labor saving tools. It also detects first emergence or peak flight activity of a pest species in a given area, often to time an insecticide application or to signal the need for additional scouting.



A) B)

FIG 19.6: A)**Pheromone traps and yellow sticky traps with high effectiveness B) phermonal trap**

The addition of attractants to many types of bait will attract large numbers of specific insects. Baited pitfall traps are generally common collecting devices. The bait is (FIG 19.7) placed at the bottom of the collecting device which is covered with a screen, or it is suspended into or over the trap. Dead animals, rotting foods and dry cereals are considered to be as good baits for various crawling insects. One type of pitfall trap is made from a cereal bowl filled with 70% ethanol and sunk into the ground. The bait is suspended in a small cup over the trap, supported by a mesh wire coat. Once the insect get into the bowl it is unable to escape.

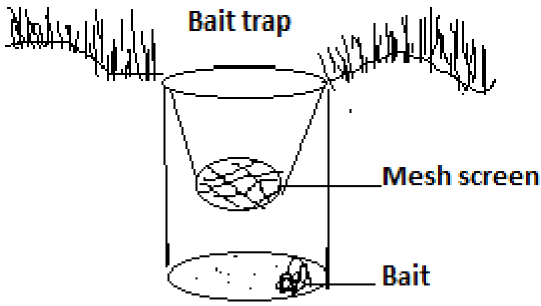
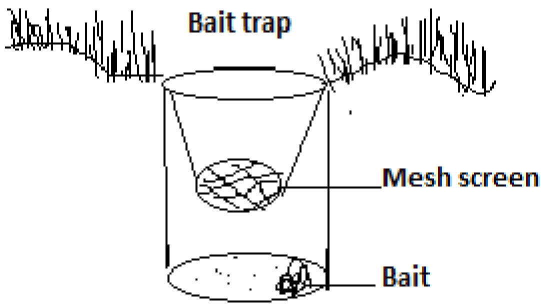
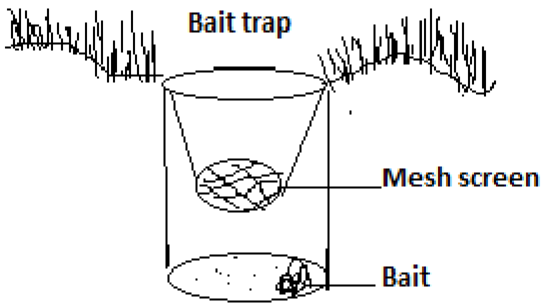
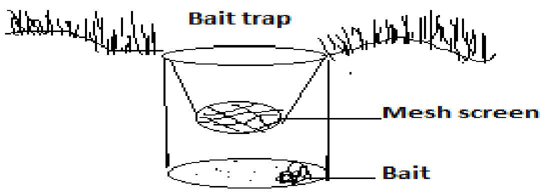


FIG. 19.7: Bait trap.







3. Visual attractants

Specific colors behave as attractive to some insects. For example, yellow objects attract many insects and are often used in traps designed to capture winged aphids and adult whiteflies. Red spheres and yellow cards attract apple maggot flies. Like other attractants, colored objects can be used in traps for monitoring or mass trapping. Yellow plastic tubs filled with water, for example, are used to monitor the flights of aphids in crops where these insects are important vectors of plant viruses. Aphids attracted to the yellow tub land on the water and are unable to escape. Yellow color sticky coated cards/ plastic cups/ or any other material are widely used in mass trapping programs to help control whiteflies in greenhouses. Although recommended trap densities in greenhouses are based on studies involving only a few crops, recommendations of 1 trap per 5 square yards or 1 trap every 3 to 4 feet along benches are common. Almost all the visual traps are made by knowing the biology and food of specific insect. Therefore these generally control the flying pest more easily and quickly than the larval stages or other crawling insects.

4. Barrier attractant Traps

When insects hit a barrier having attractants in their flight path, they will either fly upward or drop downwards. Barrier traps (FIG 19.8) placed in flyways rely on such behaviors to capture flying insects. One simple barrier trap is the window pane trap, which consists of a piece of clear glass or plastic with a shallow trough filled with 70% ethanol attached at the bottom. When the trap is hung across a path, in a flyway, or at the edge of the woods, flying insects crash into it. Those that drop after hitting the glass fall into the trough and are killed.

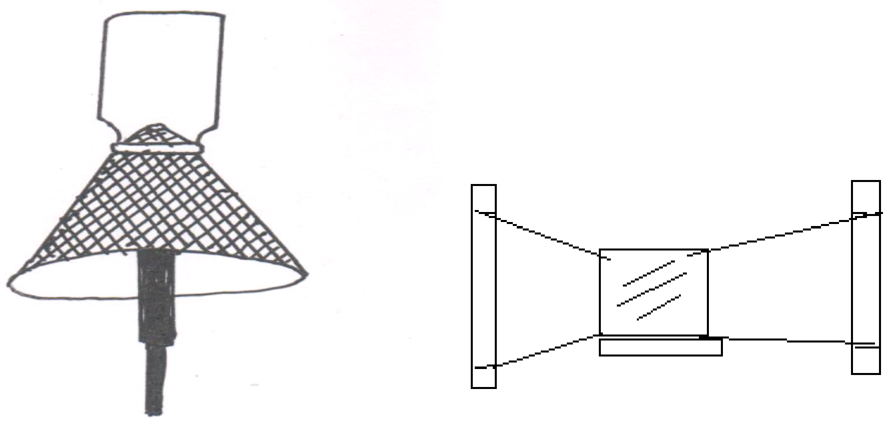


FIG. 19.8: Barrier traps model

5. Light attractants

A great number of insect species generally the light emitting insects are attracted towards light of various wavelengths (FIG 19.9). Several species respond uniquely to specific portions of the visible and non visible spectrum. They are attracted by fluorescent bulbs or bulbs that emit ultraviolet wavelengths (black lights). Certain species of moths, flies, beetles and other insects are attracted to artificial light as they shows mating behavior in bioluminescent insects and some insects are attracted in search of food. They may fly to lights throughout the night or only during certain hours. Key pests that are attracted to light include the European corn borer, codling moth, cabbage looper, many cutworms and armyworms, diamondback moth, sod webworm moths, peach twig borer, several leaf roller moths, potato leafhopper, bark beetles, carpet beetles etc.

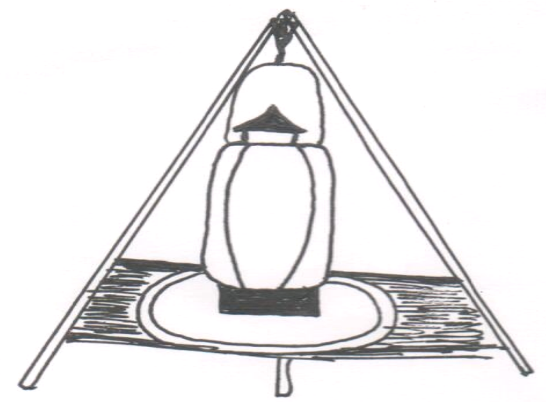


FIG 19.9: Light trap

Lights attractants are likewise useful with varying degrees of success in monitoring populations and in mass trapping. But because pheromone attractants and traps are much more specific and more convenient, light traps are no longer as widely used. Certain limitations of light attractants are like

1. Many insects that are attracted to the area around the light traps do not actually fly into the trap inspite of they remain nearby, indirectly increasing the total number of insects in the immediate area.

2. These light attract and kill a wide variety of insects much of them are non targeted pests, biological controlling insects or beneficial insects.

6. Malaise

Basically it's not attractant but it's a way to capture those flying insects that move upward when they strike a barrier. This trap is a tent-like structure made of netting with a collecting chamber at the top filled with alcohol. Insects entering the trap eventually fly or crawl upward while attempting to escape. Instead of escaping, they become trapped in a killing jar or a container of ethanol. Malaise traps placed across paths of most insects fly upward.

7. Pheromone based Attractant or Sex Attractants

Hundreds of pheromones are known with which one sex (usually the female) of an insect species attracts its mates. Many of these sex attractants or their close chemical relatives are available commercially. For example, male cockroach secrete seducin, *Danus* butterfly secretes musculure. They have proved useful controlling agents against insect pests in two ways:

Male Confusion: Distributing a sex attractant which can be artificially prepared distributed throughout an area masks the insects own attractant and thus may prevent the sexes getting together for mating. This *communication disruption* has been used as one way in IPM. For example, the sex attractant of the cotton boll weevil has reduced the need for conventional chemical insecticides by more than half in some cotton growing areas.

Insect Monitoring: Insect sex attractants are also valuable in monitoring pest population. By baiting traps with the appropriate pheromone, a build-up of the pest population can be spotted in early stages. Even if a conventional insecticide is the weapon chosen, its early use reduces:

- the amount needed
- damage to the crop
- cost to the grower
- Possible damage to the environment.

The pheromone attractants are effective for catching insects; numerous traps placed in environment can sometimes remove many insects to substantially reduce the local population and limits the injury it causes. Efforts to trap out insect pest called *removal trapping or mass trapping* have utilized species specific aggregation pheromones that attract both male and female beetles and there are also the attractants that are not only species specific but also sex specific. When aggregation pheromones are used to attract adult beetles of both sexes, traps may reduce the feeding damage caused by the adult insects and reduce reproduction by capturing adults before they lay eggs. When sex pheromones are used to capture moths, success depends upon capturing males before mating occurs, after mating there is no use of pheromone based attractants.

