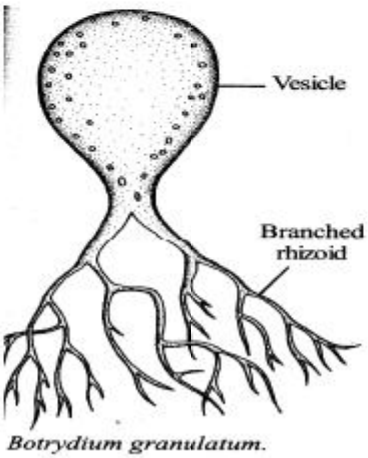
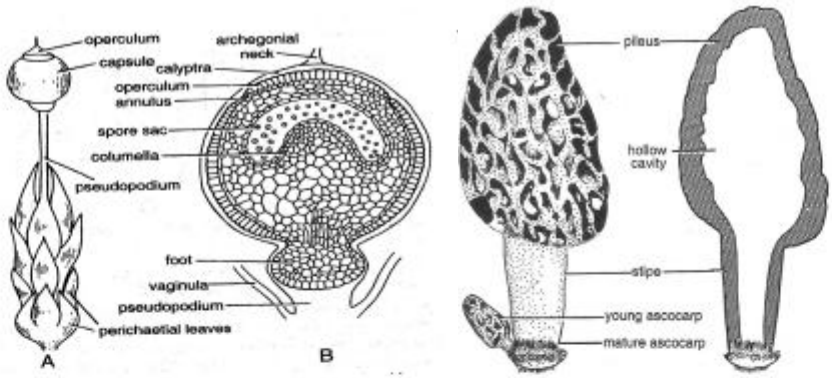
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Botrydium granulatum.



Biology and Diversity of Microbes and Non-Vascular Cryptogams

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Preface

The present book entitled "**Biology and Diversity of Microbes and Non-Vascular Cryptogams**" has been designed so as to cover the unit-wise syllabus of MBO-01 course for M.Sc. Botany (Previous) 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. The unit writers have consulted various standard books on the subject and they are thankful to the authors of these reference books.

Unit - 1

Bacteria: Archaebacteria and Eubacteria

NOTES

Structure of the Unit

1.0 Objectives
1.1 Introduction
1.2 Archaebacteria
  1.2.1 Methane producing bacteria
  1.2.2 Halobacteriaceae
  1.2.3 Thermoacidophiles
1.3 Eubacteria
1.4 General Account of Bacteria
1.5 Structure of Bacteria Cell
1.6 Nutrition
1.7 Reproduction
  1.7.1 Asexual Reproduction
  1.7.2 Sexual Reproduction
1.8 Economic Importance of Bacteria
1.9 Summary
1.10 Glossary
1.11 Self-Learning Exercise
1.12 References and further readings

1.0 Objectives

After going through this unit you will be able to understand about :

- General characters of Eubacteria and Archaebacteria.
- Types of Archaebacteria.
- Ultrastructure, nutrition and reproduction of Bacteria.
- Economic importance of Bacteria.

NOTES

1.1 Introduction

Bacteria are found in every habitat on Earth: soil, rock, oceans and even arctic snow. Some live in or on other organisms including plants and animals including humans. There are approximately 10 times as many bacterial cells as human cells in the human body. A lot of these bacterial cells are found lining the digestive system. Some bacteria live in the soil or on dead plant matter where they play an important role in the cycling of nutrients. Some types cause food spoilage and crop damage but others are incredibly useful in the production of fermented foods such as yoghurt and soy sauce. Relatively few bacteria are parasites or pathogens that cause disease in animals and plants.

1.2 Archaebacteria

These bacteria differ from true bacteria (eubacteria) in respect of organisation and chemical composition of their cell wall and cell membrane. Their 16s rRNA molecules also differ from other bacteria and ribosomes are insensitive to chloramphenicol. They are also unique in inhabiting extreme environments. Such physiological features coupled with morphological and structural differences make them distinct from true bacteria. They appear to be primitive bacteria and erected to the status of a kingdom, distantly related to other prokaryotes.

They include the methanogens of anaerobic muds; the extreme red halophiles; the salt loving bacteria of saturated brine and salted fish; and the thermoacidophiles, found in hot sulphur spring or smouldering coal wastes. It is suggested that they represent a very ancient lineage which diverged from the eubacteria very early in evolutionary process, and have survived only in these specialised ecological niches. They include the following three groups:

1.2.1 Methane-producing bacteria

They, also known as methanogens represent a highly specialised physiological group. Members of the family Methanobacteriaceae form methane by the reduction of carbon dioxide. They are very strict obligate anaerobes. In order to produce methane they utilise electrons generated in the oxidation of hydrogen or simple organic compounds, such as acetate and methanol. They are unable to

use carbohydrates, proteins or other complex organic substrates. Methanogens often form consortia in association with other microbes. Microbes associated with methanogens maintain the low oxygen tensions and provide the carbon dioxide and fatty acids required by the methanogens. Such associations are extremely important in the rumen of herbivore animals as cow. A major source of atmospheric methane is the rumen of these animals.

NOTES

Methanogenic bacteria may have been among the earliest living organisms on earth because they can grow autotrophically (chemoautotroph's) on hydrogen and carbon dioxide under anaerobic conditions and it is presumed that the early atmosphere of the earth would have permitted the growth of just such organisms. Methanogens can be differentiated on the basis of relatively few morphological and physiological features

Table 1.1: The Methanogenic Bacteria

Order Family	Methanobacteriales *Methanobacteriaceae.*	Cells short rods, lancet-shaped cocci to long filaments; cells appear Gram-positive but lack murein; strict anaerobes; oxidise hydrogen; reduce CO_2 to CH_4.
Genera :	*Methanobacterium* *Methanobrevibacter*	Slender rods often forming filaments. Short rods or lancet-shaped cocci often in pairs or chains.
Order Family	Mcthanococcales Methanococcaceae	Cells cocci; oxidise hydrogen or formate; reduce CO_2 to

NOTES

Genus	*Methanococcus*	CIH_4; Gram-negative, with protein units external to cell membrane.
Order	Methano microbiales	Cocci single, in pairs or clumps. Cells cocci to rods; Gram- negative or Gram-positive; motile or non-motile; strict anaerobes; oxidise hydrogen or format; reduce CO_2 to CH_4 or form CH_4 via fermentation of methanol and related compounds.
Family	Methanomicrobiaceae	Gram-negative cocci to rods. Short motile rods Irregular coccoid cells curved, slender motile rods often forming filaments.
Genera	*Methanomicrobium Methanogenium Methanospirillum*	
Family	Methanosarcinaceae	Gram-positive coccoid cells occurring in packets.
Genus	*Methanosarcina*	

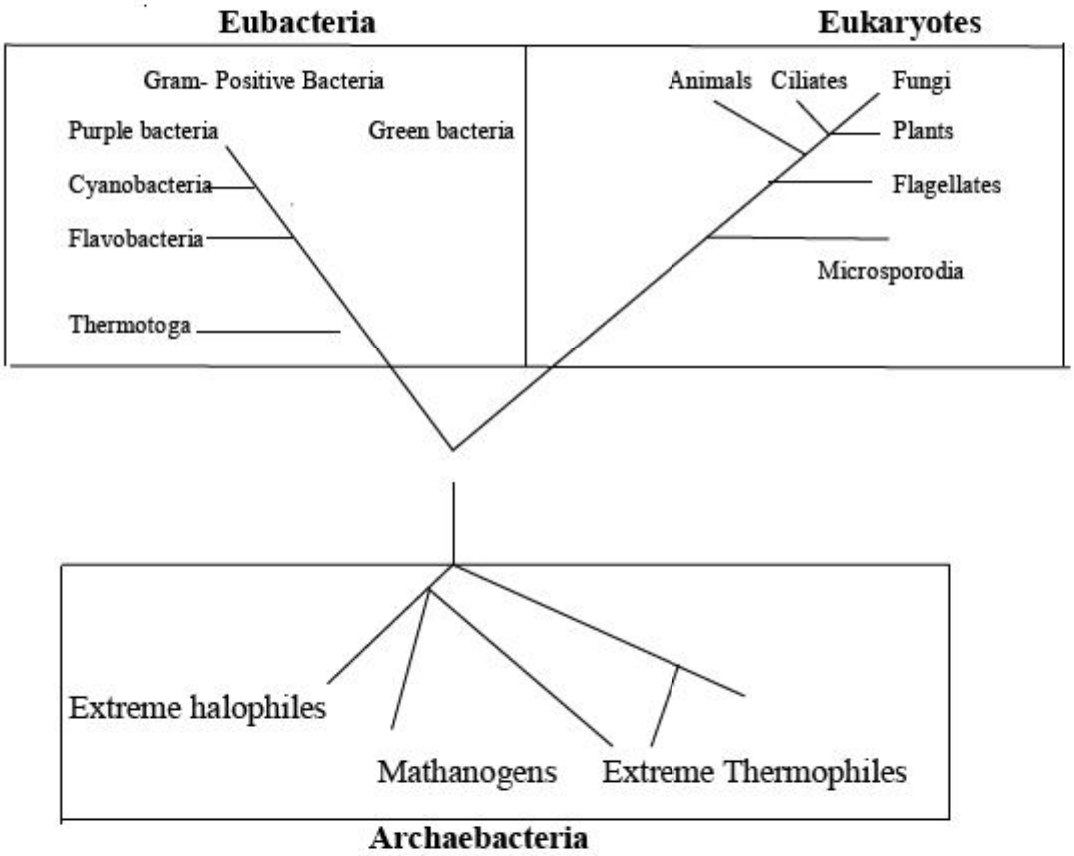
1.2.2 Halobacteriaceae

The genera *Halobacterium* and *Halococcus* of this family have the characteristic features of archaebacteria. *Halobacterium* possesses the unusual bacteriorhodosporin - mediated phototrophic metabolism. Besides this unique feature, all members of this family are obligate halophiles, growing only in media containing at least 15% NaCl They are found in ecosystems having extremely high NaCl concentrations, such as salt lakes, the dead sea, and foods preserved by salts.

1.2.3 Thermoacidophiles

They include members of the genera like Thermus and sulpholobus. The members of sulphur-oxidising genus, *Sulpholobus,* on the basis of staining reactions, have been characterised as Gram-negative spherical cells. The cell walls of Sulpholobus lack murein. They also have other features of archaebacteria including rRNA homology and membrane structure. They are thermophiles with an optimum growth temperature of 70-750C *Sulpholobus* spp. Occur in hot, acidic environments (thermoacidophiles). Habitat conditions in which these groups of archaebacteria are found in nature are considered as microorganisms of extreme environments.

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1.3 EUBACTERIA

These are unicellular, prokaryotic, microscopic organisms. Leeuwenhoek discovered them from his teeth scrapings first and named them as animalcules.

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Ehrenberg gave the term bacterium. The significance of bacteria was known due to the works of Louis Pasteur and Robert Koch. They observed the pathogenic nature of bacteria in plants, animals and men. Earnest Haeckel placed bacteria in the kingdom Protista. Some of the scientists placed them in Schizomycetes because of their mode of reproduction by fission. Whittaker, in his five kingdom classification placed them under kingdom Monera that also includes another group of organisms known as Blue Green algae.

1.4 General Account of Bacteria

They are cosmopolitan in distribution. They can withstand extreme cold (-190°C) and heat (75°C) and drought. Some are parasitic on animals, plants and man and some others are saprophytic. Some are bacteria grow as symbionts in the root nodules of angiosperm (*Rhizobium*) *Escherichia coli* are common inhabitant of human intestine.

Size

The size of most of the bacteria ranges from 0.5 to 1.0 in breadth and 2.0 to 5.0 in length. The size of bacterium *Epulopiscium fishelsoni* present in the intestine of brown Surgeon Fish *Acanthurus nigrofuscus)* is 200 to 50. It is a bacillus. The recently discovered largest bacterium is *Thiomargarita namibiensis*.

Shape

It differs from one bacterium to the other. Spherical bacteria are known as Cocci. A single spherical bacterium is known as Monococcus, two spherical cells as Diplococcus, a group of spherical cells as Tetracoccus, a chain of spherical cells as Streptococcus, a group of spherical cells arranged irregularly in three planes as Staphylococcus and spherical cells arranged in cuboid manner as *Sarcina*.

Bacilli are rod shaped bacteria. They are monobacillus with a single rod like cell, Diplobacillus with two rod like cells and Streptobacillus with a chain of rod cells. Vibrios are comma shaped bacteria. Spirillae are bacteria with completely coiled, body. Flexible spirillae are called as Spirochaetes. Some bacteria are in the form of thread of filament e.g. *Beggiatoa.*

Bacteria without definite shape are known as Pleomorphic bacteria and the phenomenon is known as Pleomorphism. e.g. *Acetobacter* It occurs in the form of small rods, long rods, ellipsoid or a chain of small rods.

Gram's stain

NOTES

Christian Graham Gram developed bacterial, staining technique. He classified bacteria into Gram +ve and Grame. The bacteria are stained with crystal violet and later with iodine. These are transferred to ethanol or acetone. Some bacteria retain their purple colour after ethanol treatment and they are called as Gram +ve bacteria. Some bacteria lose the purple colouration and they are called Gram -ve.

1.5 Structure of Bacterial Cell

It is prokaryotic cell because it lacks nuclear envelope.

Cell wall

It is present around the protoplast. It is made up of two several layers of peptidoglycan Mucopeptide. Teichoic acid is absent in Gram-ve bacteria but present in Gram +ve bacteria.

Functions of Cell wall

It gives a definite shape to the cell. It protects the cell from osmotic lysis and toxic substances. Cell wall components contribute for the pathogenic nature of bacteria. It is the site for the action of antibiotics.

Structures present peripheral to the cell wall

These structures are glycocalyx, flagella and pili. Glycocalyx and Slimy layer.