19.7.4 Some attractants used towards insect:

- Methyl eugenol against *Dacus sps* (Oriental fruit fly)
- Eugenol+geraniol (1:9) against *Popillia sps*. (Japanease beetle)
- Eugenol+Q-lure+trimedlure against melon fly
- Anethol against *Cydia pomonella* (codling moth)
- Gyplure against male *Porthetria dispar* (gypsy moth)
- Butyl sorbate against chafer beetles
- Singlure against *Ceratitis capitata* (Mediterranean fruit fly)
- Heptyl butyrate against *Vespula* spp. (yellow jacket wasp)

19.7.5 Advantages

1. All these attractants are mixed with food to make poison baits, trap baits etc.
2. They have no harmful effects, non polluted, and biodegradable in nature.
3. It shows specificity and sensitivity.
4. Insect do not develop resistance against attractants.
5. Environment containing attractants do not able the male to locate its mate so it is also called **Male Confusing Technique**.
6. Main reproductive forms attracted and population decreases below the economic injury level.

19.7.6 Disadvantages

1. It is very costly and time consuming technique.
2. Individual respond to stimuli according to relationship between the intensity of stimulus and their response threshold.

3. It varies according to physiological condition and may change with time to time.
4. Many insects have migratory phase during which they are less responsive to this control.
5. It produces variable results.
6. Temperature, rainfall, wind speed, direction and other physical factors influence attractant release, insect flight and control efficiency. Many insects fly and respond to semio-chemicals only at certain time (dawn, midday, dusk, night, etc.), and then only if temperatures at that time exceed a minimum level (often 50 to 60° F). Wind speed and direction determine the extent of insect movement from surrounding areas to traps within a field or orchard.
7. It is affected if any other controlling measures run simultaneously.

19.8 Chaemosterilants

19.8.1 Definition

Chemosterilants, i.e., chemical compounds that reduce or eliminate the reproductive capacity of the organism to which they are applied.

19.8.2 Main objective

1. To sterilize wild population of pests
2. To release large number of sterile individual so that wild population is outnumbered or suppressed.
3. To minimize the reproductive potential of the insects, keep the population below their threshold levels.

According to LaBrecque chemosterilants are that

- Causes sterility by preventing developments of sperms or ova
- Causes death of ova
- Injure genetic makeup of sperms or ova that fertilized results in sterile progenies

Practical application depends upon

- Nature of active compound;

- Mode of administration and
- Diversity of insect species**.**

19.8.3 Mode of application

- Orally: by ingesting food containing chemosterilants when treated food placed in infested area.
- Topically/ contact: direct spray of dust of chemosterilants, direct contact or sterile male release method.
- Injection: best procedure for evaluating the insect activity but limited to water soluble compounds.

It is a chemicobiological method in which insect sterilized by chemicals and on mating with normal ones do not produce offspring. It can affect one or both sex. Many insects procure the pest status as reproductive capacity is too high and their exploding population creates pressure on man's environment and food resources. Any process that interfere pest's reproduction capacity can be a significant useful control method. The successful eradication of the screwworm, *Cochliomyia hominivorax* (Coquerel), from certain islands in the West Indies and from the southeastern United States (1) was a convincing example of a novel approach to pest control in which interference with reproduction played a key role. Firstly Knipling sterilize screwworm males by gamma irradiation (Laboratory ARS, U.S. Department of Agriculture, Beltsville, Maryland 20705). April 1976 areas in which the sterility concept could be utilized: the sterile male technique, in which artificially reared male insects would be sterilized by radiation or chemicals and released into infested areas; the direct sterilization technique, in which chemosterilants would be applied like insecticides to sterilize rather than to kill pest insects; and the genetic technique, in which special mutant strains would be released to suppress the natural population. Chemosterilants, i.e., chemical compounds that reduce or eliminate the reproductive capacity of the organism to which they are applied, may be utilized in each of the three areas mentioned, though only in the direct sterilization technique are they essential and irreplaceable. In the other two techniques, sterilization by ionizing radiation is the most common alternative. On the basis of their structural and chemical characteristics important chemosterilants are:

1. **Alkylating agents:** It is effective against males; alkylation is a substitution of alkyl group from hydrogen atom.
    - Aziridined and non aziridines like Tepa, Metepa, Thiotepa, Apholate;
    - Sulphuric acid esters;
    - Nitrogen mustard.
2. **Antimetabolites:** It's a female sterilants like
    - Folic acid;
    - analogues of amino acids;
    - analogues of purines and pyrimidines, etc.
3. **Miscellaneous compounds:** Biological effects closely resemble those produced by irradiations. Such compound contains radioactive isotopes of carbon and phosphorous, phosphoramide (hempa), tin derivatives (triphenyltin chloride), colchicines, comuarin, methionine etc.

19.8.4 Advantages

1. Reproductive potential of insect decreases with killing.
2. It can be applied as baits or mixed with attractants.
3. **Bonus effect:** Sterilized population competes with unsterilized population.
4. **Space effect:** Sterile individuals move and affect the reproductive potential of an individual outside the area treated.
5. **Population crash**: Treated individuals compete with untreated for food, space, shelter and other requirements.
6. **Time effect**: For long lived individuals sterilization is very much significant as it compete for subsequent generations.

19.8.5 Disadvantages

1. It is effective or can be applied as far as insect is alive.
2. Technique is very much costly and laborious.
3. The chemicals used are hazardous and toxic can affect handlers or workers.
4. Field experiments are restricted.
5. Less significant for short lived individuals.

19.9 Antifeedants

19.9.1 Definition

These are the chemical compounds that possess the property of inhibiting the feeding of insects or other pest. In short, an antifeedant is any substance that tastes bad to insects.

According to some authors, any substance that reduces feeding by an insect can be considered an antifeedant/ deterrents. They are behavior modifying substance that deters eating through a direct action on taste organs/peripheral sensilla in insects. This definition excludes chemicals that suppress feeding by acting on the central nervous system followed by stopping of ingestion and absorption or a substance that has sub lethal toxicity to the insect.

19.9.2 Mode of action

It acts as inhibitors of gustatory organs. Maxilla and maxillary palps are the most important sense organ for recognition of inhibitory chemicals and the receptors of mouth parts. Organometallic compounds like fentins found to inhibit the taste receptors of mouth region and ultimately insect fails to recognize treated plants or food and stop feeding may die due to starvation. It also affects the secretion of enzymes in the digestive tract of insects.

The need to protect our food, standing crops and storage stations from pest insect attack using ecofriendly acceptable methods has led to a rapidly growing interest in behavioral modifying chemicals from natural sources. Use of antifeedants has also become a part of IPM as other sources are toxic, broad spectrum insecticides with negative impacts on natural enemies, pollinators and other non-target organisms. And continuous use of specific insecticides also leads to secondary resurgence of pest.

19.9.3 Sources and Chemistry

Plants produce a diverse group of secondary metabolites; there is compelling evidence that at least some of these are important in the defense of plants against herbivores. It is not surprising, that the majority of substances documented to deter feeding by insects have been isolated from plants. Antifeedants can be found amongst all the major classes of secondary metabolites – alkaloids, phenolics and terpenoids (Frazier, 1986). It has great diversity of antifeedants, and the most potent, have been found are chemically speaking, triterpenoids. Based on a thirty carbon skeleton, these substances often occur as glycosides and are often highly oxygenated. Especially well studied in this regard are the limonoids from the neem (*Azadirachta indica*) and chinaberry (*Melia azedarach*) trees, exemplified by azadirachtin and toosendanin, and limonin from *Citrus* species. Other antifeedant triterpenoids include cardenolides, steroidal saponins and withanolides. Several types of diterpenes (based on a twenty carbon skeleton) are well known as antifeedants, including the clerodanes and the abietanes. Sesquiterpenes (15-carbon skeleton) with potent antifeedant action include the drimanes, and the sesquiterpene lactones. One particularly well-studied example is the drimane polygodial, which occurs in foliage of the water pepper, *Polygonum hydropiper*.

19.9.4 Classification

There are five classes on the basis of chemicals manifesting antifeedants properties.

1. Triazenes: AC20455
2. Organotins: Fentin acetate (Brestan), fentin hydroxide (Duter), fentin chloride (Brestanol)
3. Carbamates: Baygon
4. Botanicals: Plant phenolics, the best known antifeedants include the furanocoumarins, neolignans, pyrethrum, neem seed which are highly potent contact insecticides.
5. Others: cycocel, phosphore, copper resinate, mercuric chloride.

19.9.5 Some antifeedants against insects

- ZIP: zinc salt/ dimethyl dithiocarbonic acid with cyclohexylanine. It was the first antifeedants used in agriculture on barks and twigs against rodents and dear.
- Fentin acetate against *Pericallia sps*. (black headed caterpillar), *Athalia sps*. (mustard saw fly), *Prodenia* (tabacco caterpillar), *Agrotis* (cutworms) generally pest of castor, mustard, seasam, sunflower, maize and cucurbits.
- Fentin chloride against tobacco caterpillar, paddy army worms, mustard saw fly.
- Fentin hydroxide against black headed caterpillar, cutworms
- Neem formulation against *Amascata* sps., *Schistocerca* spp., *Pieris* spp. , *Spodoptera* spp. and stored grain pests.