Glycocalyx is present as a layer outside the cell wall. It consists of polysaccharides and very rarely proteins. 'It aids in attaching to solid objects of aquatic environments and tissue surfaces of plants and animal hosts. If it is in the form of a loose sheath, it is called as Slime layer. It protects the cell from loss of water and nutrients. If the glycocalyx closely invests the cell wall, it is

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called as Capsule. Capsule gives gummy or sticky nature to the cell. It is immunogenic and protects the cell, from desiccation. S-layer is made of proteins or glycoprotein's and present around the cell wall of many gram+ve bacteria and some. Gram-ve bacteria. It protects the bacterial cell from pH fluctuations, osmotic stress, enzymes and predaceous bacteria such as *Bdellovibrio bacteriovorous*. It also contributes for the virulence of the pathogen.

ii) Flagella

These are slender, elongated coiled structures that arise from basal granule of protoplasm and involved in locomotion. These are usually present in bacilli, vibrios and spirillae. These are absent in cocci and some bacilli. These are 1 to many in number. Atrichous bacteria do not have flagella. Monotrichous bacteria have a single flagellum on only one side of the cell. Lophotrichous bacteria have a tuft of flagella at only one end of the cell. Amphitrichous bacteria have flagella at both the ends of cell. Peritrichous bacteria have flagella all over the body. Bacterial flagella lack 9 + 2 structure. They have three long coiled filaments made of protein called as flagellin. Flagellum rotates around the axis during movement of the bacterium.

iii) Pilli of fimbriae:

These are short, straight, slender and rigid appendages of bacteria. These help in adhering to other surfaces organisms. These are usually present in Gram—ve bacteria. A Gram +ve bacterium known as *Corynebacterium renale* also has pili. These are around 1000 in number and made of a protein known as pilin. Sex pili are larger than normal pili and present in F+ strain bacteria. These are helical tubules with a hollow core. These are few in number. They help in conjugation for binding to the F^- strain and establishing conjugation canal.

Protoplast

It is demarcated into three regions known as cell membrane, cytoplasm and nucleoid.

Cell membrane

It is lipoproteinaceous differentially permeable membrane present around the protoplasm. It helps in maintaining the turgor and osmoregulation. In +ve bacteria, it is invaginated into protoplasm to form globular finger like structures known as Mesosomes. Mesosomes take part in the formation of daughter cells during binary fission, replication of chromosome and the distribution of daughter chromosomes into daughter cells and increase in absorption of nutrient.

NOTES

Cytoplasm

It consists of ribosomes, chromatophores, reserve food materials and other organic and inorganic Substances. The ribosomes are of 70 S types and occur as groups known as Polysomes or Polyribosomes. Chromatophores are groups of membrane bound tubular or flattened or spherical vesicles. They have chlorophylls, proteins and lipids. Reserve food material is present in the form of glycogen or poly hydroxy butyrate granules. Gas vacuoles with organic inclusion bodies are seen in purple and green photosynthetic bacteria and some other aquatic forms. These are aggregates of a number of small, hollow cylindrical vesicles, these are not permeable to water but permeable to gases. These help the bacteria to float on or near the surface of water.

Nucleoid

It is the region of bacterial protoplasm with its only circular chromosome made of only double stranded DNA. Extrachromosomal DNA rings seen in some bacteria are known as plasmids or episomes. These have genes for fertillty factor, antibiotic resistance, new pathogenic abilities, metabolic pathways and tumor inducing abilities. Plasmids occur either freely or in integrated form with the main chromosomes. They can replicate themselves irrespective of replication of main chromosome.

Plasmids are of 1. F-plasmids 2. R-plasmids 3, Col plasmids.

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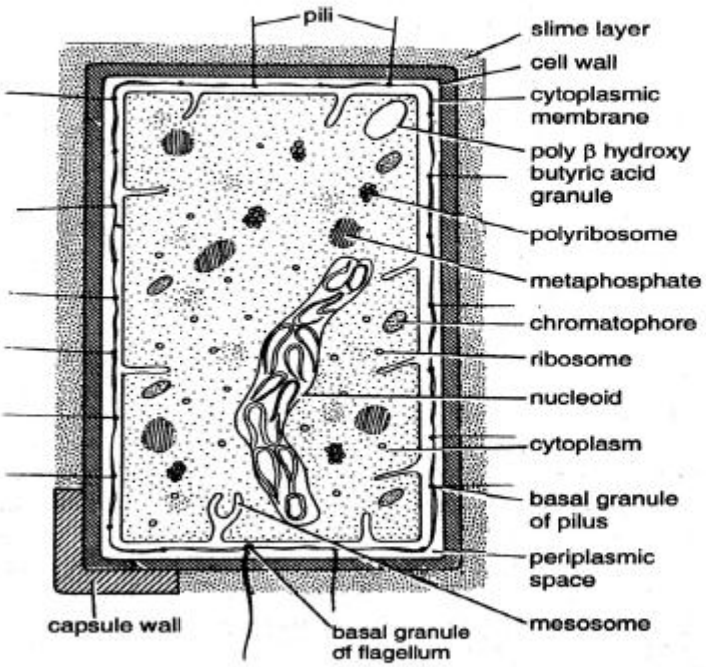


Fig. 1.1 : Bacterial Cell

1.6 Nutrition

Based on the carbon source utilised, bacteria are classified into Autotrophs and Heterotrophs. Autotrophic bacteria derive their carbon from either CO_2 or Carbonates.

Heterotrophic bacteria, obtain their carbon from organic substances like glucose and amino acids.

Photoautotrophic bacteria have chlorophyll, obtain their carbon from CO_2 and utilise the sunlight as energy source e.g. Purple Sulphur Bacteria (*Chromatium*), Green Sulphur Bacteria (*Chlorobium*).

Photoheterotrophic bacteria obtain energy from sunlight and carbon from organic sources, e.g.: Purple Non-Sulphur bacteria (*Rhodospirillum, Rhodopseudomonas* and *Rhodomicrobium).*

Chemoautotrophic bacteria obtain their energy from the oxidation of inorganic substances and carbon from CO_2. These are Hydrogen bacteria that oxidise

hydrogen in the presence of oxygen (*Hydrogenomonas*), Sulphur bacteria that oxidise elemental sulphur into Sulphuric acid (Thiobacillus thio oxidlans) and H_2S into elemental sulphur (*Beggiatoa*), Iron bacteria that oxidise ferrous iron to ferric iron (*Ferrobacillus*) and nitrifying bacteria that oxidise NH_3 into nitrites (nitrosomonas) and nitrites into nitrates (*Nitrobacter*).

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Chemoheterotrophs derive both carbon and energy from organic substances such as glucose and amino acids. These are symbionts, saprophytes and parasites.

Saprophytes grow on dead decaying organic matter (*Bacillus*).

Parasites grow in or on other living organisms and cause diseases in them *Xanthomonas, Salmonella). Bdellovibrio bacteriovorous* is parasitic on other parasitic bacteria.

Symbiotic bacteria grow in other organisms in mutual beneficial association (*Rhizobium* of root leguminous root nodules).

1.7 Reproduction

Bacteria reproduce asexually and sexually.

1.7.1 Asexual reproduction

Asexual reproduction takes place by binary fission and endospore formation.

Binary Fission

It is the most common type of reproduction occurs in favorable conditions. The cell slightly elongates and the DNA is replicated into two daughter DNA molecules. In the mean time the plasma membrane invaginates at the middle of the cell at mesosomal area and advances towards the centre to divide the protoplasm into two units. Later a furrow appears at the centre of the cell and deepens in centripetal manner to divide the cell into two daughter cells. The bacterium undergoes binary fission once in every 18 - 20 minutes.

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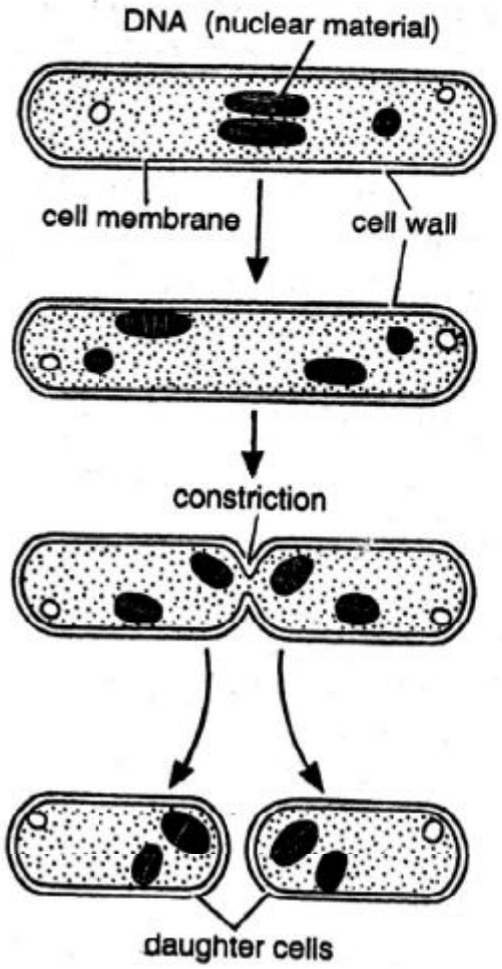


Fig. 1.2: Binary Fission in Bacteria

Endospores

These are formed in unfavorable conditions (dry and nutrient deficiency) in bacteria like *Bacillus* and *Clostridium.* Usually a single endospore is formed in a cell. Sometimes two endospores are formed. It is spherical or oval in shape. It consists of DNA, small amount of RNA and large amount of organic acids (dipicolinic acids). Its protoplasmic content is surrounded from periphery towards the centre by a delicate pore, wall, thick layered cortex and several protein layered Spore coat. In some cases a thin delicate covering exosporium is present around the spore coat. Endospore is terminal, sub terminal or central in position. Endospores are liberated after their maturation from the parental cell wall and dispersed through wind. They are dormant for months and years.

Under suitable environmental conditions, they germinate and give rise bacterial cells.

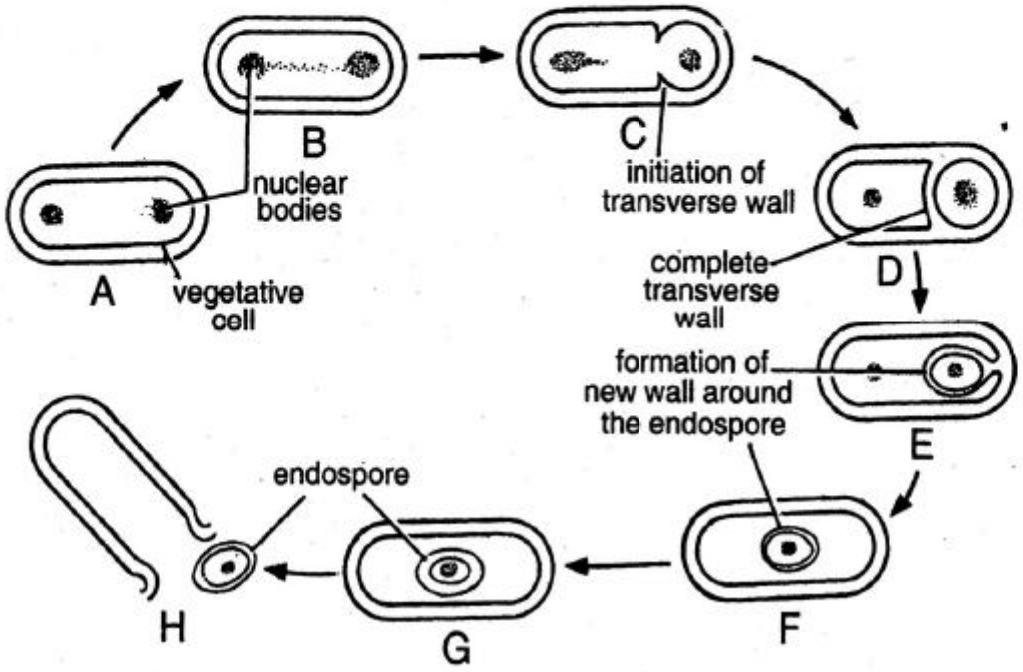


Fig. 1.3: Endospore Formation

1.7.2 Sexual Reproduction

True sexual reproduction is absent in bacteria. They show genetic recombination that occurs by means of transformation, conjugation and transduction.

Transformation

It is absorption of naked DNA molecule by a bacterium from its surroundings and its incorporation into its DNA to change into a new heritable form. Griffith discovered it in *Streptococcus pneumonia*. It is seen in soil and marine bacteria belonging to Gram +ve and Gram -ve such as *Streptococcus, Bacillus, Azotobacter* and *Pseudomonas*. The naked DNA of the surroundings is bound to the cell wall of recipient bacterium with the help of DNA binding protein of bacterium. Endonucleases cleave the bound DNA into small segments. One strand of each DNA fragment is hydrolysed by the exonucleases. The other

strand is associated with small competence proteins moves into the protoplasm through plasma membrane. The competence specific proteins are associated with the undegraded single strand, and integrate it the homologous portion of host DNA.

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Conjugation

It is transfer of genetic material due to cell-to-cell contact. Lederberg and Tautum discovered it in *Escherichia coli*. It is of the following two types.

i) F+ x F$^-$

E coli have two strains known as F^+ (donor) and F^- (Recipient) strains. F^+ strain has a plasmid for fertility and sex pili. F stain lacks these two. The F plasmid replicates and forms two daughter plasmids. The F^+ strain adheres to F^- strain with the help of sex pili and establishes conjugation canal through which the F plasmid is incorporated into the F^- strain to transform the F^- to F^+ strain.

ii) HFr x F- mating

HFr means High Frequency recombination strain. In this the F plasmid is integrated into the main chromosome. The HFr strain adheres to the F- strain and establishes conjugation canal. The HFr chromosome is opened at the point of insertion of plasmid. The main part of the replicated chromosome and rarely a part of the plasmid present rear end enters into the F- strain and exchanges the genetic material. In this the F- cannot be converted to F because there is no complete entry of plasmid part.

Transduction

It is transfer of genetic material from one bacterium to another bacterium through bacteriophage. Lederberg and Zinder discovered it in *Salmonella typhimurium*. It takes place during lytic and lysogenic cycles of bacteriophages during which a part of bacterial chromosome is not degraded is transferred.

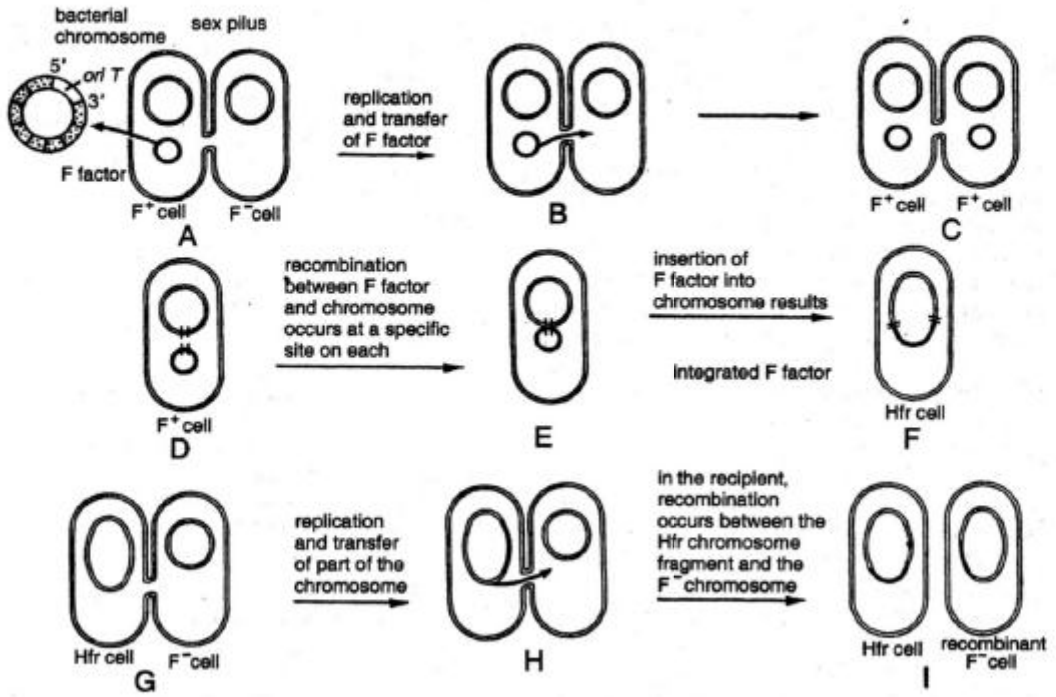


Fig. 1.4 : Transduction in Bacteria

1.8 Economic Importance of Bateria

Some bacteria are beneficial to mankind and some other bacteria cause diseases in man, animals and plants. Hence they are considered as Friends and Foes of man.

Beneficial activities

Bactria has important role in Bio-geo-chemical cycles. Saprophytic bacteria decompose the dead bodies of plants and animals and convert them to minerals by humification and mineralisation. The plants absorb these minerals. In this way they not only help in recycling of materials but also clean the environment. That is why bacteria are described as scavengers of nature.

Agriculture

Bacteria help in maintaining and increasing soil fertility. Ammonifying bacteria such as *Bacillus* liberate ammonia from nitrogenous organic substances such as nucleic acids, proteins and aminoacids. Among nitrifying bacteria, *Nitrosomonas* converts ammonia into nitrite and *Nitrobacter* converts nitrite

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into nitrate. Photosynthetic bacteria *(Chlorobacterium, Rhodospirillum, Rhodomicrobium)*, non-symbiotic bacteria (*Azotobacter, Azospirillum, Clostridium)* and symbiotic bacterium *Rhizobium* are nitrogen fixing bacteria. They convert the nitrogen of atmosphere into ammonia and increase soil fertility. *Bacillus thuringiensis* is used as bioinsecticide to eradicate larvae of disease causing insects.

iii. Industry

Table – 1.2 Role of Bacteria in Industry

S.No.	Industry in which the bacterium is employed	Bacterium
1	Tanning industry	Some bacteria
2	Retting of Sunhemp and	*Clostridium butyricum, C. butyricum*
3	Flax fiber	*Bacillus megatherium*
4	Tobacco curing	*Micrococcus*
5	Tea curing	*Lactobacillus*
6	Milk fermentation	*Methanococcus, Methanobacillus*
7	Gobar gas (methane gas) production	*Clostridium acetobutylicum*
8	Acetone, Butane	*Acetobacter aceti, A.pasteurianum*
9	Vinegar (Acetic acid)	*Lactobacillus delbruckil*
10	Lactic acid	*Propionibacterium propionum*
11	Propionic acid	*Zymomonas mobilis, Thermoanaerobacter ethanolicus*
	Ethanol	

iv. Medicine

Corynebacterium glutamiclum produces an essential amino acid Lysine. Diphtheria and Pneumonia vaccines are produced by employing bacteria.

Several antibiotics are produced by using bacteria such as Streptomyces, Bacillus species.

V. Biotechnology

NOTES

Genetically engineered *E. coli* is used for the production of human insulin known as humulin. It is also used to crack various secrets of biochemistry, molecular biology, genetics and physiology. Bacteria such as *Brevibacterium* are used as Single Cell Proteins. Plasmid of *Agrobacterium tumefaciens* is used as vector in plant genetic engineering. *Bdellovibrio bacteriovorous* purifies the water of Ganges by parasitising on harmful bacteria.

2. Harmful activities

i. Spoilage of Food materials

Achromobacter, Pseudomonas, Proteus, Flavobacterium, Micrococcus, Clostridium, Salmonella, Staphylococcus etc. grow on different food stuffs and render them useless for consumption. *Clostridium botulinum* releases a potential toxin known as botulin. It is responsible for the disease Botulism or Food poisoning.

ii. Denitrification

Some bacteria like *Thiobacillus denitrificans* liberate molecular nitrogen from inorganic nitrogenous substances such as nitrates, nitrites and decrease soil fertility.

iii. Plant diseases

About 170 species of bacteria cause diseases in plants.

Table-1.3: Plant Diseases caused by Bacteria

S.No.	Plant disease	Bacterium
1	Blight of Rice	*Xanthomonas*
2	Angular leaf spot of cotton	*oryzae*
3	Citrus canker	*X. malvacearum*
4	Solanacearum	*X. axonopodis citri*
5	Agrobacterium	*Pseudomonas*

6	Crown galls of apple & pear	*tumefacien*
7	Fire blight of apple	*Erwinia amylovora*

iv. Human diseases

NOTES

Table-1.3: Human Diseases caused by Bacteria

S.No.	Disease	*Bacterium*
1	Dysentery	*Bacillus dysentery*
2	Diphtheria	*Corynebacterium diphtheria*
3	Cholera	*Vibrio cholerae*
4	Typhoid	*Salmonella typhi*
5	Pneumonia	*Diplococcus pneumonia*
6	Tuberculosis	*Mycobacterium tuberculosis*
7	Leprosy	*M. leprae*
8	Plague	*Pasteurella pestis*
9	Gonorrhea	*Neisseria gonorrhoea*
10	Tetanus	*Clostridium tetani*
11	Syphilis	*Treponema pallidum*

v. Animal diseases

Table-1.3: AnimalDiseases caused by Bacteria

S.No.	**Diseases**	**Bacterium**
1	Anthrax of sheep	*Bacillus anthracis*
2	Tuberculosis of dog's cattle etc.	*Mycobacterium*
3	Actinomycosis of cattle Vibriosis	*Tuberrculosis*
		Mycobacterium bovis
		Vibrio tetus

1.9 Summary

Bacteria are single celled microbes. The cell structure is simpler than that of other organisms as there is no nucleus or membrane bound organelles. Instead their control centre containing the genetic information is contained in a single loop of DNA. Some bacteria have an extra circle of genetic material called a plasmid. The plasmid often contains genes that give the bacterium some advantage over other bacteria. For example it may contain a gene that makes the bacterium resistant to a certain antibiotic.

NOTES

Bacteria are classified into 5 groups according to their basic shapes: spherical (cocci), rod (bacilli), spiral (spirilla), comma (vibrios) or corkscrew (spirochaetes). They can exist as single cells, in pairs, chains or clusters.

1.10 Glossary

- **Bacterium** (plural: bacteria): A one-celled microorganism that contains no nucleus. Some bacteria are helpful, such as those in the intestines that help digest food, while others cause disease. Bacteria are frequently used as model organisms to study basic biological processes. See prokaryotic cell and model organism.
- **Microorganisms:** A microscopic form of life including bacteria, viruses, fungi, protozoa and some multicellular parasites.
- **Pili:** Short, hair like appendages of bacteria that anchor the cell to surface, pili are also involved in fluid is taken into the cell.
- **Plasmid:** A small closed loop molecule of DNA apart from the chromosome, plasmids carry genes for drug resistance and pilus formation and are used in genetic engineering experiments.
- **Microbiology:** The study of microorganisms, such as bacteria, viruses and parasites.
- **Cilium (cilia, plural):** A tiny hair-like structure on the surface of some micro-organisms or cells which beats rhythmically to either propel trapped material out of the body, for example in the lungs, or make a free-living microbe to move.

NOTES

- **Autotroph :** An organism that uses CO2 as its sole or principal source of carbon.
- **Antibiotic:** A microbial product or its derivative that kills Susceptible microorganisms or inhibits their growth.
- **Bacillus:** A rod shaped bacterium.
- **Coccus:** A roughly spherical Bacterial Cell.
- **Coccus Colony:** A cluster or Assemblage of microorganisms growing on a solid surface such as the surface of an agar culture medium; the assemblage often is directly visible, but also may be seen only microscopically.
- **Chemolithotrophic autotrophs :** Microorganisms that oxidize reduced inorganic compounds to derive both energy and electrons; CO2 is their carbon source. Also called chemolithoautotrophs.
- **Chemoorganotrophic heterotrophs :** Organisms that use organic compounds as sources of energy, hydrogen, electrons, and carbon for biosynthesis.
- **Endospore:** An extremely heat and chemical resistant, dormant, thick-walled spore that develops within bacteria.
- **Episome :** A plasmid that can exist either independently of the host cell's chromosome or be integrated into it.
- **Fimbri :** A fine, hair like protein appendage

1.11 Self-Learning Exercise

Section -A (Very Short Answer Type Questions)

1. Differentiatiae between protista and monera.
2. Define pathogenicity.

Section -B (Short Answer Type Questions)

1. Write short notes on:

   (a) Photosynthetic bacteria

   (b) Morphotypes of bacteria

2. Write short notes on Bacteria:

A. Mode of reproduction

B. Mode of dormancy

C. Mode of vegetative multiplication

NOTES

Section -C (Long Answer Type Questions)

1 Describe the general structure of flagella in Gram-negative bacteria with labeled diagram.

2. Write a brief note on types of bacterial on the basis of their shapes.

3. Describe the general structure of cell wall of Gram-negative bacteria with labeled diagram.

4. Write a brief note on bacterial structures external to cell wall.

1.12 References and further readings

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NOTES

Unit- 2

Cyanobacteria and Economic Importance of Algae

Structure of the unit

2.0 Objectives
2.1 Introduction
2.2 Cyanobacteria: Salient Features
- 2.2.1 Distribution
- 2.2.2 Classification
- 2.2.3 Vegetative Structure
- 2.2.4 Cell Structure
- 2.2.5 Movement
- 2.2.6 Heterocyst and Nitrogen fixation
- 2.2.7 Reproduction

2.3 Biological Importance of *Microcystis* and *Spirulina*
2.4 Economic Importance of Algae
2.5 Summary
2.6 Glossary
2.7 Self-Learning Exercise
2.8 References and further reading

2.0 Objectives

After studying this unit you will be able to understand:

- Salient Features of Cyanobacteria and its important role in nitrogen fixation
- Biological importance of *Microcystis* and *Spirulina*
- Economic importance of algae

2.1 Introduction

The cyanobacteria are the largest and most diverse group of photosynthetic bacteria. They deserve special emphasis because of their great ecological importance in the global carbon, oxygen and nitrogen cycles, as well as their evolutionary significance in relationship to plants.

NOTES

Cyanobacteria are true prokaryotes and have characteristic photosynthetic pigments including biliproteins (Phycocynin, Phycoerythrin & Allophycocynin) in addition to Chlorophyll a and B- Carotene. They carry out oxygenic photosynthesis. Cyanobacteria use phycobiliproteins as accessory pigments.

They were formely classified as blue-green algae due to possession of chlorophyll rather than bacteriochlorophyll and their photosynthesis production of oxygen by a two- photo system process as in algae and higher plants but they differ from most of other algae being prokaryotes and the recent trend among scientists is to call them cyanobacteria, in order to emphasize their close relationship with bacteria.

According to fossil records they have existed for approximately 3.5 billion year ago. Layered chalk deposits called stromatolites, which exhibit a continuous geological record covering 2.7 billion years, are produced when colonies of cyanobacteria bind calcium rich sediments.

The photo autotrophic algae are the major producers of organic materials and they play a key role at the base of food chain. Besides this their extracts have a potential role in manufacture of human welfare products in various uses however certain algae also play nuisance role.

2.2 Cyanobacteria: Salient Features

2.2.1 Distribution

Their distribution is cosmopolitan. They are predominantly fresh water, a few species are marina. Often some are planktonic, inhabiting the surface layers of water, forms dense bloom. The cyanobacteria are the only organisms that grow in adverse and harsh environment i.e. hot springs: *Colteronema, Synechoccocus, Heterohormogonium,* even they can grow on snow. Certain cyanobacteria are

symbiont of bryophytes within thallus of *Anthoceros*, ferms in fronds of *Azolla* and gymnosperms roots of *Cycas* (*Nostoc, Anabaena*) and also photosynthetic partner in the formation of Lichens. Certain cyanobacteria form intracellular & extracellular symbiotic association with other organisms and help in Nitrogen fixation.

NOTES

2.2.2 Classification

Cyanobacteria include 5 orders (Fritsch 1945) given in table 2.1:

Table 2.1 Classification of Cyanobacteria (Fritsch 1945)

S. No.	Order	Salient features
1	Chroococcales	Single cell or cells loosely bound into gelatinous, irregular colonies.
2	Pleurocapsales	Filaments without hetrocysts. Thallus is divided into an erect and prostate system (heterotrichy).
3	Nostocales	Fillamentous thallus without true branching and with no heterotrichy. Heterocysts are commonly present. Reproduction is mostly by hormogonia and akinetes.
4	Chamaesiphonales	Epiphytes with a thallus showing polarity, where multiplication is by endospores or exospores.
5	Stigonematales	Filamentous thallus with true branching and heterotrichy

2.2.3 Vegetative Structure

The thallus comprises of unicellular, Colonial (palmelloid), filamentous and hetrotrichous forms.

- Unicellular forms are with only one cell (*Synechococus, Synechocystis*).
- Colonial forms formed as unicellular individuals are retained in common matrixe of mucilage (*Chroococus, Gleococapsa, Anacystis*).
- Filamentous type unbranched thallus consists of cell arranged end to end. It includes the row of cells as well as the surrounding gelatinous sheath, if it consists of cells without a distinct sheath; it is designated as tricome (*Oscillatoria, Arthrosprira, Spirulina, Gleotrichia*).
- Hetrotrichous: Two types of branching are present.

I. False branching: When more than one trichome is present within the common sheath, the filaments appears to be branched (*Scytonema, Tolypothrix*) & this phenomenon is Pseudo/ false branching.

II. True branching: It is produced by the division of an apical cell or one of its derivatives (*Stigonema, Haplosiphon*).