- Calotropis against *Schistocerca* spp.
- *Triazenes* against Lepidoptera larvae.
- Methyl salicylate against aphid populations.

19.9.6 Advantages

1. It can be as water or oil based spray in the same manner used to apply an insecticide.
2. Many antifeedants do not kill pests out right as insect may die due to starvation.
3. They are specific in nature and do not disrupt biotic balance as parasites, pollinators and predators remains unaffected.
4. They show complete coverage of plants and have short residual action.
5. No harmful effects and show low mammalian toxicity.
6. It's a modern technique to control pest.

19.9.7 Disadvantages

1. Only surface feeding insects can be prevented by antifeedants.
2. Piercing and sucking insects are not affected.
3. Much knowledge is needed to ensure the results
4. There are very little chemicals known showing antifeedants properties.
5. Antifeedants suffer from greater interspecific differences in bioactivity.

19.10 Genetic control

19.10.1 Definition

Genetic control is a kind of biological control in which insect pest population are controlled by to creating genetic abnormalities or mutations.

19.10.2 `Mode of action

Insects are responsible for the transmission of number of vector borne diseases and other infectious diseases. The innovative approach of insect control includes one of the methods by modifying insect genomics and transformation technology that created a new technique in IPM and insect pest management. Insects are genetically modified with genes that block pathogen development. The other way is to suppress insect populations by releasing either sterile males or males carrying dominant lethal genes into the environment. This insect control strategy has offered many advantages over insecticide based strategies.

The effectiveness of genetic control depends upon released radiation-sterilized males in an area where they compete with non sterilized males for mating, reproductive potential and rate of immigration into the target population. This technique is now being considered as a good control method applied against agricultural pests especially in Mexico, Egypt and Japan. Sterile male approach to control pest was firstly discovered by Knipling (1955). He noted that female screwworm flies mat only once and he sterilized two billion male screwworm fly, *Cochliomyia hominivorax*, with Co^{60} radiation. It is a serious pest of cattle and the result showed the control of screwworm fly in 13 weeks after the sterile males are released.

Genetic manipulation can be done by any of the methods using cytoplasmic incompatibility, chromosomal rearrangements, hybrid sterility, developmental alteration, irradiations, creating lethal mutation and meiotic drive mechanism.

19.10.3 Advantages

1. There is no disturbance in food chain and food web as the insects are not killed. The genetically modified individuals show normal life table.
2. If any insect is a biological control agent, these modifications shows no disturbance in their feeding.
3. Sterile male is not different as compared to non sterile male; therefore, they can compete for mating.
4. This technique can be used against those insects that are pesticide resistant.

19.10.4 Disadvantages

1. Mass rearing cannot be done if insect is much more complicated.
2. Insects having short life cycle is not feasible to control genetically.
3. It is very expensive as it requires sophisticated instruments and well settled laboratory.
4. The release of genetically modified insects into the environment should proceed with great caution, after ensuring its safety, and acceptance by the target populations.
5. The reproductive biology and sex separation of the test insect must be known.
6. The test insect must be mass reared in the laboratory in a short period to release large number of individuals in an area.

7. If large number of insects is to be released they should not impose any serious economic impact in the ecosystem.
8. The reared individuals must be able to compete with the non-sterile individual.

19.11 Plant Proteinase Inhibitors

Many of the plant contain proteinase inhibitors (PIs) and can be isolated from various cereal, leguminous species and their storage organs like seeds and tubers. These proteinase inhibitors are effective against various insect pest species. Recent work is being carried out which is basically focused to isolate as well as sequencing the PI genes so that we can get protection against different insect species that damage crop plants like pigeon pea, cotton, maize, soybean and chick pea (*Agrobios Newsletter, October, 2010*).

In nature, plants also protect themselves against pests by synthesizing specific macromolecules derived from secondary metabolic pathways. The α-amylase inhibitors can act specifically when the insect depends primarily on carbohydrate metabolism. Specific lectins also show resistance to pests infesting seeds.

Proteinase inhibitors are low molecular weight proteins components that are present in seeds and offer natural defense. It is one of the most abundant classes of proteins in plants. Storage organs like seeds of family *Leguminosae*, *Graminae* and tubers of family *Solanaceae* contain 1 to 10% of their total protein as PIs, which inhibit different types of enzymes. Based on the amino acid is active during reaction centre the catalytic mechanisms they are classified as serine, cysteine, aspartic and metallo-proteinase inhibitors. There are at least 12 PI families found in which Soybean trypsin inhibitor was the first PI isolated and characterized. Mickel and Standish observed that larvae of certain insects were not able to develop on soybean products. Later they found that soybean trypsin inhibitors were toxic to *Tribolium confusum* larvae.

Insects require a process proteolysis to degrade proteins they consume. Proteinase inhibitors inhibit the action of the digestive enzymes and hence they are considered anti-nutritional. When such proteins are abundant in consumed food of animals, they interfere with growth and development.

These studies strongly implicate plant PIs to interfere with the growth and development of many phytophagous insects including members of Lepidoptera (*Helicoverpa armigera* and *Spodoptera*), Coleoptera (*Diabrotica* sp., *Callosobruchus chinensis* and *Anthonomus* sp.) and Hemiptera (*Myzus persicae* and Aphids).

19.12 Summary

Behavioral control of pest by modifying their behavior, pheromones help to trace pest, hormone mimics or antagonist to change their development and growth accordingly are some recent discoveries made by scientist. Also, antifeedants, chaemosterilants, attractants, repellants are integrated to control targeted pest.

After going through this unit you are able to answer the importance of innovative approaches, their significance and use. However, all the techniques mentioned above has some advantages and disadvantages at their places but they are also the solution of many problems like pest resistance , residual effect, high lethal concentrations of many chemicals, biomagnifications of hazardous component in our food chain and food web. Recent advances are now the basis of applied entomology.

19.13 Glossary

- **Antifeedants-** are chemical that inhibit the feeding of insects.
- **Attractants-** chemicals which makes oriented movements towards a substance.
- **Chaemosterilants-** chemicals used to sterilize male or female insect.
- **Hormones analogues-** synthesized chemicals which are similar in function to hormones.
- **Hormones antagonist-** synthesized chemicals function against hormones.
- **Hormones-** are chemicals secreted by endocrine glands to maintain internal environment of body.
- **Insect Growth Regulators (IGRs)-** that regulate growth and development on insect.

- **Pheromones-** chemicals secreted by insect to communicate within the species.
- **Protein inhibitors-** that inhibit protein to work normally.
- **Repellants-** chemicals which makes oriented movements away from a substance.

19.14 Self Learning Exercise

Section A- Very short answer type questions

1. Insect Growth Regulators (IGRs) are also called …………generation pesticides.
2. Name pheromone secreted by honeybee queen?
3. Name one sex pheromone and aggregation pheromones?
4. What is the trade name of methoprene and hydropene?
5. Give botanical name of plant paper factor/ balsam fir?
6. Name one chemical and botanical repellent?
7. Muscemone is an attractant to……………?
8. Which organ is inhibited to respond by antifeedants?
9. Glypure is used to control which pest?

Section B- Short answer type questions

1. Give difference between attractant and repellent?
2. Define antifeedants and chaemosterilants?
3. Give some advantages of genetic control?
4. How can you differentiate between hormones mimics and antagonist?
5. Give a note on Knipling discovery related to male sterile approach?
6. Name fourth generation pesticides?
7. Define kairomones, allomones and synomones?

Section C- Long answer type questions

1. Give a brief note on types of pheromones?
2. Explain different types of insect hormones and their associated glands?
3. Write a note on genetic control?
4. How behavior is important to control insects?
5. Make a note on repellents, types, advantages and disadvantages of it?

Answer key of section A

1. Third generation pesticide
2. 9-hydroxy-decinoic acid
3. *Bombyx mori* secretes bombykol and pheromone secreted by *Ambrosia* beetle.
4. Altosid and Gencor
5. *Abies balsamea*
6. DEET and oil of *Citronella* plant
7. *Musca domestica*
8. Gustatory i.e maxillae and palps
9. Gypsy moth, *Prothetria dispar*

19.15 References

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Unit - 20

Integrated Pest Management

Structure of the Unit

20.1 Objective

After going through this unit you will be able to answer the following question

- Why IPM is essential?
- What are the concept and principles of IPM?
- What are the components of IPM?
- How to determine the ETL and EIL level of pests?
- What is the importance of pest surveillance and forecasting?
- What are the constraints and strategies of IPM implementation?

- What are the importance of pest risk analysis, pesticide risk analysis, cost benefit ration and partial budgeting for IPM?

20.2 Introduction

Green revolution has attained self sufficiency in food through introduction of high yielding varieties and hybrids. Intensive cultivation of HYV invited or demanded more of inputs in the form of fertilizers especially inorganic which in turn attracted more number of pest and diseases. This necessitated intensive control measures to curtail the losses caused to the crops and the control was achieved mainly through inorganic pesticides. The strategy of exclusive reliance on insecticides for all insect pests problem led to pest resurgence, resistance, outbreaks of secondary pests, pesticides residues and ecological imbalance by killing predators and parasitoids thus affecting prey predator dynamics and resulting in environmental pollution. The combined impacts of all these problems together with the exponentially rising the costs of pesticides provided the necessary feedback for limiting the use of broad spectrum biocides and led to the development of the concept of IPM.