NOTES

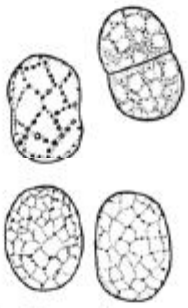


Fig. 2.1A: *Synechococus*
Unicellular



Fig. 2.1B: *Gloecapsa*
Colonial



Fig. 2.1C: *Oscillatoria*
Filamentous

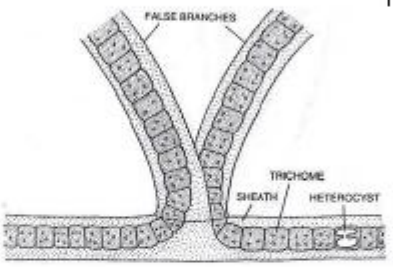


Fig. 2.1D: *Scytonema*
False branching

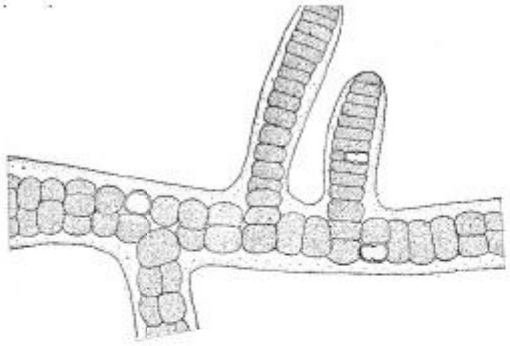


Fig. 2.2E: *Stigonema*
True branching

NOTES

2.2.4 Cell Structure

The cynobacterial cell is characterized by a primitive prokaryotic cell.

- There are no organized nuclei, choromatophores, pyrenoid & mitochondria.
- The cell wall is surrounded by a thick or thin, colorless or colored sheath of mucilage. The sheath functions in protecting the cells from drying and in gliding.



Fig. 2.2: A Typical Vegetative Cell Structure of Cyanobacteria

- The major constituent of cell wall is peptidoglycan, constitutes upto 50% of the dry weight.
- Fimbridge of pili (non flagellar proteinacieous appendage) occur protruding from the walls of some cyanobacteria.
- The circular fibrils of DNA which are not associated with basic proteins (histones) found in the central protoplasm.

- Within the cytoplasm there are numerous layers of memebranes, often parallel to one another called photosynthetic thyllakoids. Their membrane contain photosynthetic pigments such as cholorophyll-a, B-carotenes, xanthophylls and phycobilins. The commonest xanthophyll is myxoxanthophyll while phycobilins are of 3 main categories- C phycocyanin, allophycocyanin and C- phycoerythrin.
- Lamellosome is a semicircular group of coiled membranes, similar to mesosome in bacteria. It is attached to plasma membrane and plays an important role in division of nuclear body and septum formation at the time of cell division.
- Planktonic forms usally contain gas vacuoles, it is composed of gas vesicles which are hollow cylindrical tubes of protein with conical ends in cytoplasm filled with various gases. Gas vacuoles function in light shielding, help in buoyancy and to face the pressure of overlying water and also mechanical resistance to external pressure.
- The main storage product of the cyanobacteria is cyanophycean starch, cyanophycean granules and oil droplets. Cynophycean starch is related to glycogen.
- A number of cyanobacteria have a capacity to change their colour in relation to the wavelength of the incident light. This change in colour is described as compliementary chromatic adaptation or Gaidukov phenomenon.

NOTES

2.2.5 Movement

The flagella or cilia are entirely lacking in cyanobacteria even the reproductive cells are non-flagellated and the movement of mobile stages is brought about by a characteristic gliding action. Short segments may glide away at rates as rapid as 10 micrometers per second.

Gliding is the active movement of an organism in contact with a solid substrate where there is neither a visible organ responsible for movement nor a distinct change in the shape of organisms. In oscillatory movement only the ends of trichomes move accompanied by sharp bending or sliding. The Axial rotation results in the rotation of a trichome around its axis.

Several theories have been put forward to explain the mechanism of movements in cynophyceae.(1) movement caused by the secretion of mucilage (ii) caused

by osmotic and electrosmotic changes (iii) ryhtmic longitudinal waves of contraction and expansion through the trichomes (iv) movement mediated by energy utilization.

2.2.6 Heterocyst and Nitrogen fixation

NOTES

Many filamentous cyanobacteria possess specialized, enlarged, cells know has Heterocyst. Heterocysts are larger than vegetative cells with thickened walls and one or two pores. Each Heterocyst is connected to other vegetative cells with protoplasmic threads (micro plasmodesmata).

In heterocyst only photo system–I persists which is able to perform cyclic photophosphorylation .They produce ATP without Photolysis and evolution of oxygen, as they lack the oxygen-evolving photosystem –II.

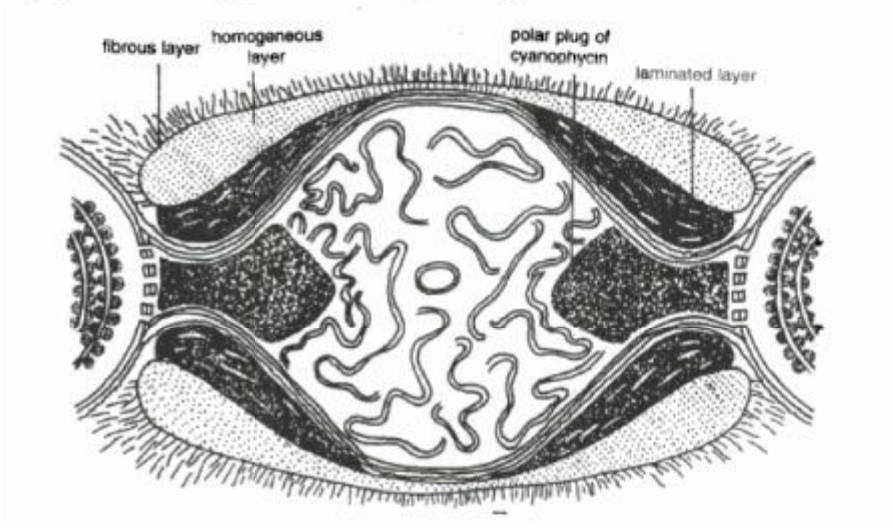


Fig.2.3: A Mature Heterocyst

Possibly heterocyst related with nitrogen fixation as nitrogenase enzyme is invariably present only in hetrocyst and it can only functions in anaerobic condition.

Nirogen from the atmosphere is fixed into ammonium in the cells which can be assimilated. Nitrogenaes is a multi subunit iron, sulphur and molybdenum containing enzyme comple. It catalyses the reduction of nitrogen from a valancy state to zero to ammonia. It contains two proteins along with different metal irons that are sensitive to oxygen.

The nitrogen fixing forms can be classified in 3 types:--

i. Unicellular forms:- They can fix nitrogen both in aerobic and anaerobic conditions (*Aphanothece, Gloeocapsa*).

ii. Non- heterocyst filamentous forms:- They can fix nitrogen only under an aerobic conditions (*Oscillatoria*).

iii. Heterocyst filamentous forms:- They can fix nitrogen in both aerobic and anaerobic condition (*Aulosira, Tolypothrix, Anabaena, Nostoc, Cylindrospermum*).

NOTES

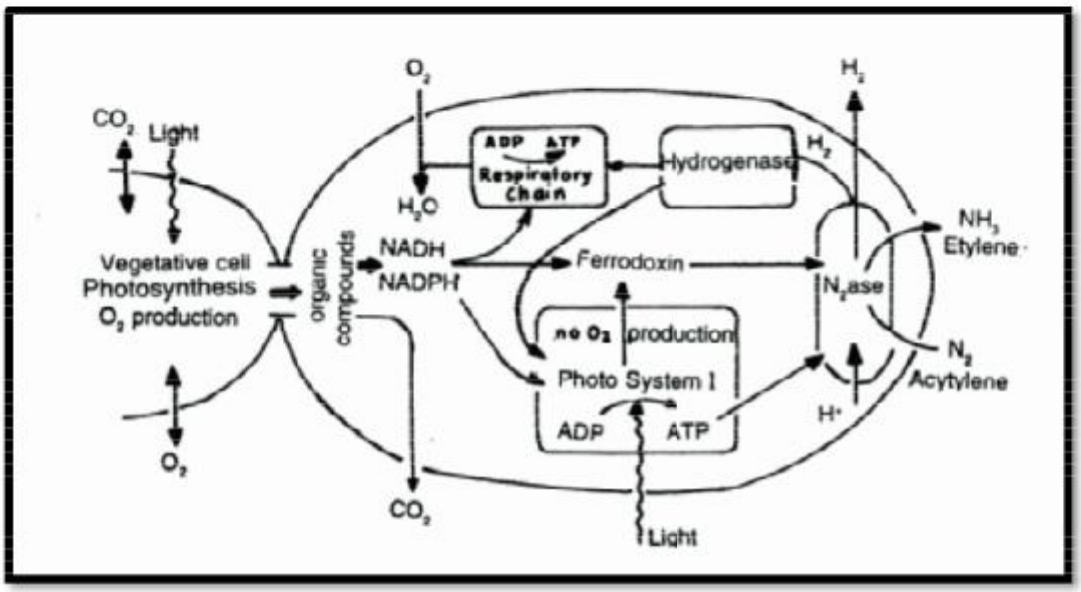


Fig.2.4: Bioenergetic Pathways in Heterocyst

Heterocyst also causes fragmentation of filament, store food reserves, secret substances which stimulate growth and cell division, control sporulation and active in nitrogen-fixation.

2.2.7 Reproduction

In cyanobacteria vegetative and asexual mode of reproduction are commonly present. Sexual reproductions are completely absent.

(a) Vegetative Reproduction :- It takes place by following three methods:--

(i) Fission:- Fission by the formation of a ring like outgrowth grows inwards and divide the cell into two.

(ii) **Fragmentation**:- It takes place in filamentous and non-filamentous colonial forms. The filament or colony breaks into small fragments and these fragments develop into full sized filament or colony e.g. *Polycystis, Chroococcus.*

NOTES

(iii) **Hormogones**:- In filamentous genera, the main filament breaks into small pieces called hormogonoes The hormogones separate from the main filament by " Separations disc" between two adjoining cells.

(iv) **Hormospores**:-In unfavorable conditions hormogones separated from the tips of trichomes and rounded cells secrete thick wall called hormospores, They function as pernnating bodies and germinate directly into new filaments in favourable conditions.

(b) Asexual Reproduction : It takes place by following means :--

(i) **Akinets:** Akinetes are thick walled specialized cells meant for perenation. They may be spherical (*Anabaena*), discoidal (*Nodularia*) or elongated (*Gloeotrichia*, *Cylindrospermum*). Mature akinetes, are larger than vegetative cells. It contains protoplasm, full of food reserves and has a normal cell wall surrounded by wide three layered coat. The akinetes of most cyanophyceae members do not show any nitrogenase activity.

Akinetes are resistant to heat, freezing and drought (desiccation) and thus allow the cyanobacteria to survive unfavorable environmental conditions. They are functionally analogous to bacterial endospores, but they bear little resemblance and lack the extraordinary resistance of end spores.

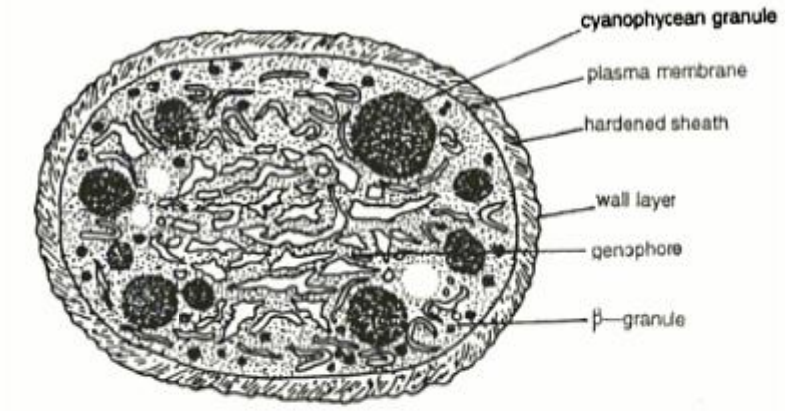


Fig. 2.5: Electron Microscopic structure of Akinete

(ii) **Endopores :** Endospores are true reproductive cells formed in the cyanophyecae. These are formed by internal division of protoplast,

resulting in an irregular mass of spores (Dermocarpa) or a row of spores (*Chamaesiphon*) called exospores.

(iii) **Nannocytes**: They are formed in non-filaments species (*Gloeocapsa, Miscrocystis*) by brisk cell division and development into new colonies.

(iv) **Conidia:** They are round and thick walled cells formed at the tips of branches in species of *Stigonema.*

(v)

NOTES

2.3 Biological Importance of *Microcystis* and *Spirulina*

Microcystis:

Microcystis is characterized by small cells (of only a few micrometers diameter), which lack individual sheats. Cells usually are organized into colonies (large colonies of which may be viewed with the naked eye). That begins in a spherical shape, but loses their coherence to become perforated or irregularly shaped over time. The coloration of the protoplast is a light blue-green, appearing dark, or brown due to optical effects of gas-filled vesticles. This can be useful as a distinguishing characteristic when using light microscopy. These vesiceles provide the buoyancy necessary to stay at a level within the water column at which they can obtain optimum light and carbon dioxide levels for rapid growth.

M. aeruginosa is a specie of fresh water cyanobacteria which can form harmful algal blooms of economic and ecological importance. They are the most common toxic cynobacterial bloom in entropic fresh water. It is favourd by warm temperatures , but toxicity and maximal growth rates are not totaly coupled, as the cynobacteria has highest laboratory growth rates at 32^0C, while toxicity as a function of increasing temperatures in excess of 28^0C. Growth has been found to be limited below 15^0C.

It produces two groups of toxins, neurotoxins and peptide hepatotoxins, such as microcystin and cyanopeptolin.

The aquatic plant *Myriophyllum spicatum* produces ellagic, gallic and pyrogallic acids and (+) catechin, allelopathic polyphenols inhibiting the growth of *M.aeruginosa. M.aeruginosa* can produce both neurotoxins (lipopolysaccharides_LPS) and the patotoxins microsystins.

M. aeruginosa can form persistent microcystin toxins under the right environmental conditions; it has come to be a source of drinking water population, which can be rendered hepatotoxic. These can lead to increased economic cost on water purification due to toxicity concerns. It affects dissolved oxygen content in water and can lead to fish kills and other marine life kills.