20.2 Integrated Pest Management

20.2.1 Definition of IPM

IPM refers to an ecological approach in pest management in which all available necessary techniques are consolidated in a unifies programme, so that pest populations can be managed in such a manner that economic damage is avoided and adverse side effects on environment are minimized. Various scientists gave different definition of IPM in different context. According to FAO (1967), IPM was defined as “a pest management system in the context of associated environment and population dynamics in pest species. It utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest population at levels below those cause economic injury. Protective management of the noxious pest in which all available techniques should be evaluated and consolidated to manage pest population so that economic damage is avoided and adverse side effects on the environment are minimized (Geier and Clark, 1961).

20.3.2 History of IPM

The term "integrated control" coined by Michel Bacher and Bacon in 1952. Later on Barlett (1956) first to coin the expression "integrated pest control" through which he meant to combine (integrated) biological agents with insecticides in the control of insect pests. Obviously, these methods stood in direct conflict with each other since the insecticides were likely to kill the biological agents. V. M. Stern and his co-workers (1959) defined integrated control as "applied pest control which combines and integrates biological and chemical control". Stern and co-workers also gave the concept of economic injury level and economic threshold level. Later on the concept of pest management has gained importance .The idea of managing pest population was proposed by Geier and Clark 1961 who called their concept as protective management which later was shortened as pest management. Later on Smith and Van Den Borsch in 1967 mentioned that the determination of the insect numbers is broadly under the influence of total agro ecosystem and the role of the principle element is essential for integrated pest management. Council on Environmental Quality (CEQ, 1972) gave the term "Integrated Pest Management". In 1985 India declared IPM as official Ministerial Policy. In 1989, IPM Task Force was established and in 1990, IPM Working Group (IPMWG) was constituted to strengthen implementation of IPM at international level. In 1992, L. P. Pedigo and L. G. Higley gave the concept of environmental economic injury levels. In 1994, Global IPM Facility established with the Secretariat located at FAO, Rome by a Task Force consisting of FAO, the World Bank, UNDP and UNEP. In 1997, Ray F. Smith and Perry Adkisson got the World Food Prize for their pioneering work in development and implementation of IPM. National Centre for Integrated Pest Management (NCIPM) was established at Faridabad in 1988 to cater to the emerging plant protection needs of different agro-ecological zones of the country. Later it was shifted to New Delhi in 1995.

20.3.3 Concept of IPM

There are two main factors *i.e* hazards of insecticides and economy of pest control in view of the high cost of insecticides lead to the origin and evolution of the concept of IPM. It seeks to minimize the disadvantages associated with use of pesticides and maximizing socio, economic and ecological advantages**.** The concept of IPM is as follows:-

- Understanding the agricultural ecosystem
- Planning of agricultural ecosystem
- Cost /benefit and Benefit/risk ratio
- Tolerance of pest damage
- Leaving a pest residue
- Timing of treatments
- Public understanding and acceptance

20.3.4 Principles of IPM

Basic principles of Integrated Pest Management are as follows:-

- **Consideration of Ecosystem:** Control of insect pest population is a function of the ecosystem itself by means of natural enemies and other factors. Knowledge of the role of the principle elements of the units is essential to an understanding of population phenomenon. The study of individual is of prime importance, their biology behaviour response to other members of the same species and to other organisms and to biotic factors in the environment. The study of individuals offers a potent method for this analysis of population change. The most effective system for controlling pests can be derived only after understanding the principles responsible for the population fluctuation in the ecosystem.
- **Pest Surveillance:** Pest Surveillance and forecasting are having an important part in the integrated pest management for constant observation on a subject *i.e.*, a crop or pest, and recording the factors observed, compilation of information obtained and prediction of future events about pest population. Hence, pest surveillance comprises of three basic components.
  - Determination of the level of incidence of the pest species.
  - Determination of what loss the incidence will cause.
  - Determination of economic benefits or other benefits the control will provide.

  The above information would be immense use in determining the need for a pest control measure. Only presence of a few numbers of pest species should not be the criterion for pesticide application and there should be sufficient justification. This can provide the necessary information to determine the feasibility of a pest control programme.

- **Utilization of Economic Threshold Levels (ETL):** The level of pest population is very important consideration for taking up control measures. Pest population must be maintained at levels below those causing economic injury. The economic threshold is the pest density at which control measures should be determined to prevent an increasing pest population from reaching economic injury level. The determination of these thresholds is a pre-requisite to the development of any pest management strategy.
- **Application of minimum selective hazards:** The application of chemical measures to pest population has to be in such a manner that target pest populations are just kept below economic injury thresholds. By observation of this principle the development of resistant populations of pest is avoided or delayed, the possibility of resurgence of treated population is decreased, adverse effect on non target organism and amount of environmental contamination are reduced, and the cost of control is also lowered.

20.4 Component of IPM

20.4.1 Host plant resistance

Resistance is an inheritable character possessed by a plant which influence the ultimate degree of damage done by the insect. Lesser damage than average damage is taken as resistance while more damage than average damage constitutes susceptible. A resistant variety produces higher yield than a susceptible variety when both are subjected to the same extent of infestation by same insect at the same time. Resistance is a relative term only compared with less resistance or susceptibility. Absolute resistance or Immunity refers to the inability of a specific pest to consume or injure a particular variety under any known-condition. R. H. Painter (1951) has grouped the mechanisms of host plant resistance into three main categories.

1. Non-preference (Antixenosis) 2. Antibiosis 3. Tolerance

However several scientists have attempted to classify the mechanisms of resistance, the terms defined by Painter (1951) – non-preference, antibiosis and tolerance were widely accepted. However, Kogan and Ortman (1978) proposed that the term non preference should be replaced by antixenosis because the former describes a pest reaction and not a plant characteristic. The three types of resistance are described in the context of the functional relationships between the plant and the insect.

- **Non-preference or Antixenosis:** The term 'Non-preference' refers to the response of the insect to the characteristics of the host plant, which make is unattractive to the insect for feeding, oviposition or shelter. Kogan and Ortman (1978) proposed the term 'Antixenosis', as the term 'Non-preference' pertains to the insect and not to the host plant.

  Some plants are not choose by insects for food shelter or oviposition because of either the absence of desirable characters in that plant like texture, hairiness, taste, flavour, or presence of undesirable characters. Such plants are less damaged by that pest and the phenomenon is called non preference. Ex. Presence of hairs on soybean and cotton varieties is not preferred by leafhoppers for oviposition.
- **Antibiosis:** Antibiosis refers to the harmful effects of host plant on the insect due to the presence of some toxic substances or absence of required nutritional components. Such plants are said to exhibit antibiosis and hence do not suffer as much damage as normal plants. The adverse effects may be reduced fecundity, decreased size, long life cycle, failure of larva to pupate or failure of adult emergence, and increased mortality. Indirectly, antibiosis may result in an increased exposure of the insect to its natural enemies. Ex: The classical example of host plant resistance is DIMBOA (2, 4 Di hydroxy -7- methoxy – 1,4 benzaxin – 3) content in maize which imparts chemical defence against the European corn borer *Ostrinia nubilalis.*
- **Tolerance:** Some plants withstand the damage caused by the insect by producing more number of tillers, roots, leaves etc in the place of damaged plant parts ,such plants are said to be tolerant to that particular pest. Ex: Early attack by the sorghum shoot fly on main shoot induced the production of a few synchronous tillers that grow rapidly and survive to produce harvestable ear heads.

20.4.2 Agronomic manipulations

The manipulation of cultural practices at an appropriate time for reducing or avoiding pest damage to crops is known as cultural control. The cultural practices make the environment less favourable for the pests and or more favourable for its natural enemies. This approach is also known as ecological management or environmental control. It is the cheapest of all methods.

There are two categories of cultural methods,

(a) Normal agricultural practices, which incidentally ward off certain pests:

By adopting these, the farmers get two-fold benefits

- Improvement of crop yields and
- The population of certain pests do not increase abnormally

a) **Proper preparatory cultivation:** Several insects which live or hide in the soil get exposed to sun as well as predators like birds etc due to Proper preparatory cultivation. Ex. Larvae, pupae and adults of moths, maggots, roots grubs etc.

b) **Clean cultivation:** Removal of weeds which act as alternate hosts. Ex. Spotted bollworms *Earias vitella, E. insulana also* breeds on weeds such as *Abutilon indicum*, *Malvastrum tricuspidatum* etc. Fruit sucking moth larvae *Eudocima ancilla* on weeds of Menispermaceae family.

c) **Systematic cutting and removal of infested parts:** Keeps down subsequent infestation. Eg. Cutting and removal of infested parts of brinjal attacked by *Leucinodes orbonalis,* Pruning of dried branches of citrus eliminates scales and stem borer. Pests like coccids get carried over to the next season through stubbles, which should be promptly removed.

d) **Crop rotation:** Crop rotation is most effective practice against pests that have a narrow host range and dispersal capacity. Eg. Cotton should be rotated with non hosts like ragi, maize, rice to minimize the incidence of insect pests. Groundnut with non leguminous crops is recommended for minimizing the leaf miner incidence.

e) **Mixed cropping:** Intended for getting some return when one crop is attacked, the other escapes. Eg. Sesame with green gram

f) **Growing resistant varieties**: certain varieties resist pest attack. Eg: PMS 8 and AE 57 resistance to shoot and fruit borer *E. vitella* in okra, Surekha variety to gall midge and Saket and Ratna for stem borer in rice.

(b) Cultural practices specially adopted for certain pests

a) **Adjusting planting or sowing or harvesting times to avoid certain pests:** Manipulation of planting time helps to minimize pest damage by producing asynchrony between host plants and the pest or synchronizing insect pests with their natural enemies. **Eg** Early sown sorghum in kharif reduces the infestation of shoot fly and timely and synchronous planting has been found to reduce bollworm damage in cotton.

b) **Trap cropping:** Growing of susceptible or preferred plants by important pests near a major crop to act as a trap and later it is destroyed or treated with insecticides. Trap crop may also attract natural enemies thus enhancing natural control. Ex: Marigold grown as trap crop with cotton for the management of *Helicoverpa armigera.*

c) **Trimming field bunds:** Grasshopper eggs, which are laid in field bunds, are destroyed by trimming field bunds

d) **Flooding:** Flooding of fields is recommended for reducing the attack of cutworms, army worms, termites, root grubs etc.

e) **Draining the fields:** In case of paddy case worm *Nymphula depunctalis* which travel from plant to plant via water. It can be eliminated by draining or drying the field.

f) Alternate drying and wetting at 10 days interval starting from 35 DAT reduces the BPH and WBPH.

g) **Alley ways:** Formation of alley ways for every 2 m in rice field reduces the BPH *Nilaparvata lugens.*

20.4.3 Mechanical and physical methods

Mechanical methods: Reduction or suppression of insect pest population by means of manual devices or labour is known as mechanical control methods. There are following methods

- Handpicking is most ancient method which can prove fairly effective under certain conditions. Egg masses, larvae or nymphs and sluggish adults can be handpicked and destroyed. Ex. Egg masses of paddy stem borer *(Scirpophaga incertulas)* and groundnut hairy caterpillar. Collection and destruction of fallen fruits is effective against fruit flies and fruit borers.

- Manual collection and destruction of pink bollworm attacked rosette flowers, withered and drooped terminals infested by spotted bollworm can reduce the incidence of these pests in cotton.
- Digging of 30 -60 cm wide and 60 cm deep trenches or erecting 30 cm height tin sheets barriers around the fields is useful against pests like hairy caterpillars. Bagging / wrapping of pomegranate and mango fruits in paper bags avoids the infestation of pomegranate butterfly *Virachola isocrates* and mango fruit fly *Bactrocera dorsalis* Tin bands are fixed over coconut palms to prevent damage by rats.
- Use of an alkathene band around the tree trunks of mango to check the migration of first instar nymphs of mealy bugs and red ants.
- Sticky bands around tree trunks against red tree ant (*Oecophylla samaragdina)*
- Shaking of red gram plants to collect and destroy later instars of *Helicoverpa armigera*

Physical Methods: Minimize the pest populations with the use of certain physical forces is known as physical methods

- Light traps are arranged for attracting the insects, which are trapped by keeping water or oil in a container or a killing bottle below the light trap. Light traps are useful for monitoring the population of important insect pests in an area. Ex: Most of the moths and beetles.
- Flame thrower is a compressed air sprayer with kerosene oil for producing flames. There is a lance, which is fitted with a burner. When the burner is heated, the kerosene oil is released and it turns into flames. Used for burning locust populations, congregation of caterpillars, patches of weeds etc.
- Male insects can be made sterile by exposing them to gamma radiation or by using chemicals. When sterile males are released in normal population they compete with normal males in copulation and to that extent reductive capacity of the population are reduced. By sterilizing the pupae of screwworm, livestock pest (*Cochliomyia hominivorax*) with radiations, sterile males were obtained. They were released @ 400/sq mile for 7

weeks. By this method total eradication was achieved in South East parts of America and in the Curacao islands in case of screwworm.

- Artificial heating and cooling of stored products will prevent insect damage. Usually high temperatures are more effective than low temperatures.
- Stored products can be exposed to 55 ^{0}C for 3 hours to avoid stored product pests- Steam sterilization of soil kills soil insects
- Oxygen stress and carbon dioxide concentration: In air tight containers small volume of air is enclosed, the available oxygen is quickly utilized by insects and raise concentration of carbon dioxide. High concentration of carbon dioxide leads to death of stored products insects.
- Vapour Heat Treatment (VHT): Heated air is saturated with water (>RH 90%) for specified period of 6 to 8 hours for raising pulp temperature to 43-44.5°C in case of mango against fruit flies.

20.4.4 Chemical methods

Control of insects with chemicals is known as chemical control. The term pesticide is used to those chemicals which kill pests and these pests may include insects, animals, mites, diseases or even weeds. Chemicals which kill insects are called as insecticides. Insecticide may be defined as a substance or mixture of substances intended to kill, repel or otherwise prevent the insects. Similarly pesticides include nematicides – which kill nematodes, miticides or Acaricides which kill mites, Rodenticides – which kill rats, weedicides- that kill weeds, Fungicides- that kill fungus etc. Insecticides are the most powerful tools available for use in pest management. They are highly effective, rapid in curative action, adoptable to most situations, flexible in meeting changing agronomic and ecological conditions and economical. Insecticides are the only tool for pest management that is reliable for emergency action when insect pest populations approach or exceed the economic threshold. A major technique such as the use of pesticides can be the very heart and core of integrated systems. Chemical pesticides will continue to be essential in the pest management programmes.

20.4.5 Bio-control agents

The successful management of a pest by means of another living organism (parasitoids, predators and pathogens) that is encouraged and disseminated by man is called biological control. In such programme the bio-control agents (natural enemies) are introduced, encouraged, multiplied by artificial means and disseminated by man with his own efforts instead of leaving it to nature.

Techniques in biological control: Biological control practices involve three techniques *viz.,* Introduction, Augmentation and Conservation.

- **Introduction or classical biological control:** It is the deliberate introduction and establishment of natural enemies to a new locality where they did not occur or originate naturally. When natural enemies are successfully established, it usually continues to control the pest population.
- **Augmentation**: It is the rearing and releasing of natural enemies to supplement the numbers of naturally occurring natural enemies. There are two approaches to augmentation.
    - **Inoculative releases**: Large number of individuals are released only once during the season and natural enemies are expected to reproduce and increase its population for that growing season. Hence control is expected from the progeny and subsequent generations and not from the release itself.
    - **Inundative releases**: It involves mass multiplication and periodic release of natural enemies when pest populations approach damaging levels. Natural enemies are not expected to reproduce and increase in numbers. Control is achieved through the released individuals and additional releases are only made when pest populations approach damaging levels.
- **Conservation:** Conservation is defined as the actions to preserve and release of natural enemies by environmental manipulations or alter production practices to protect natural enemies which are already present in an area or non use of those pest control measures that destroy natural enemies.

  Important conservation measures are

    - Use selective insecticide which is safe to natural enemies.
    - Avoidance of cultural practices which are harmful to natural enemies and use favorable cultural practices
    - Cultivation of varieties that favour colonization of natural enemies

- Providing alternate hosts for natural enemies.
- Preservation of inactive stages of natural enemies.
- Provide pollen and nectar for adult natural enemies e.g. for predator wasp etc.

Parasite: A parasite is an organism which is usually much smaller than its host and a single individual usually doesn't kill the host. Parasite may complete their entire life cycle (e.g. Lice) or may involve several host species. Or Parasite is one, which attaches itself to the body of the other living organism either externally or internally and gets nourishment and shelter at least for a shorter period if not for the entire life cycle. The organism, which is attacked by the parasites, is called hosts.

Parasitism: It is the phenomena of obtaining nourishment at the expense of the host to which the parasite is attached.

Parasitoid: It is an insect parasite of an arthropod, parasitic only in immature stages, destroys its host in the process of development and free living as an adult. E.g.: Braconidae wasps

Some successful examples

- Control of cottony cushion scale, *Icerya purchasi* on fruit trees by its predatory vedalia beetle, *Rodolia cardinalis* in Nilgiris. The predator was imported from California in 1929 and from Egypt in 1930 and multiplied in the laboratory and released. Within one year the pest was effectively checked.
- Biological Control of Water Hyacinth**,** *Eichhornia crassipes ,*three exotic natural enemies were introduced in India viz. hydrophilic weevils – *Neochetina bruchi* and *N. eichhorniae* (Argentina) and galumnid mite *Orthogalumna terebrantis* (South America) in 1982 for the biological suppression of water hyacinth.
- Apple woolly aphid, *Eriosoma lanigerum* in Coonor area by *Aphelinus mali* (parasitoid)
- *Centrococcus isolitus* on brinjal; *Pulvinaria psidi* on guava and sapota; *Meconellicoccus hirsutus* on grape and *Pseudococcus carymbatus* on citrus suppressed by *Cryptolaemus montrouzieri.*

20.4.6 Genetic control

The basic principle in genetic control of insects is to utilize factors which will lead to reproductive failure. Genetic control of insects is not limited to the use of insects sterilized by radiation or chemicals but also include cytoplasmic incompatibility, induced sterility, hybrid sterility etc.

A) Induced Sterility

i) Sterile male release technique:

When a sterile male mates with normal female there will be no progeny. If adequate number of vigorous and competitive sterile males is introduced systematically into natural population the population will soon cease to exist. This theory of Male Sterile Technique was conceived by E F Knipling as early as 1937 and was published in 1955. He suggested two procedures,

- Rearing, Sterilization and Release (@ 9:1 sterile to fertile insects) of sterile insects to compete with the normal population.
- Sterilizing a portion of the natural population Eg: Screw-worm (*Cochliomyia hominivorax*) a cattle pest was completely eradicated from Curacao Islands and south eastrun parts of USA by male sterilization by irradiation with gamma rays (C060).