NOTES

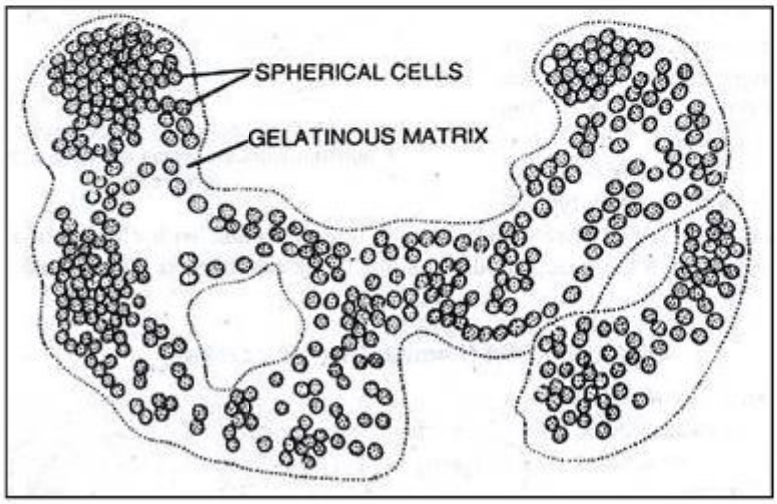


Fig. 2.6: *Microcystis*

Spirulina



Fig.2.7: *Spirulina*

The trichomes of *Spirulina* are cylindrical, loosely or tightly coiled, varied in length. Each cell is square or rectangular, spiral shaped lack gas vesicles and has thylakoids. The apical cells are rounded. Hetrocysts and spores are not present. Reproduce mainly by the formation of hormogones, occassinally propogate by

fragmentation. This is most commonly found in lakes rich in Sodium Carbonte. It grows naturally in warm and highly alkaline lakes in sub tropical areas.

The potential biotechnological application of *Spirulina* in the field of food, feed, medicines, cosmetics, and biochemistry and in the environmental deplollution are well established and documented.

NOTES

Spirulina is the only single, natural source providing the highest amount of protein (71%) ever known to man. It is commercially important due to its nutritional and therapeutic qualities. It has high contents of iron, pro-vitamin A, vitamin B-12, & essential fatty acids like (gamma) linolenic acid, so it is richest source of nutrients for malnourished population.

Spirulina have pharmaceutical role in arthritis, obesity and hypercholestrol related discases in human. It performs as antiviral and anti-inflammatory agents in cases of Herpes Simplex Virus type-I and HIV-1.

The phytonutrients (pigments and polysaccharides) of *Spirulina* makes it useful in cosmetics, nutraceutical etc. A large number of formulations are available for the preparation of food using *Spirulina* powder like Soup, noodless, candies, low calorie bread.

Spirulina is also used as an agent for combating water pollution. Its polysaccharides have promising potentials in their utilization such as waste water treatment, clarification of water in reservoirs and sedimentation of colloids in chemical and food industries.

It is largly marketed in different form but still much more is required to be done for popularization of *Spirulina*.

2.4 Economic Importance of Algae

Around 90% of the total photosynthesis is performed by algae which not only provide us organic food, but also purify air in which we live and have various beneficial roles for the welfare of human beings. Only a few of them are harmful.

NOTES

Algae as Food

There are about 100 species of algae which are edible, mostly from three genera *Porphyra, Laminaria* and *Undaria.* The algae are eaten in salads as vegetable, in soups and in desserts.

Laminaria sps. is the important edible seaweed in Japan and the food item Kombu is prepared from it. Aonori from *Monostroma,* Asakusa Nori from *Porphyra* are prepared in different countries.

The nutritional value of *Chlorella* is very high. It contains protein (50%), Earbohydrate (20-30%), Fats (20%, vitamins (A,B,C) and minerals. *Chlorella* and *Spirulina* which are unicellular algae are rich in protein and they are used as Single cell protein source.

Caulerpa racemosa, Gelidiella, Laurencia and *Gracilaria* sps are eaten directly as protein and vitamin rich vegetables and also in salads in Canada, U.K. and Philippines.

Larger sps of *Nostoc, Oedogonium, Monostroma, Ulva lactuca (sea lettuce), Codium, Alaria, Durvillea, Rhodymnia* are cooked with vegetables, mixed in soups or mixed with sugar and coconut milk.

Algae as Feed

Sea weed fed directly to cattle as fodder are commercially harvested, dried and ground into meals which are added to supplements to prepare feed. The principal genera used are *Laminaria, Ascophyllum, Fucus.*

Addition of *Pelvetia* to the fodder increases milk yield by 10% and improves fat content. Similarly *Ascophyllum, Gracilaria, Laminaria* improve egg laying in Poultry. *Rhodymeria* is a good fodder used for increase milk yield.

Algae in Industry

Algae serve as raw material for many industrial products. A variety of complex polymers are produced. The algal polysaccharides have industrial importance.

Agar-Agar

It is dried or gel like non- nitrogenous gelatinous product. It is a mixture of two polysaccharides agarose and agropectin. Dried agar is solube in hot water but

insoluble in cold water. It is solid at room tempreture but melts on heating at 90^0C -100^0C.

The common agar producing algae are: *Gelidium, Gracilaria, Gigartina, Ceramium*, *Phyllophora, Euchema*. They are used in food industry for gelling and thickening confectionaries and bakery, in the production of puddings jams and jelly and in the prepararion of cheese. Agar-agar is also used in the meat and fish industries particularly for canned products as it acts a protective agent against undesirable effects of the foul smelling metals. It is also used as a clarifying agent for wines, beers and liquors.

NOTES

It is almost a necessity to research as it is used as a base of culture media for bacteria, fungi & algae.

Alginates

Alginates are present in the form of alginic acid in the middle lamella and cell wall of the sea- weeds. Alginic acid is a polysaccharide containing galuronic and mannuronic acids. It yields alginates of commercial importance.

Common algin producing algae *Laminaria, Alaria, Ascophyllum*, *Sargasum* etc. are used in the textile industry for the refinement of the fabrics, finishing, sizing, impregenating, increasing mesh strength, fixation of base material and for the achievement of water impermeability. Alginates have a good specificity for divalent ions are used in treating toxicity of chemical like radio-active strontium.

It is employed in the preparation of dental impressions, ointments, dressing materials and agents to stop building; they are also used in the preparation of creams, fellys, soup, sauces, and ice-creams because of their non- toxic and colloidal properties.

Carrageenan

Chemically it is a polysaccharide complex of D-galoctose -3,6 anhydro D-galactose and monoesterified sulphuric acid. It is found in the cell walls of some red algae.

NOTES

Common carrageenan producing algae are: *Chondrus, Gigartina, Eucheuma*. It is used in the preparation of bakery and coonidment products, confectionery, chocolates, milk pudding, custard powders, milk shakes and cocoa production.

Funcellamn

It is got from *Furcellaria festigiata* and used in confectionery, condiments, baby food, milk pudding powder, canning industry and in tooth pastes.

Many other produces like Mannitol and Fucoidan extracted from brown algae are used in medical industry and is also added to inks and plastics. Minerals, Iodine, potash obtained from the algae are employed in soap, alum and glassware industries.

Diatomite

Big deposits of fossilized diatoms in the sedimentary rocks make diatomaceous earth or diatomite. The siliceous cell walls of diatoms are indestructible. Now these depostis have several properties.

It is used as filtration and in several industries as chelating agent in soaps, tooth pastes and metal polishes for enhancing the night visibility of paints, for insulating boilers, refrigerators, sound proof : as a filter in paper paints and rubber, as an industrial catalyst, and also handling and storage of strong acids, dynamites etc.

Iodine

Many sea- weds such *as Laminaria, Focus, Macrocystis pyrifera*, are used to extract soda and iodine. The iodine is an important constitutent of thyroid hormones and used in the treatment of thyroid and goiter.

Algal in Medicine

Algal have been extensively used in the traditional medicines as vermifuges, anesthetics and ointments. A number of compounds of algal origin have been purified and used in medicines.

I. Antibiotic chlorellin was obtained form chlorella also. It is effective against a number of pathogenic bacteria.
   Extracts of *Cladophara* and *Lyngbya* also possess antiviral properties.

II. Dried *Laminaria* strips are used as cervical dilators to facilitate obstetrical procedure.

A drug called sodium laminarian sulphate obtained from *Laminaria* is blood anti- coagulant.

III. *Sargassum* and *Laminaria* mainly used in manufacture of various goiter medicines due to their high iodine content.

IV. Agar- agar is used as laxatives and in the preparation of pills and ointments.

V. Extract of *Corallina* and *Codium* are used in the treatment of kidney, bladder and lung diseases.

VI. The saxitoxins produced by dinoflogellates are used in neurological research.

VII. An effective vermifuge is obtained from the extracts of *Digenea, Codium*, *Alsidium* and *Durvillea* .

NOTES

Single Cell Protein

Chlorella, Scenedesmus, Spirulina are important as single cell protein, due to their high nutritional value both in humans and animals. *Spirulina* is rich in protein content (71 %), five times more than soyabeans. It is quite rich in amino- acids. It has low nuclcie acid content. It has unsaturated fatty acids.

Algae in the Agriculture

Biofertilizer are living organism like bacteria, fungi, algae which are capable of fixing atmospheric N_2 or convert insoluble phosphate in the soil into forms available to plants. Biofertilizers are eco-friendly and palys a vital role in maintaining long term soil fertility and sustainability.

In nature atmospheric N_2 is converted to nitrates, nitrites and ammonia by the process of nitrogen fixation. One the most important category of biological organism responsible for this is blue- green algae.

The blue green algae can be advantageously used to supplement the inorganic nitrogen fertilizers for rice cultivation. High yield of lady's finger reported with sea weed (*Fucus*) extracts.

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In Inida mud silt from dried up ponds is used as manure in field as it contains high content of blue- green algae. The algae produce organic acids, polypeptides etc. which chelate organic and inorganic ions to maintain them in a state readily available to plants. *Tolypotrix tenius* and *Aulosira fertilissima* inoculation in field has shown to give high yield of peddy.

Blue green Algae (*Anabaena, Nostoc, Cylindrosperum, Aulosira, Scytonema, Oscillatoria, Plesctonema*) are known to fix nitrogen. *Aulosira fertilissima* is regarded as the most active nitrogen fixer in rice yields in India. It adds 47-50 Ib of nitrogen per crop per year. Besides forming abundant nitrogen the nitrogen fixing blue green algae also posses mucilage which improves the water holding capacity of soils. The nitrogen content of healty blue green algal cells is usally 4%to 09% of the dry weight. *Anabaena cylindrical* contain high phycocyanin content indicates the higher amount of nitrogen.

Apart from using algae in nitrogen fixation and as manure, they can also be used in reclamation of degraded soils, correction of soil acidity and prevention of soil erosion. The PH of the soil decreases by the acidic secretions of the algae.

Algae in Parasitism

Parasitic green alga *Cephaleuros* caused red rest to tea. Species of dinoflagellates *Oodinium* parasitize fresh water fishes and marine tunicates. Some algae parsitize on aquatic invertebrates such as *Paramecium*, Hydra, Snails, Sponges and Mussels. The algal involved mostly belong to the genera *Chlorella* or *zoochlorella* and *Protococcus*, *Chlamydomonas, Carteria.*

Algae as Indicator of Water Pollution

Indicator organisms can be any biological species that defines a trait or characteristics of the environment, algae are known to be good indicators of pollution and can be used to identify and qualify the effects of pollutants on the environment.

Algae of many kinds are really good indicators of water quality. Many desmids are known to be present in oligotrophic waters. Species of *Gomphonema* which is commonly found in highly organically polluted water. *Amphora*

ovalis and *Gyrosigma attenuatum* are also introduced as good examples of diatoms to be affected by high organic content of water. Many algal genera have species that grow well in water containing a high concentration of organic wastes. Green algae *Chlamydomonas*, *Euglena*, diatoms, *Navicula*, *Synedra* and blue- green algae *Oscillatoria* and *Phormidium* are emphasized to tolerate organic pollution. At species level, *Euglena viridis* (Euglenophyta), *Nitzschia Oscillatoria alea*
(Bacillariophyta),limosa, O.tenuis, O.princeps and Phormidium uncinatum (Cyanophyta) are reported to be present than any other species in organically polluted waters.A community composed of the diatom *Cocconeis* and the blue-green alga *Chamaesiphon* is claimed to be present in the portion of the stream which has returned to normal following purification of a polluted condition. Two groups of algae, Cryptophyta and Chrysophyta, are reported to be indicators of clean and/or unpolluted water as the members of these algal groups tend to occur in abundance, oppositely reacting adversely to pollution. The absence of blue-green algae was also accepted an indication of clean water.

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Algal Bloom

An algal bloom is a rapid increase or accumulation of the algal population in an aquatic system. They may occur in fresh water as well as marine environments.

Mostly it is a natural phenomenon and their density is increased by nutrient pollution under warm water and cold weather. Algae can multiply fastly with abundance of nitrogen and phosphorous. The continuous enrichment of water body by the addition of substances that provide for the increasing growth of aquatic life is called as eutrophication. However human activity often can trigger or accelerate algal bloom formation. Due to this proliferation water turns green or other colures, algae grows in clumps covered in a gelatinous coating, cell stick together & form large surface scum & thick mats. Thus over abundance of organic nutrients cause significant imbalance in the ecology of water body and blooms are one symptom.

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Algal blooms can benefits by boosting primary productivity but it may lead to anoxia by dissolved oxygen depletion due to the large number of dead algal decay.

Blooms involving toxin producing sps can pose serious threat to animals & humans. It led to fish kills and responsible for rashes, respiratory failures, unappealing odors etc.

Algal sps. involve in the algal bloom are *Syndra, Hydrodictyon, Cladophora, Anabaena, Uroglenopis. Microsystis aeruginosa Anabaena flos-aquae and Lygnbya gracilis* are toxic planktonic algae forms harmful blooms.

2.5 Summary

Cyanobacteria are photosynthetic bacteria (true prokaryote) , having chlorophyll –a, phyco biliprotiens and glycogen as a storage product, also known as blue-green algae. Their distribution is cosmopolitation. Thallus ranges Unicellular, colonical, filamentous & hetrotrichous forms. Cell wall has peptidoglycan. Movement is only by gliding motion. Certain sps. have gas vesicles which is helpful to maintain buyoncy. Some genera shows Gaidukov phenomenon. Hetrocyst & Akinete are specialized cell. They reproduce by vegetatively & asexually only, sexual reproduction completely absent.

Microcystis aruginosa is a sps. of cyanobacteria which can form harmful algal blooms of economic and ecological importance.

Cyanobacteria *Spirulina* have the potential biotechnological applications in the field of food, food, medicines, cosmetics, biochemical and in environmental pollution.