Limitation: Applicable only to species, where the female mates only once in its lifetime.

ii) Aspermia: Inactivation of sperms. In some cases, as in mosquitoes the sperm of the incompatible male is blocked before it could fuse with the nucleus of the egg of native female. This principle was employed for eradication of *Culux pipens quinquifasciatu*s in Rangoon. The possibility is, the incompatible strain could be identified, multiplied in large numbers and released in infested areas for eradicating the pests.

iii) In fecundity: Sterile eggs by dominant lethal mutations

iv) Use of non-mutagenic chemicals: To induce sterility by preventing mating by developing monogamous females, inhibition of spermatogenesis/oogenesis or by sperm inactivation

B) Cytoplasmic Incompatibility

Sterility is due to a cytoplasmic factor transmitted through the egg, which kills the sperm of incompatible male after its entry into the egg. Crosses between certain populations give no off-spring at all, in other cases females of one population may cross with males of another population and off-spring are produced, but the reciprocal cross is completely sterile. Recently it has been observed that in the case of some species of insects, there exist different strains with different genetic set up. When males of one such strain mate with females of another such strain, the offspring fails to develop because of incompatibility between the genes of the egg and the sperm. At an inter-specific level the sperm of hetero-specific males are often disadvantaged in competition with those of con-specific males.

C) Hybrid Sterility:

In some insect cross-types or races which produce fertile females but sterile males among progeny. These sterile hybrids are excellent material for use in insect control. These sterile males are more vigorous and competitive than the sterile males produced after radiation or chemo-sterilization.

D) Population Replacement:

The ability of disease transmission of vectors *i.e.* replacement of specific vector populations can as well be changed by genetic methods.

E) Auto-Sterilization:

Sterilization of native insects in their natural environment by using chemosterilants along with the species specific attractants / lures/ bait traps. Through this both the sexes can be sterilized, and also negate the reproductive ability of those insects which have escaped the lure/bait treatment.

20.4.7 Behavioral control

The utilisation of chemicals that affect insect behaviour, growth or reproduction, for suppression of insect populations is often referred to as bio-rational control.

I) Chitin synthesis inhibitors disrupt molting by blocking the formation of chitin, the building block of insect exoskeleton. Without the ability to synthesize chitin, molting is incomplete, resulting in malformed insects that soon die. It suppresses egg-laying and causes egg sterility in treated adults through secondary hormonal activity.

II) Insect Repellents: Chemicals which cause insects to move away from their source are referred to as repellents (or) Chemically that prevent insect damage to plants (or) animals by rendering them unattractive, unpalatable (or) offensive are called repellents.

III) Insect Antifeedants: Antifeedant is a chemical that inhibits feeding but does not kill the insect directly; the insect often may remain on the treated plant material and possibly may die of starvation. These are also caused as "Feeding deterrents". There are three main sites for the sense of taste in insects located in the mouth, on the tarsi and on the antennae. Insect feeding deterrents may be perceived either by stimulation of specialized receptors (or) by distortion of the normal function of neurons which perceive phago-stimulating compounds. Since the sugars are very important components of an insect sustained feeding, the inhibition of its receptors is an effective antifeedant action

IV) Insect Attractants: Chemicals that cause insects to make oriented movements towards their source are called insect attractants. They influence both gustatory (taste) and olfactory (smell) receptors (or) sensilla.

Types of Attractants

1. Pheromones 2. Natural food lures 3. Oviposition lures and 4. Poison baits

1) Pheromones: In 1959, Karlson and Butenandt coined the term pheromone. For a Chemical that is secreted into the external environment by an animal and that elicits a specific response in a receiving individual of the same species. It is also referred to as "ectohormone". Depending on their mode of action pheromones are divided into two general classes. i) One which gives a releaser effect – an immediate and reversible behavioural change is produced in the receiving animal. ii) One which gives a primer effect - a chain of physiological changes is triggered off in the receiving animal. E.g. Gustatory stimulation, controlling caste determination and reproductive control in social Hymenoptera (Ants and Bees), Isoptera (Termites). Behaviour – releasing pheromones are typically odorous and act directly on the central nervous system of the receiving animal.

a) Sex pheromones: A Sex pheromone released by one sex only triggers off a series of behaviour patterns in the other sex of the same species and thus facilitates mating. The male insects respond to the odorous chemical released by the female.

In certain species of insects the males are known to produce the sex pheromone which attracts the females. E.g. In the cotton boll weevil *Anthonomus grandis*

The sex pheromones are specific in their biological activity, the males responding only to a specific pheromone of the female of the same species, and their reactions are directed towards the air currents carrying the odour. The time of release of the pheromones by the females and response by male to them appears to be specific for

each species. The following sex pheromones have been isolated and identified.

Bombycol: Silkworm, *Bombyx mori*

Gyplure: Gypsy moth, *Perthetria dispar;*

Gossyplure: Pink bollworm, *Pectionophora gossypiella*

Trimedlure: Meditarrnian fruifly, *Ceratitis capitapa*

Cuelure: Melon fly, *Bactroceracucurbitae*

Litlure: Tobacco cutworm, *Spodoptera litura*

Helilure: Red gram pod borer, *Helicoverpa armigera*

Amlure: Chaffer beetle, *Amphimallon* sp

Looplure: Cabbage looper ,*Trichoplusia ni*

Ferrolure: Coconut Red Palm Weevil , *Rhynchophorus ferrugineus*

Leucilure: Brinjal Shoot and Fruit Borer, *Leucinodes orbonalis*

Sex pheromones in insect pest management

- **Monitoring of insect pests:** Traps baited with synthetic sex pheromones is useful in estimating population and detecting early stages of pests. Four pheromone traps per acre is recommended.
- **Mass-trapping: (Male annihilation technique):** Large number of pheromones baited traps can be used in the fields to capture male moths of newly emerged and reduce the number of males for mating.
- **Control of pest by mating disruption:** By permeating the atmosphere with higher concentration of the pheromone the opposite sex is rendered confused and unable to locate their mates.

b) Aggregation pheromones: The pheromone released by one sex only elicits response in both sexes of a species. In scolytid (or) bark beetles the males secrete the pheromone into the hind gut which gets incorporated in to the faecal pellets and through them attracts flying males and females towards the galleries. In *Trigoderma granaria* mixture of fatty acid esters and methyl and oleate function as aggregation pheromones.

c) Trail marking pheromone: At low concentrations mostly used by foraging ants and white ants. In ants *Formica rupa,* formic acid while in termites, *Zootermopsis nevadensis* hexanoic acid functions as the trail marking pheromone.

d) Alarm pheromones: These substances are elaborated by mandibular glands, sting apparatus, anal glands which typically results in fight or aggression. *Dolichoderine* ants – release a fruity odour by the worker that results in an erratic behaviour of workers, when this is discharged into mandibles onto intruding insects that becomes marked as aggressor.

- **Natural Food lures:** These are Chemicals present in plant and animal hosts that attract (lure) insects for feeding. They stimulate olfactory receptors and may be
  - A floral scent in case of the nectar feeding insects
  - Essential oils for the phyto-phagous insects.
  - Carbon dioxide, lactic acid and water for the blood sucking insects.
- **Oviposition Lures:** These are chemicals that govern the selection of suitable sites for oviposition by the adult female for example, P-methyl acetophenone attracts adult female rice stem borers to oviposit.
- **Poison Baits:** Poison baits are a mixture of food lures and insecticides. The effort is made to make the bait more attractive to insects than their natural food and also a smaller quantity should be able to attract the largest number of insects. Baits are used when for some reason spraying (or) dusting of insecticides is not practicable. For instance, when insects live hidden under the soil, inside the fruits and vegetables (or) for household insects like ants, cockroaches and houseflies.

20.5 IPM strategy for field and horticultural crops

20.5.1 IPM for cotton

Several numbers of pests like aphids, leafhoppers, thrips, whiteflies etc and bollworms (Pink, Spotted and American bollworms) infest cotton during early vegetative growth to maturity of crops. Hence strategies for managing these pests have direct impact on success of IPM strategies which emphasize survival and build up of natural enemies in cotton ecosystem. The IPM practices are:

- Selection and use of resistant/tolerant varieties against major pests
- Use of light trap to monitor hoppers, bollworms, cutworm
- Use of pheromone traps for monitoring/mass trapping bollworms
- Collection and destruction of infested plant parts, squares and bolls
- Growing trap crop (e.g.) Castor for *Spodoptera litura*
- Manual collection and removal of egg masses of *S. litura*
- Hand picking of bollworm larvae
- Use of insect viruses SlNPV and HaNPV against *Spodoptera litura* and *Helicoverpa armigera* respectively
- Avoid ratoon and double cotton crop
- Avoid staking of stalks in the field
- Synchronize sowing time at village level
- Follow crop rotation with unrelated crops
- Removal of alternate hosts
- Judicious use of nitrogen and water to manage hoppers and white flies
- Use of yellow sticky traps for whiteflies
- Observe IRM (Insecticide Resistance Management) practices like
    - Treat seeds with Imidacloprid 7.5 g/kg seed of cotton to manage early stage sucking pests
    - Use of predators like *Chrysoperla carnea*
    - Use of egg parasitoid *Trichogramma* sp. against bollworms
- Apply insecticides only based on need, when pest population/damage reaches

20.5.2 IPM in cruciferous vegetables

Cole crops are invariably infested with diamond back moth, leaf webber, cabbage borer and cabbage butterfly; *Spodoptera litura* and *Helicoverpa armigera* also appear as head borers at times. IIHR has developed the effective IPM package mainly using mustard as a trap crop. The IPM practices are:

- Removal and destruction of crop residues to break the cycles of painted bugs as well as leaf webbers in specific localities,
- Selecting the derivatives of PI 234599 in cabbage having shiny leaves with moderate resistance to diamond back moth.
- Growing mustard as trap crop in cabbage or cauliflower fields. Mustard should be sown in paired rows (one row 15 days after planting and another 30 days after planting cabbage or cauliflower) for every 25 rows of cauliflower/cabbage.
- Application of neem seed kernel extract (5%) in synchrony with the incidence of diamond back moth/leaf webber on cabbage, which is found safer to parasitoids like *Cotesia plutellae*
- Resorting to cartap hydrochloride /Bt formulation applications, if head borers (*Hellula / Spodoptera / Helicoverpa*) appear.
- Opting for insecticide like dichlorvos only when situation warrants and sufficient time gap is available between spraying and harvesting.

20.6 IPM case histories

IPM programme successfully implemented in different countries. The following are few examples of successful IPM programmes worldwide

- In Philippines, in 1993, IPM farmers obtained 4.7 to 62% higher rice yield and reduced pesticide use by 15% compared to non-IPM.
- In India in 1995, IPM farmers obtained 6.2 to 42.1% increased rice yield, and reduced pesticide use by 50% compared to non-IPM farmers.
- In Thailand in 1993 adoption of IPM technology resulted in 145% increase in net profit in IPM fields over non-IPM fields in cruciferous vegetables.

- In India on cotton crop, adoption of IPM technology resulted in 73.7 and 12.4% reduction in the number of insecticide sprays against sucking pests and bollworms. In spite of reduction in pesticide sprays 21-27% increase in seed cotton yield was obtained in IPM areas compared to non-IPM. Natural enemy population also increased 3 folds.
- IPM is useful and economical in high value, plantation crops like Coconut, Coffee, Tea, Cashew nut and Areca nut.

20.7 Concept of damage levels

Presence of insects in crop field does not mean that it needs chemical control. Low infestation sometimes is beneficial to yield by stimulating plant growth or by allowing fewer fruits to develop greater size. Therefore, it is the important decision of how far a particular pest population can be allowed to grow before the application of insecticides. Economic damage was defined as the amount of injury which will justify the cost of control measures. It should be kept in mind that there is a difference between injury and damage. Injury is the effect of pest activities on host physiology that is usually deleterious. Damage is a measurable loss of host utility, most often including yield quantity, quality, or aesthetics.

20.7.1 Economic injury levels (EIL) & its determination

EIL is lowest population at which the pest will cause economic damage or it is the pest level at which the damage can no longer be tolerated and therefore it is the level at or before which the control measures are initiated. EIL is usually expressed as the number of pests per unit area. EIL can be determined using following formula

$$\mathbf{EIL = C/V \times I \times D \times K \qquad (or) \qquad C/\ VIDK}$$

Where

EIL = Economic injury level in insects/production (or) insects/ha

C = Cost of management activity per unit of production (Rs./ha)

V = Market value per unit of yield or product (Rs./tonne)

I = Crop injury per insect (Per cent defoliation/insect)

D = Damage or yield loss per unit of injury (Tonne loss/% defoliation)

K = Proportionate reduction in injury from pesticide use

20.7.2 Economic threshold levels (ETL) & its determination

It is the index for making pest management decisions. ETL is defined as the population density at which control measures should be applied to prevent increasing pest population from reaching the economic injury level. It indicates the number (density) of the potential pest at which management action should be taken. For this reason, it is also called the action threshold level. Although expressed in insect numbers, the ETL is a really time parameter. Just as with EILs, ETLS also can be expressed in insect equivalents. E.g. ETL value for BPH in rice is 25 insects/hill; Grasshoppers or cutworms is 1 insect/hill; rice stem borer -5% dead hearts; Gall midge of rice-5% silver shoots.

Relationship between EIL and ETL can be expressed as when no action is taken at ETL the population reaches or exceeds EIL. ETL represents pest density lower than EIL to allow time for initiation of control measure. The market value of crop and management costs are the primary factors and degree of injury per insect and Crop susceptibility to injury are secondary factors Influencing ETL and EIL.

20.8 System approach

Control of insect pest population is a function of the ecosystem itself by means of natural enemies and other factors. Knowledge of the role of the principle elements of the units is essential to an understanding of population phenomenon. The study of individuals is of prime importance, their biology behaviour response to other members of the same species and to other organisms and to biotic factors in the environment. The study of individuals offers a potent method for this analysis of population change. The most effective system for controlling pests can be derived only after understanding the principles responsible for the population fluctuation in the ecosystem.

The important rational planning for effective land use to promote efficiency is well recognized. The ever increasing need for food to support growing population @ 2.1% (1860 millions) in the country demand a systematic appraisal of our soil and climatic resources to recast effective land use plan. Since the soils and climatic conditions of a region largely determine the cropping pattern and crop yields. Reliable information on agro ecological regions homogeneity in soil site conditions is the basic to maximize agricultural production on sustainable basis. This kind of systematic approach may help in planning and optimizing land use and preserving soils, environment.

India exhibits a variety of land scopes and climatic conditions those are reflected in the evolution of different soils and vegetation. There also exists a significant relationship among the soils, land form climate and vegetation. All crops cannot be grown in all types of agro climatic zones. Some crops can be possible to grow in all zones and some crops will be grown in some zones.

Every plant has its own agro-ecosystem.

Decision making in IPM requires an analysis of the ecosystem. Sampling and thresholds are important parts of this analysis. Some parts of the ecosystems interact. Now we will begin to use a method of ecosystem analysis(ESA) to facilitate discussion and decision making.

20.9 Agro-ecosystem

Agro-ecosystem is mainly created and maintained to satisfy human wants or needs. It is not a natural ecosystem but is manmade. Agro-ecosystem is the basic unit of pest management. It is a branch of applied ecology. A typical agro-ecosystem is composed of more or less uniform crop-plant population and has weed, animals (including insects) and micro-biotic communities which reacted with physical environment.

Unique features of Agro-ecosystem: It is dominated by plants selected by man and there is no diversity in species and no intra-specific diversity and is genetically uniform. Phenological events like germination, flowering occurs simultaneously. Lack of temporal continuity - due to various agricultural operations carried out by man like ploughing, weeding, pesticide application etc. Plants contain imported genetic material and nutrients are added. Outbreak of pests, weeds and diseases occur frequently.

20.9.1 Cropping system versus IPM: AESA is an approach which can be gainfully employed by extension functionaries and farmers to analyse field situations with regard to pests, defenders, soil conditions, plant health, the influence of climatic factors and their interrelationship for growing healthy crop. Such a critical analysis of the field situations will help in situations will help in taking appropriate decision on management practices. The basic components of AESA are:

i. Plants health at different stages. Monitor symptoms of diseases and nematodes.

ii. Built-in-compensation abilities of the plants.

iii. Pest and defender population dynamics.

iv. Soil conditions.

v. Climatic factors.

vi. Farmers past experience.

20.10 IPM implementation

Although IPM has been accepted in principle as the most attractive choice for the protection of agricultural crops from the ravages of insect and non insect pests, yet implementation at the farmer's fields is limited.

20.10.1 Constraints in IPM implementation

The Consultant Group of the IPM Task Force found following cconstraints in implementation of IPM in farmer's fields and these are listed below:

- **Institutional constraint:** IPM requires interdisciplinary approach to solve pest problem. Lack of coordination among different institutions is a main constraint. Lacking of farmer's need based research programme.
- **Informational constraint:** Lack of information or training on IPM among farmers and extension workers.
- **Sociological constraint:** Some farmers feel it is risky to adopt IPM compared to use of pesticides alone. Our farmers are habituated to using more pesticides.
- **Economic constraint:** Lack of funding for research, extension and farmer training needed for and accelerated programme is one of the major constraints.

- **Political constraint:** Vested interest associated with pesticide trade and pesticide subsidy given by Government.

20.10.2 Strategies for IPM implementation

Acceleration of IPM implementation requires the following

- **Farmer's participation:** Farmers must be encouraged to participate in IPM and give their views through trainings,
- **Government support:** Government can remove subsidies on pesticides and allot more funds for IPM implementation.
- **Legislative measures:** Suitable legislation (law) may be passed for adopting IPM by all farmers (IPM will be successful only if adopted on community basis).
- **Improved institutional infrastructure:** National level institution for implementation of IPM is a must. Data base on role of biotic and abiotic factors on pest population, crop yield are required.
- **Improved awareness:** Awareness should be generated at all levels on IPM i.e. Policy makers, farmers, consumers and general public. NGOs (Non Governmental Organization) should be made aware of the advantages of IPM.