Algae have important contribution in the welfare of human beings, They are of importance in the fields of agriculture, industry and medicines. In addition they are used as food, feed, manure etc. No doubt a few of algal spes, are harmful effects.

2.6 Glossary

- **Cyanobacteria :** Bacteria, also known as blue green algae, that contain chlorophyll-a and can photosynthesize.

- **Algal Bloom** : The rapid increase in populations of algae and other phytoplankton, in particular cyanobacteria, that occurs in inland water systems, such as lakes.
- **Spirulina :** A genus of filamentous cyanobacteria in which the filaments are characteristically spiral in shape. They are capable of gliding motility.
- **Agar :** An algal product product of algal origin used in medium to grow microorganisms.
- **Algae** : Unicellular or multicellular photosynthetic eukaryotes that generally lack roots, stems, leaves, conducting vessels and complex sex organs.
- **Buoyancy :** The tendency of a substance to float in some other substance.
- ***Microcystis*** : A genus of cyanobacteria in which the small cells are densely packed in mucilage to form irregularly shaped often perforated colonies and then forms blooms.
- **Akinete** : A thick-walled resting cell formed by certain cyanobacteria. Akinetes can survive unfavourable environmental conditions and can germinate to produce new vegetative growth.
- **Heterocyst**: A specialized cell found in nitrogen-fixing cyanobacteria. Heterocysts are enlarged cells with thick cell walls and they lack chlorophyll, giving them a colourless appearance.
- **Hormogone** : A small piece of filament that breaks from main filament
- **Phycobilisomes** : An organelle, occurring on the laminae of red algae and cyanobacteria, that contains the red pigment phycoerythrin and/or the blue pigment phycocyanin.Trichome : In certain bacteria and cyanobacteria, a chain of vegetative cells; a cyanobacterial trichome is often surrounded by a slimy sheath.
- **Filament :** A chain of vegetative cells surrounded by a gelatinous sheath.
- **Trichome :** Filament without gelatinous sheath is Trichome.
- **Phycocyanin :** An accessory photosynthetic pigment occurring mainly in cyanobacteria and red algae. It is a phycobiliprotein, in which the

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pigmented prosthetic group is phycocyanobilin, which gives phycocyanin its blue colour.

- **Phycoerythrin** : An accessory photosynthetic pigment occurring mainly in the red algae and cyanobacteria. It is a phycobiliprotein, in which the pigmented prosthetic group is phycoerythrobilin, which gives phycoerythrin its red colour.
- **Gaidukov Pheomenon:** Tendency of some cyanobacteria to change their colour in relation to wavelength of the incident light.
- **Gliding:** Gliding is the active movement of an organism is contact with a solid substrate where there is neither a visible organ responsible for the movement nor a distinct change in the shape of organisms.
- **Biofertilizer:** Biofertilizer are living organism like bacteria, fungi, algae, which are capable of fixing atmospheric N_2 or convert insoluble phosphate in the soil into forms available to plants.
- **Single Cell Protein:** Unicellular organism which are rich source of protein.

2.7 Self-Learning Exercise

Section-A (Very Short Answer Type Questions)

1. Name the pigments found in cyanobacteria.
2. What is the difference between trichome and filament?
3. Name one Parasitic Alga.
4. What do you mean by Biofertilizer?
5. What is Agar-agar?
6. Name one antibiotic yield from any algae.
7. What is Diatomite?
8. Mention the role of mucilage sheath in cyanobacteria.

Section-B (Short Answer Type Questions)

1. Write a short note on cyanobacteria.
2. Draw a well labelled drawing of Cyanobacterial cell.
3. Distinguish between Akinete, Heterocyst and Hormogones.
4. What is Gaidukaov Phenomenon? Explain it.
5. What are the major functions of Heterocysts?
6. Write down the Biological importance of *Spirulina.*

7. What is algal bloom? How does it affect the lakes?
8. Write a short note on nitrogenase enzyme.

Section-C (Long Answer Type Questions)

1. Describe the major characteristics of the cyanobacteria in detail.
2. Write an essay on economic importance of algae.
3. Describe the general characters of cyanobacteria and mention its resemblance with other related groups.
4. List some important positive and negative impacts of cyanobacteria on humans and the environment.
5. Briefly discuss the means of reproduction in cyanobacteria.

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Unit- 3

Mycoplasmas

NOTES

Structure of the unit

3.0 Objectives
3.1 Introduction
3.2 Classification
3.3 Historical Background
3.4 Characteristics
3.5 Cell Morphology
3.6 Role in causing Diseases
3.7 Applications of Mycoplasma
3.8 Summary
3.9 Glossary
3.00 Self-Learning Exercise
3.11 References and further readings

3.0 Objectives

The purpose of this chapter is :-

- to provide an overview of the mycoplasma and
- to describe the basic concept of mycoplasma.
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3.1 Introduction

Mycoplasma is the simple cells which lack chlorophyll and which is usually reproduce by cell division. Mycoplasma can be considered as simple forms of bacteria which lack cell walls. In nature, mycoplasma is essentially dependent upon leafhoppers for their dispersal. In some cases, bacteria can be disseminated by insects but may also be dispersed by splashing rain, wind, contact, etc. Mycoplasmas are the smallest known aerobic prokaryotes without a cell wall.

These microorganisms were first discovered by Louis Pasteur, in 18th century but in 1898, two French microbiologists, Nocard and Roux, were successful in obtaining pure cultures of these microorganisms. They observed that these organisms could produce disease when inoculated in healthy plants. Mycoplasmas are frequent contaminants in tissue culture rich in organic matter. They found in hot water springs, and other thermal environments. They occur in soil, Sewage water, and different substrates and in plants.

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3.2 Classification

Mycoplasma are placed in the taxonomic cells Mollicutes which contains the single order mycoplsmatales. This order includes three families.

1- **Mycoplasmataceae-** In this family the mycoplasma is parasitic in nature and remains in mucous membranes and joints of human and animals. Most of the species of genus mycoplasma are pathogenic for animals.

2- **Acholeplasmataceae-**In this family does not require the cholesterol for growth. They are commonly found in vertebrates, in sewage, soil and sometimes in plants. It includes single genus acholeoplasma.

3- **Spiroplasmataceae-** They has of helical morphology and possesses swimming motility. This family includes single genus. The genus is pathogenic in nature and cause disease in citrus and other plants.

Kingdom	-	Bacteria
Phylum	-	Tenericutes
Class	-	Mollicutes
Order	-	Mycoplasmatales
Family	-	Mycoplasmataceae
Genus	-	*Mycoplasma*
Species	-	*gallisepticum, haemofelis*

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3.3 Historical Background

Louis Pasteur, in 18th century was the first to discover the smallest free living organism when he recognized that the highly contagious disease "bovine pleuropneumonia" of cattle is caused by a microbial agent. He was, however, unlucky as he could neither isolate it nor could see it due to its small microscopic size. This disease spread and reached England, Australia and finally United States during 19th century. A few were also found growing as saprophytes in decaying organic matter. All of these organisms were called as *Pleuropneumonia - Like organism* or PPLO and are, now commonly called Mycoplasmas. However, many years later with further discovery mycoplasmas were confused with the L-forms, which are bacteria that have lost their cell walls either completely or partially. Nevertheless, in 1950s and 1960s this confusion came to end when first genomic analysis data through the DNA hybridization were obtained. This analysis ruled out any relationship of mycoplasmas to the L-forms. Currently, the mycoplasmas are considered to have evolved from gram-positive, walled eubacteria by degenerative evolution, meaning their evolutionary history appears to include the loss of cell wall. Further, in 1960s and 1970s knowledge about ultra structure, cell membrane, and genome and metabolic pathways of mycoplasmas resulted in conclusion that they are the smallest and simplest self-replicating organisms.

3.4 Characteristics

1. They are filterable, highly pleomorphic cells.
2. They are smallest free living Gram-negative cells (0.1 to 0.3 µm in size).
3. They are unicellular non-motile procaryotic cell forming fried egg shaped colonies.
4. A rigid cell wall is absent. Plasma-membrane- three layered outer covering is present.
5. Like Eucaryotes the cell membrane is made up of proteins and sterols.

6. They are resistant to penicillin but are highly sensitive to low concentrations of tetracyclines

7. Mycoplasmas are a group of eubacteria that lack a rigid a cell wall and are among the smallest of all living cells.

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3.5 Cell Morphology

The mycoplasma cells are unicellular non-motile pleomorphic cells. They are characterised by very small coccid bodies, swollen ring like forms and filamentous branched forms of variable length. The smallest mycoplasma, units, capable of independent growth, is small Coccoids ranging 0.25 to 0.1μm in diameter. It is because of their small size that they easily pass through filters which otherwise do not permit bacteria to pass through them. Mycoplasmas, like animal cells are without cell wall and possess only a plasma membrane—the protective layer of the cytoplasm. The cell membrane is three layered or "Unit" type. It is rigid, externally thin, and resistant because of chemicals like sterol present in it. These sterols as a matter of fact, are not synthesized by these organisms but are taken up from the surrounding medium.

The internal structure of the mycoplasms is similar to typical procaryotic cell and closely resemble with bacteria. The nuclear structure is in the form of DNA, which is in very less amount than typical bacteria, but has sufficient genetic information necessary for independent existence of the cell. The DNA like higher organisms is a double standard helix. In addition to DNA approximately double amount of RNA is found in mycoplasma cells. A good amount of ribosomes, soluble proteins and amino acids are also present with other metabolites in expected ratio. Mesosomes are conspicuously absent in myco-plasmas perhaps because of the elasticity of cell membrane. Enzyme systems and metabolic phenomenon of mycoplasma are slightly differ from typical bacteria but the differences are not extreme.

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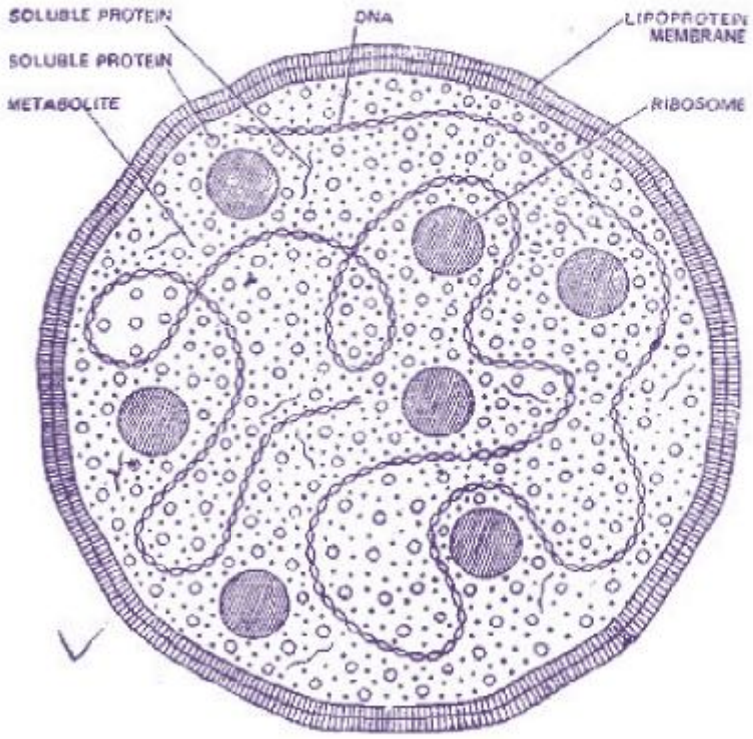


Fig. 3.1 A Single Cell of Mycoplasma

Nature of mycoplasma

Mycoplasma can pass through many filters and grow in media which do not contain living tissue. Therefore, they are considered to be microorganism intermediate between bacteria and viruses. Chemically, they are much closer to bacteria because they possess 4% DNA and 8% RNA

3.6 Role in causing Diseases

Many species of Mycoplasmas are causing serious diseases in human beings, animal and plants, few examples of these diseases are given below.

Mycoplasma like organisms causes yellow type diseases in plants. Now Mycoplasma like organisms (MLOS) have been found causing about 75 types of plant diseases, which occur from tropical to temperate regions. But in tropical areas MLOS cause serious losses in crops like rice, maize, brinjal, cotton, citrus and potato etc. some common *diseases* of crops are explained below.

1. **Little Leaf Disease of Brinjal (egg plant)** is caused by Mycoplasma. The leaves of the egg plant become reduced in size, the newly developing leaves at the top of plants become progressively smaller and sterile (influence is not emerged). The lamina of leaves becomes soft glabrous and pale green. Internodes of top branches are shortened resulting in a bushy appearance of the affected plant.

2. **Rice Yellow Dwarf** is caused by Mycoplasma in U.P., Bihar, Orissa and Andhra Pradesh. The leaves become chlorotic, pale green to yellow causing stunting growth and profuse tillering. The disease is lethal to plants infected at early stage of seedlings. If plants are infected in late stage it reduces in grain yield.

3. **Sandal Spike** is caused by Mycoplasma like Bodies (MLB) it is a seriously destructive disease of Sandal wood, threatening whole of the Sandal industries throughout Sandal producing Karnataka state and neighboring areas. The symptom of the disease is the severe reduction of leaf size. The shortening of internodes accompanied with reduced leaf size gives the appearance of rosette spike. There is no flowering and fruiting in the infected plant.

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3.7 Applications of Mycoplasma

Plant diseases associated with mycoplasma in the sieve tube of the plants have one feature in common i.e. upsetting the hormonal balance. Premature development of adventitious buds, normally remain dormant in common. It is also expression of disturbed apical dominance. In many cases no anthocyanins are formed in petals. In flower leaves then usually assume the foliage leaves. And various intermediate stages between flowers and leafy sprouts can be found. As a result of mycoplasma infection seed setting may be considerably affected and this may be disastrous crop espically cultivated for seed. Degenerative processes that may often occur in the sieve tube frequently lead to plant stunting, wilting or leaf yellowing.

Degenerative effects caused by mycoplasma, such as cell necrosis and excessive callose formation in sieve tubes are visible under a fluorescence microscope.

3.8 Summary

Plant disease can decrease the economic, aesthetic and biological value of all kinds of plants. Plant pathology is the study of the nature, causes, prevention

and socioeconomic aspects of plant diseases. The plant diseases are recognized by the symptoms such as necrosis, chlorosis, wilting, rot, dwarfing etc. Plant diseases are separated into nonparasitic and parasitic diseases. Nonparasitic diseases are caused by improper environmental conditions such as deficiencies and excesses of nutrients, biological toxicants, adverse soil and weather conditions and pollutants. Most plant diseases are caused by parasitic mycoplasma and viruses.

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3.9 Glossary

- **Biological control :** Total or partial destruction of pathogens populations by other organisms.
- **Blight :** A disease characterized by general and rapid killing of leaves, flower and stem.
- **Disease :** Any malfunctioning of host cell and tissues that result from continuous irritation by a pathogenic agent or environmental factor and leads to development of symptoms.
- **Host :** A plant that is invaded by a parasite and form which the parasite obtains its nutrient.
- **Mycoplasma like organism :** Microorganism found in the phloem and phloem parenchyma of diseased plants and assumed to the cause of the disease. They resemble mycoplasma I n all respects except that they cannot yet be grown on artificial nutrient media. Now called phytoplasma.
- **Pathogens :** An entity, usually a micro-organism that can cause diseases.
- **Purification :** The isolation and concentration of virus particles in a pure form, free from cell components.
- **Resistance :** The ability of an organism to exclude or overcome, completely or in some degree, the effect of a pathogen or other damaging factor.
- **Sterilization :** The elimination of pathogen and other living organisms from soil, containers etc by means of heat and chemicals.
- **Symptoms :** The external and internal reactions or alterations of plants as a result of diseases.
- **Wilt :** Loss of rigidity and drooping of plant part generally caused by insufficient water in the plant.

3.10 Self-Learning Excercise

Section -A (Very Short Answer Type Questions)

1. Name of pathogen which is responsible for pleuropneumonia in cattle?
2. Which pathogen is responsible for little leaf of brinjal?

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Section -B (Short Answer Type Questions)

1. Differentiation between virus and mycoplasma?
2. Write a note on mycoplasma?

Section -C (Long Answer Type Questions)

1. What is mycoplasma? Describe their structure and also comment briefly on their economic importance.
2. Describe the structure of mycoplasma infected plant, and explain of a plant disease caused by it?
3. Describe the structure and reproduction of mycoplasma?
3. Give labelled diagram of mycoplasma. Give example of plant disease caused by it ?
3. What is the main component of outer covering of mycoplasma?
4. What is mycoplasma?

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Unit-4

Virus

Structure of the unit

4.0 Objectives
4.1 Introduction
4.2 Characteristics, Ultrastructure and Morphology of Virus
4.3 Classification
4.4 Isolation and Purification of Virus
4.5 Chemical Nature
4.6 Replication
4.7 Transmission of virus
4.8 Cyanophages
4.9 Economic Importance of Virus
4.10 Summary
4.11 Glossary
4.12 Self-Learning Exercise
4.13 References and further readings

4.0 Objectives

After suding this unit you should be able-

- to provide an overview of the plant viruses
- to describe the basic concept of a virus, the structure of virus particles, genomes, and plant virus diseases.

4.1 Introduction

In nature, there are many ultramicroscopic particles, known as viruses. Virus has been a subject of considerable speculation in the scientific community. However, there is a general agreement that viruses probably infected bacteria during the period when archaea and eubacteria were the sole life form on the earth. Later, when eukaryotic were evolved, they were also attacked by virus.

Name of virus (Latin *virus*-venom of poision fluid) was given by Pasteur to the causative agents of infectious diseases. In the 1886, Mayer described that Tobacco Mosaic disease but he could not find any causal agent. Credit of the

discovery of viruses goes to the Russian botanist Iwanowsky in 1892 who found the causal organism of the mosaic disease of tobacco. He was reported that the sap of infected plant, filtered through bacteria proof filter was equally potent in causing the disease and concluding that the cause of disease was not bacteria but some other smaller particle are known as virus. A virus is a smallest particle. This is composed of two types of substances, protein and nucleic acid. They are seen by the help of electron microscope. Viruses have an important position in comparative study of living and nonliving, because they are sharing the characters of both living and nonliving. It is now well established that viruses are obligatory parasitic, self-replicating non-cellular organism and essentially composed of a protein covering surrounding a central nucleic acid molecule either DNA or RNA. The study of viruses has become so important and detailed that their study is treated in a new branch, known as Virology.

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4.2 Characteristics, Ultrastructure and Morphology of Virus

On the basis of character we can say that viruses are connecting link between living and nonliving.

Character of nonliving

1. They do not have protoplasm.
2. They do not have enzyme system.
3. They do not have respired.
4. They can be crystallized.

Character of living beings

1. They replicate, although inside the living cells.
2. Nucleic acids, present in their body are capable of synthesizing protein for their coat, although they use ribosome of the host for the purpose.
3. Nucleic acid show similar gene mutations as chromosomes of the living organisms.
4. They cause disease like bacteria and fungi.

Viruses are the microscopic particles which have been studied in detail by electron microscopic. Simple virus particles are known as virions.

Size- The size of the virus was measured by the using the technique of filtration through collodion membranes of known porosity. Virus is very small in size, varying wide range from 20 to 350 nm. The largest virus is the orthopox virus;

range of this virus is about 240 nm x 300 nm. The smallest viruses are enterovirus, which are less than 30 nm in diameter.

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Size of some virus:

Turnip yellow mosaic virus- 28 nm

Tomato bushy stunt virus- 30 nm

Polio virus- 28-30 nm

Alpha virus- 35-80 nm

Tobacco mosaic virus- 17.5x300 nm

Beet yellow virus- 10x1250 nm

Nucleic acid- Viruses contain only one type of nucleic acid which may be either DNA or RNA. The virus containing DNA are called Deoxyvirus, whereas those having RNA are known as Ribovirus. In general case of plant viruses have single stranded RNA but in animal viruses have either single or rarely double stranded RNA or double stranded DNA. In case of bacterial viruses contain mostly double stranded DNA but it can also have single stranded DNA or RNA, most of the insect viruses contain RNA and only a few DNA. Virion contains only a single molecule of nucleic acid. The number of nucleotide pairs in a molecule varies from 1000-250,000 pairs. The amount of nucleic acid depends on the size of virion, usually in larger the size of virion greator in the amount of nucleic acid.

Protein coat-The nucleic acid core of virus is protected by the protein coat are called the capsid. Each capsid consists of several identical protein subunits which are known as capsomeres. Some viruses the proteins composing the capsomeres are of a single type, while in others several types of protein may be present. These subunits usually arranged in the helical or polyhedral geometric forms. The capsomeres forming the capsid of a virion are of two types.

First is Pentomere (made of five identical monomeres)

Second is hexomere (having six monomeres)

Each monomere is connected with the neighbouring monomere. The capsomeres are connected with each other, but the bonds between the capsomere are weak. Some complexes form of capsids is covered by an envelope. It is usually made up of some combination of lipids, proteins and carbohydrates. Some animal viruses, which are released from the host cell by an extrusion process, get coated by the host cell's plasma membrane. This

membrane eventually becomes the viral envelop. Envelop of many viruses have projections called spikes.

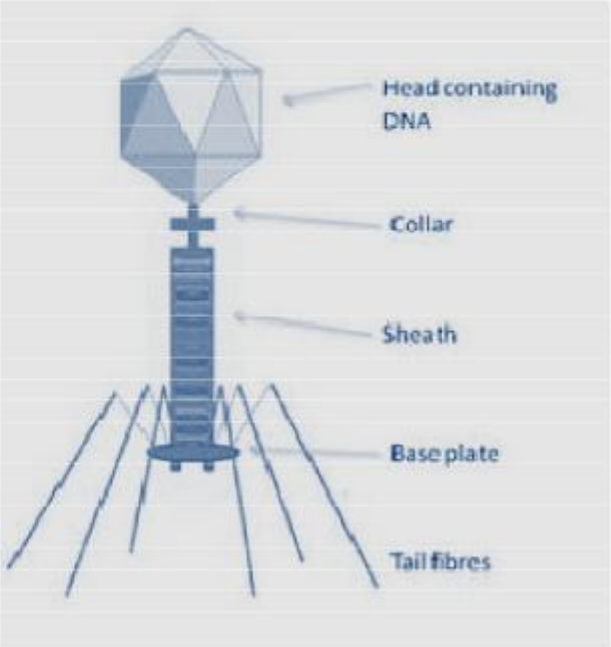


Fig. 4.1 Electron Microscopic Structure of Virus

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Ultrastructure of Virus

The morphology of the virus has been intensely studied over the past few decades because of the importance of viruses and the realization that virus structure was simple enough to be understood. All virions, even if they possess other constituents, are the constructed around a nucleocapsid core (indeed, some viruses consist only of a nucleocapsid). Nucleocapsid is composed of a nucleic acid, either DNA or RNA, held within a protein coat called capsid. Viruses may be classified into various morphplogical types on the basis of their capsid architecture. The structure of capsid and individual capsomere can be studied by electron microscopy and X-ray crystallography. Some common morphological forms of viruses are given below.

Helical viruses- These viruses are cylindrical or it may be rod likes in and central nucleic acid strand is coiled like a helical spring. The protein subunits are helically arranged around the helical spring. The example is Tobacco virus.

Polyhedral virus- In these viruses the nucleic acid is packed in an unknown manner within a polyhedral head. They have been classified as further into

tetrahedral, octahedral and icosahedral forms depending upon the number of phases. The examples are adenovirus and poliovirus.

Enveloped viruses- The capsid of the viruses are covered by an envelope.

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Complex viruses- Bacterial viruses have a complex structure and are called complex viruses. The examples are T-even bacteriophages.

Tobacco Mosaic Virus

Tobacco mosaic virus (TMV) was discovered by Iwanowski in 1892 but its isolation from the infected plants and crystallization was done by W. M. Stanely in 1935.TMV particles are appear as bundle of rods or needles under the electron microscope. The electron microscope and X-ray crystallographic investigations have revealed that these particles have two constituents first is protein coat and second is nucleic acid. The protein coat is made up of approximately 2130 identical protein subunits called capsomeres. Each capsomeres consists of a long chain of 158 amino acids and its molecular weight is 18,000. The capsomeres are helically arranged around a single stranded RNA molecule. The total length of each rod is about 130 helical and in each helix there are approximately 16.5 protein subunits.

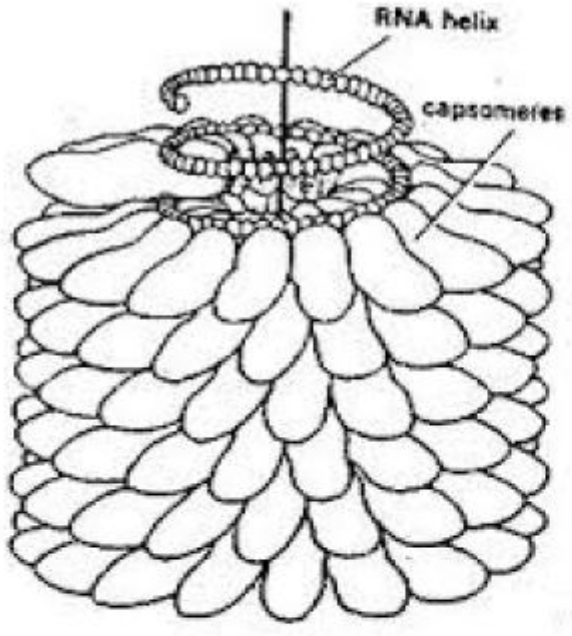


Fig. 4.2 : Structure of Tobacco Mosaic Virus

The genetic information is necessary for the formation of a complete TMV particle is contained RNA. This information is determined the replication of RNA and sequence of amino acid in the protein subunits of the capsid. All subunits are identical; only one coded gene is required for the formation of all capsomeres. It is possible to remove the protein coat from RNA. The naked RNA is capable of infecting Tobacco plant, once inside the host cell; the virus RNA directs the protein synthesizing apparatus of the host cell to synthesize its own protein. Thus the RNA has two functions. First is self replication and second is synthesis of virus specific protein for which it takes the raw material from the host cell. Although naked RNA is capable of infecting the host cell, the efficiency of infection is usually one thousand to one million that of the intact virion. At the time of infection, usually the entire virion enters in to the host cell. Immediately after entering the host cell, the protein coat of virion degenerates, whereas RNA starts the synthesis of messenger RNA which eventually synthesizes protein subunits.

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4.3 Classification

Classification of viruses has been problematic due to their ultramicroscopic size, presence of both living and non-living features and the absence of fossil records. Viruses are classified into the following four groups on the bases of their host range and pathological symptoms.

Plant viruses-These viruses infect only plants like as algal viruses and fungal viruses.

Invertebrate viruses- Viruses that infect invertebrates have been included in this group.

Vertebrate viruses- This group includes virus infecting vertebrate animals.

Dual-host virus- This group includes those viruses which infect two different hosts.

In a recent scheme of classification of plant virus, followed the virus taxonomy-Sixth report of the international committee on taxonomy of viruses. The highest level of virus classification recognises six major groups, based on the nature of the genome.

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1- **Double-stranded DNA (dsDNA):** There are no plant viruses in this group, which is defined to include only those viruses that replicate without an RNA intermediate. It includes those viruses with the largest known genomes (up to about 400,000 base pairs) and there is only one genome component, which may be linear or it may be circular. Well-known viruses in this group include the herpes and pox viruses.
2- **Single-stranded DNA (ssDNA):** There are two families of plant viruses in this group and both of these have small circular genome components, often with two or more segments.
3- **Reverse-transcribing viruses:** These have dsDNA or ssRNA genomes and their replication includes the synthesis of DNA from RNA by the enzyme reverse transcriptase; many integrate into their host genomes. These groups include the retroviruses, of which Human immunodeficiency virus (HIV), the cause of AIDS, is a member. There is a single family of plant viruses in this group and this is characterized by a single component of circular dsDNA, the replication of which is *via* an RNA intermediate.
4- **Double-stranded RNA (dsRNA):** Some plant viruses and many of the mycoviruses are included in this group.
5- **Negative sense single-stranded RNA (ssRNA-):** In this group, some or all of the genes are translated into protein from an RNA strand complementary to that of the genome. There are some plant viruses in this group and it also includes the viruses that cause measles, influenza and rabies.
6- **Positive sense single-stranded RNA (ssRNA+):** The majority of plant viruses are included in this group. It also includes the SARS corona virus and many other viruses that cause respiratory diseases (including the "common cold"), and the causal agents of polio and foot-and-mouth disease.

4.4 Isolation and Purification of Virus

Isolation or as it is usually called, purification of viruses is done in the following steps.

1. **Selection of suitable buffer system-** Virus are susceptible to small changes in pH, ionic strength and the type of ions, selection of suitable buffer are very important. Since viruses are also susceptible to oxidation, a reducing agent as ascorbic acid is used in this solution used during grinding.