20.11 Pest survey and surveillance forecasting

20.11.1 Pest Surveillance and forecasting

Pest surveillance is the systematic monitoring of biotic and abiotic factors of the crop ecosystem in order to predict the pest outbreak or it is the study of the ecology of the pest which provides the necessary information to determine the feasibility of a pest management programme. By the Pest surveillance programmes, the population dynamics and the key natural mortality factors operating under field conditions can be known which in turn helps in devising the appropriate management strategies. The important components of pest surveillance are

- Identification of the pest.
- Distribution and prevalence of the pest and its severity.
- The different levels of incidences and the loss due to the incidences.

- Pest population dynamics.
- Assessment of weather.
- Assessment of natural enemies etc.

This study will give advance knowledge of probable pest infestation and will help to plan cropping patterns and to get best advantage of pest control measures.

Forecasting for Pest Management: The Pest surveillance programmes are highly useful in forecasting of the pests. It is the advance knowledge of probable infestation by the pests in a crop. Forecasting is made through studies of population carried over several years, pest life history, effect of climate on the pest and its environment in fields and empirical data on the pests of the previous season in predictions form. Pest forecasting may serve to predict the forthcoming infestation levels of a pest which is very useful in taking control measures and to find out the critical stages at which the application of insecticides would afford maximum protection. Forecasting is mainly of two types.

- **Short term forecasting:** Covers one or two seasons mainly based on the populations of the pest within the crop by sampling methods.
- **Long term forecasting:** It covers large areas and based mainly on the possible effects of weather on the insect abundance. Ex. Locust warning stations.

Pest surveillance and monitoring in India: Pest surveillance and monitoring form an integral part of IPM technology. Directorate of Plant Protection , Quarantine and Storage (DPPQS), Faridabad, is organizing regular rapid roving pest surveys on major field crops in different agro ecosystems in collaboration with ICAR and SAU's and a consolidated report then issued by Plant Protection Adviser (PPA) to the Government of India.

20.11.2 Types of surveys

Survey is conducted to study the abundance of a pest species in particular crop in particular time and space. Qualitative survey is useful for detection of pest whereas quantitative survey is useful for enumeration of pest.

There are two types of survey is generally conducted.

(1)Roving survey (2) Fixed plot survey

Roving survey: in this survey, assessment of pest population/damage from randomly selected spots representing larger area in short period and provides information on pest level.

Fixed plot survey: Assessment of pest population/damage from a fixed plot selected in a field. The data on pest population/damage recorded periodic from sowing till harvest.

20.11.3 Remote sensing methods

Remote sensing is collection of data from a distance. Data sensors can simply be hand-held devices, mounted on aircraft or satellite-based. Remotely-sensed data provide a tool for evaluating crop health. Plant stress related to moisture, nutrients, compaction, crop pests and other plant health concerns are often easily detected in overhead images. Electronic cameras can also record near infrared images that are highly correlated with healthy plant tissue. New image sensors with high spectral resolution are increasing the information collected from satellites. Remotely sensed images can help determine the location and extent of crop stress. Analysis of such images used in tandem with scouting can help determine the cause of certain components of crop stress. The images can then be used to develop and implement a spot treatment plan that optimizes the use of agricultural inputs, rationally.

20.11.4 Factors affecting surveys

A successful survey programme consideration has to be given to the nature of the sample, mode of the samplings, the size and number of samples. The precision of a pest population estimate based on a given sampling technique would depend upon both the properties of the population in terms of its density and degree of aggregation and upon the characteristics of the sampling plan *i.e.* the number and size of the samples. Surveys are influenced by number of factors like variation in

- Behavior of an insect with change in age
- Level of activity of the pests as influenced by its diurnal cycle
- Responsiveness of sexes to trap stimuli
- Efficiency of the trap or the searching method, besides the pest population.

20.12 Risk analysis

20.12.1 Pest Risk analysis

It is an evolving and dynamic field which informs about decisions for regulatory plant protection, from domestic activities such as prioritizing pests for surveillance to making quarantine decisions regarding the importation of the products. Analysis of pest risk in plant introduction is essential to decide as to whether a particular planting material could be permitted entry or not. Such risk analysis provides sound biological basis to decide quarantine policies. The attitude towards 'entry status' of a material may be liberal or conservative depending on the risks involved in its introduction. If risks are low, quarantine would be liberal in permitting the entry.

20.12.2 Pesticides risk analysis

Risk can affect pesticide decision making either because of risk aversion or because of its influence on expected profit. Risk does not necessarily lead to increased pesticide use by individual farmers. Uncertainty about some variables, such as pest density and pest mortality, does lead to higher optimal pesticide use under risk aversion. However, uncertainty about other important variables, such as output price and yield, leads to lower optimal levels of pesticide use. In general, the pesticide dosage which maximizes expected profit is lower under risk than under certainty. Depending on the balance of forces to increase and decrease pesticide use under risk, in many circumstances the net effect of risk on optimal decision making for pest control may be minimal.

20.13 Cost benefit rations and partial budgeting

20.13.1 Cost benefit ration

As we improve the capability for predicting pest appearance, we can determine precisely the ETLs a, and know exactly when to apply control measures. There is a need to emphasize costs and benefits. The preparation of crop life tables provides a solid foundation for analysis of pest damage and, cost /benefit ration in pest management. If a crop is grown more than once in a year in the same field we should work out the crop-season life tables. In most pest control activities, the benefits are usually not known, because those cannot be measured, hence the cost of prevention becomes the cost of production. In other word the use of pesticides can rarely contribute for an increase in yield and, at best, it can prevent the loss of yield, making the benefit both indirect and incalculable.

20.13.2 Benefit risk ration

It provides the means for assessing relevant economics versus risks in pest control. The judicious use of insecticides should be the philosophy of pest management. It is estimated that generally, 1 per cent of the insecticides applied reaches the target pest and the rest merely contaminate the environment as residue or causes mortality of the non target or even useful species. Some non degradable insecticides, such as the chlorinated hydrocarbons, attain biological magnification in the environment through food chains. Thus a grower while ensuring safety in handling and applying a higher toxic pesticide should also consider its injurious effects in the environment.

20.13.3 Partial budgeting

It is also known as marginal analysis or incremental analysis. This is an estimate of the net benefit from a small change to a farm operation in order to guide a farm decision. It focuses only on the things that change to increase the net profit. In this budgeting, build on enterprise budgets only, do not make budget for each enterprise completely. In this budget, holds all else fixed and evaluate effect of a small change is done in practice. In IPM, partial budgeting is made for specific management practices change for particular pest.

20.14 Summary

IPM is the development of a set of management tactics or practices (cultural, physical, mechanical, biological, chemical, genetic, behavioural etc.) that maintain pest populations at economically low level with as little disturbance to the ecosystem particularly the beneficial insects and natural enemies as may be absolutely necessary. Chemical intervention is minimal or a last device and other measures are given due consideration. It is essentially non-prescriptive, which means that the farmers must understand it and practise it intelligently. The IPM practices vary with plants; therefore, we need to develop IPM strategies against pests of each crop in every habitat. Understanding of EIL and EIL and pest surveillance are important aspects for implementation of IPM. Pest and pesticides risk analysis are also essential parameters for making quarantine decisions regarding the importation of the products.

20.15 Glossary

- **Antibiosis:** It refers to the harmful effects of host plant on the insect due to the presence of some toxic substances or absence of required nutritional components
- **Aspermia:** Inactivation of sperms
- **Augmentation**: It is the rearing and releasing of natural enemies to supplement the numbers of naturally occurring natural enemies.
- **Auto-Sterilization:** Sterilization of native insects in their natural environment by using chemosterilants along with the species specific attractants / lures/ bait traps.
- **Economic Threshold Level:** It is the population density at which control measures should be applied to prevent increasing pest population from reaching the economic injury level.
- **Ecto-hormone:** Chemicals that is secreted into the external environment by an animal and that elicits a specific response in a receiving individual of the same species.
- **Incremental analysis**: It is an estimate of the net benefit from a small change to a farm operation in order to guide a farm decision.
- **Parasite:** It is an organism which is usually much smaller than its host and a single individual usually doesn't kill the host.
- **Poison Baits:** These are a mixture of food lures and insecticides.

20.16 Self Learning Exercise

Section -A (Very Short Answer Type)

1. The density of pest population at which control measures should be applied is known as ________________.
2. Pest population that produces incremental damage equal to the cost of preventing the damage is called as__________________.
3. NCIPM is situated at _________________.
4. Who got World Food prize in the field of IPM?
5. _______________ is the phenomena of obtaining nourishment at the expense of the host to which the parasite is attached.

6. Crop rotation is most effective practice against pests that have a narrow_________________ and _______________.

Section -B (Short Answer Type)

1. Define EIL and ETL?
2. Differentiate between cost benefit and benefit risk ration?
3. What is pest surveillance?
4. Explain pesticide risk analysis?
5. What are the types of survey?
6. Write a short note on genetic control?
7. Write differences between aggregation and trail pheromone?

Section -C (Long Answer Type)

1. Outline various practices applied in the insect pest management?
2. What are the strategies for implementation of IPM?
3. Write down in brief the IPM practices should follow in cotton agro-ecosystem?
4. Define the IPM and write down the concept and principles of IPM?
5. Write in detail about insect attractants?

Answer Key of Section-A

1. Economic Threshold Level
2. Economic Injury Level
3. New Delhi
4. Ray F. Smith and Perry Adkisson
5. Parasitism
6. host range and dispersal activity

20.17 References

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