2. **Grinding of infected tissues-**Infected tissue could be chopped or squashed by hand. After disintegration of the tissue the juice is passed through several layer of cheese cloth to remove large particles. The crude juice now contains plant cell organelles, dissolved salts, sugars including the virus.

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3. **Removal of extra particles and solutes-** The crude juices are treated in various ways and sedimented by centrifugation. This is called as clarification. The supernatant liquid above the pellet in the centrifuge tube still contains the virus. The crude juice is filtered through any of the virus is precipitated by organic solvents. In this step most of the host contaminants are removed.

4. **Purification-**Actual and last separation of the virus particles from other macromolecules is done by the several methods. The methods are gel filtration, chromatography, electrophoresis and ultracentrifugation. The most common technique is ultracentrifugation of the plant sap. This involves 3 to 5 cycles of alternate high and low speeds. Sucrose solutions of decreasing concentration from 60%-5% are layered one on top of another in a plastic centrifuge tube, and allowed to spin in nearly horizontal position. The virus band is clearly seen. The band is collected by the inserting a syringe into plastic centrifuge tube.

5- **Concentration and storing of the viral fraction-**Virus is obtained in a pure state. It can be concentrated by removal of most of the solvent from the suspension or removal of the virus from the suspension. Absorption of water by the help of dry gels, ultra filtration are the common method to remove the solvent from virus suspension, whereas ultracentrifugation is the method to remove the virus from the suspension.

In all these methods, the virus is finally obtained as a colourless pellet in a test tube. The purified particles are then used for infection, detection and identification of the viruses by using electron microscope.

4.5 Chemical Nature

Each plant virus consists of two components the nucleic acid and the protein coat or capsid. The mature particle of a plant virus is generally called virion and the whole infective particle is called as Nucleocapsid.

Nucleic Acid of Viruses

Nucleic acid portion of the virus particle is called as Genome. It is actual infective component.

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Majority of plant viruses contain RNA (Ribonucleic acid).Some viruses (Cauliflower mosaic virus, bean yellow mosaic virus, maize streak virus) contain DNA (Deoxyribo nucleic acid).The nucleic acid may be in a single strand or in a double strand. Most of the plant viruses contain single strand of RNA. These strands may be free at both ends (liner RNA strand) or the end may be joined together to form a circular nucleic acid molecule (Circular RNA). In double stranded viruses (ss RNA or ds DNA) the two strands are called around each other helically. The nucleic acid may be present as a single continuous strand or it may be present as two or more piece in the same or different particles.

The Virus Protein

The virus protein is termed as capsid. It protects nucleic acid (RNA or DNA) of virus. It is made up of different type of amino acid sequences in different viruses. This amino acid is linked by Peptide bonds. The protein sub units of the capsid are known as structural units when these units form groups of 2,4,6 are called Morphological units or capsomers. The sequence of the amino acids constitutes the primary structure of the protein. Helical structure are produced by the amino acids is known as secondary structure of the protein and folding of protein gives tertiary structure. Protein shell or coat protects viral nucleic acid from environment.

Viruses differ greatly from other pathogens (fungi and bacteria). Viruses differ in shape and size. Nearly half of them are elongated, many are spherical, cylindrical and rod shaped. Some elongated virus as TMV and barley strip mosaic virus are rigid rods and measure about 15x300 nm and 20x130 nm respectively. The rabdovirus are short, bacillus-like, cylindrical rods approx three to five times as long as they are wide (52-75x300-380 nm).

Most of the spherical viruses are polyhedral, ranging in diameter from 17nm to 60nm. Plant viruses consist of more than one component. Tobacco rattle virus has two rods, a long and a shorter, alfalfa mosaic virus consist of four components of different sizes. The surface of plant virus consists of a definite number of protein subunits. Which are spirally arranged in elongated viruses, and packed on the sides of polyhedral particles of the spherical viruses? In the cross-section, elongated virus appears as hollow tubes with the protein subunits.

The spherical viruses are may or may not be hollow. The visible shell is consisting of the protein subunits, with the nucleic acid inside the shell and arranged in yet unknown manner.

4.6 Replication

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Nucleic acid in a virion does not contain all the genes needed for the synthesis for new viruses. Although genes governing the synthesis of the virions structural components are present on its nucleic acid, the enzyme needed for protein synthesis, ribosomes, tRNA and energy production are supplied by the host cell. These are used for synthesizing viral protein including viral enzymes. Thus for a virus to multiply, it must be invade a host cell and take over the host's metabolic machinery. Once inside the host cell, even a single virus can give rise to thousand of virus.

The basic mechanism of the penetration and multiplication is similar in all the viruses. In the bacteriophage virus can multiply by two alternate methods first is the lytric cycle and second is the lysogenic cycle.

1-Lytic cycle- The process of multiplication involves the following four steps.

a- Infection

b- Synthesis of phage components in the host cells

c- Assembly of phage particle

d- Liberation of the phage particles from the host cells

Infection- The two important events of this step are adsorption of the phage on the host bacterium by means of its tail fibers, and transfer of the phage nucleic acid into the host cell. Adsorption of phage on the host bacterium depends on the mutual affinity of the phage and bacterium. Some factors are such as composition and viscosity of the medium and temperature also affect adsorption. Adsorption of phage on the surface of host is facilitated by interaction of amino groups of protein present at the margins of the phage tail, and negatively charged carboxyl groups on the surface of the host. After adsorption, the phage particle secretes a special enzyme of lysozyme type which is hydrolysesmuramic acid peptide complex of the bacterial cell wall. A minute pore is formed through which the nucleic acid of the phage enters into the host cell. When virus landing on the host surfaces of the tail fibres bent, bringing the end plate of the phage in contact with the bacterial cell wall. The tail sheath then contracts, pushing the central tubular part of the tail into the host cell wall just

like an injection needle. The protein cell of the phage remains attached to the host cell even after the transfer the nucleic acid. Such empty protein shells are called ghost.

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Synthesis of phage components in the host cells-The synthesis of bacterial protein and direct the metabolism of the cell to synthesize the protein of the phageparticle. This is an accomplished by the synthesis of viral specific m-RNA. The replication of the phage DNA follows the semi conservative mechanism. Most of the phage DNA serves as a template in its own synthesis and the rest is used as a template for the synthesis of viral specific m-RNA. The latter directs the host cell to synthesize protein which is used as subunits of the protein coat of the phage particle. These proteins are called as late proteins. The end of replication of phage nucleic acid, a late protein, called phage lysozyme is synthesized.

Assembly of new particle- Assembly of nucleic acid and protein into new phage particle is called the maturation. This process is called as viral genome. The first step in the maturation is the condensation of the nucleic acid molecule in the crystalline form. The protein subunits then aggregate around DNA to form the head of the phage. It is initiated with the attachment of core tube with the tail plate. The sheath around the core tube is formed afterwards. At this stage the tail gets attached to the base of the head. The tail fibers are attached to the end plate in the last.

Liberation of the phage particles from the host cells-Infected bacterium 7-8 phage particles are formed as per minute and a total of about 200 phage are formed in a bacterium. The host cell ruptures as a result of lysis and the phage particles are liberated.

2-Lysogenic cycle- In the lysogenic cycle the phage DNA gets incorporated into the host cell's DNA and the host cell DNA and the host cell multiplies indefinitely along with phage nucleic acid. Phage multiplying by this method is known as lysogenic phage. The phage injects its DNA into the host cell. The linear phage of DNA becomes circular and integrates within the bacterial chromosome by recombination. The inserted phage DNA is now called as prophage. The activity of this gene is repressed by two repressor proteins which are synthesized by the phage genes. This checks the synthesis of new phages within the host cell. However, each time bacterial cell devides, the prophage multiplies along with bacterial chromosome. The prophage remains latent

within the progeny cells. However, exposure of host cells to mutagenic agents may lead to the excision of phage DNA and initiation of the lytic cell.

4.7 Transmission of Virus

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Virus moves from one host to another for its survival and in search for the suitable host. The transmission of virus is depending on the external carriers. The plant viruses are rarely come out of the plant spontaneously. Therefore, viruses are not disseminated by wind or by water. Viruses are transmitted from plant to plant in a number of ways-vegetative propagation, mechanical transmission through sap, seed, pollen and specific insect or fungi etc. Some common mode of transmission of plant viruses are given below.

1- **By the help of vegetative propagation-** When plants are propagated vegetatively by budding, grafting, cuttings, bulb or rhizomes if any virus present in the mother plant from which these organ are taken will almost always be transmitted to the progeny. This mode of transmission is most important for all fruits and ornamental plants. In the trees viruses are transmitted through natural root grafts of adjacent plant.

2- **Mechanical transmission through sap-** In the natural conditions direct transfer of sap through contact of one plant with another is uncommon. This type of transmission may take place between closely placed plants. Strong wind may cause the leaves of adjacent plants to rub together and if wounded, some of their sap is exchanged, thus transmitting of any virus present in the sap. Mechanical transmission is the only authentic means to prove the ability of the infection by a virus. For mechanical transmission of a virus, young leaves and flower petals are ground to crush the cells and release the virus in the sap. The sap may be strained to remove tissue fragments and is then applied to surface of healthy leaves. The sap is applied by gentle rubbing to leaves with a cheese cloth, finger, and glass spatula or by sprayer. In local lesions, symptoms usually appear with in three to seven days.

3- **By Insects-**Plant viruses need to be transmitted by vector most often insects such as leafhoppers. One class of the viruses are, the Rhabdoviridae has been proposed to actually be insect viruses that have evolved to replicate in plants.

4- **Nematodes-**Soil borne nematodes that have been shown to transmit the viruses. They acquire and transmit them by feeding on infected roots.

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Viruses can be transmitted both non-persistently and persistently, but there is no evidence of viruses being able to replicate in nematodes. The virions attach to the stylet (feeding organ which are found in nematodes) when they feed on an infected plant and can then detach during later feeding to infect other plants.

5- **Seed transmission-**Plant virus transmission from generation to generation occurs in about 20% of the plant viruses. When viruses are transmitted by seeds, the seed is infected in the generative cells and the virus is maintained in the germ cells and sometimes, but less often them in the seed coat. When the growth and development of plants is delayed because of situations like unfavorable weather, there is an increase in the amount of virus infections in seeds. There does not seem to be a correlation between the location of the seed on the plant and its chances of being infected.

6- **Pollen transmission-**Virus transmitted by pollen not only infect the seed and the seedling growing for it, but more important, it can in some cases also spread through fertilised flower and down into the mother plant, that thus become infected with the virus. This method is important in stone fruit ringspot virus of some plants as prunus necrotic ringspot virus.

4.8 Cyanophages

A cyanophage is a virus that infects cyanobacteria. The name is constructed from the term phage, for a virus that targets bacteria, and cyanobacteria for the specific type of bacteria this virus uses for replication. Because of the important role of cyanobacteria as primaty producer in the world's oceans, the study of their phage ecology is important toward understanding global carbon cycling.

4.9 Economic Importance of Virus

Viruses cause many important plant diseases and are responsible for huge losses in crop production and reducing both quality and quantity of the final production. Also keeping quality of plant produce is also affected. Infected plants may show the range of symptoms depending on the disease but often there is leaf yellowing (either of the whole leaf or in a pattern of stripes or blotches), leaf distortion (e.g. curling) and other growth distortions (e.g. stunting of the whole plant, abnormalities in flower or fruit formation). Viruses cause serious disease of crop plants. Some of the important viral diseases are Tobacco mosaic virus, Tomato mosaic, Tomato spotted wilt, Potato leaf roll, Potato virus

X and Y in Potato, Papaya mosaic, Citrus tristiza, chilly leaf curl, Banana bunchy top etc.

Viruses also cause many diseases of international importance. Amongst the human viruses, smallpox, polio, influenza, hepatitis, human immunodeficiency virus (HIV-AIDS), measles and the SARS corona virus are particularly well known. While antibiotics can be very effective against diseases caused by bacteria, these treatments are ineffective against viruses and most control measures rely on vaccines (antibodies raised against some component of the virus) or relief of the symptoms to encourage the body's own defense system.

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4.10 Summary

Viruses are infectious pathogens that are too small to be seen with a light microscope. The simplest viruses are composed of a small piece of nucleic acid surrounded by a protein coat. As is the case with other organisms, viruses carry genetic information in their nucleic acid which typically specifies three or more proteins. All viruses are obligate parasites that depend on the cellular machinery of their hosts to reproduce. Viruses are not active outside of their hosts, and this has led some people to suggest that they are not alive. All types of living organisms including animals, plants, fungi, and bacteria are hosts for viruses, but most viruses infect only one type of host. Viruses cause many important plant diseases and are responsible for losses in crop yield and quality in all parts of the world.

4.11 Glossary

- **Biological contro :** Total or partial destruction of pathogens populations by other organisms.
- **Blight :** A disease characterized by general and rapid killing of leaves, flower and stem.
- **Canker :** A necrotic, often sunken lesion on a stem, branch or twig of a plant.
- **Chlorosis :** Yellowing of normally green tissue due to chlorophyll destruction or failure of chlorophyll formation.
- **Disease :** Any malfunctioning of host cell and tissues that result from continuous irritation by a pathogenic agent or environmental factor and leads to development of symptoms.

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- **Grafting :** A method of plant propagation by transplantation of bud. Also the joining of cut surfaceof two plants so as to form a living union.
- **Host :** A plant that is invaded by a parasite and form which the parasite obtains its nutrient.
- **Isolation :** The saperation of pathogen from its host and its culture on a nutrient medium.
- **Local lesion :** A localized spot produce on a leaf upon mechanical inoculation with virus.
- **Mosaic :** Symptoms of certain viral diseases of plants characterized by intermingled patches of normal and light green or yellowish in colour.
- **Necrotic :** Dead and discoloured.
- **Pathogens :** An entity, usually a micro-organism that can cause diseases.
- **Phytoplasma :** Mollicutes that infect plants and cannot yet be grown in culture, as contrasted to spiroplasmas, which can be cultured.
- **Purification :** The isolation and concentration of virus particles in a pure form, free from cell components.
- **Resistance :** The ablity of an organism to exclude or overcome, completely or in some degree, the effect of a pathogen or other damaging factor.
- **Sterlization :** The elimination of pathogen and other living organisms from soil, containers etc by means of heat and chemicals.
- **Symptoms :** The external and internal reactions or alterations of plants as a result of a diseases.
- **Virion :** A virus particles.
- **Viriods :** Small, low-molecular weight ribonucleic acids thar can infect plant cells, replicate themselves and cause disease.
- **Virulence :** The degree of pathogenicity of a given pathogen.
- **Virulen :** Capable of causing a severe disease, strongly pathogenic.
- **Virrus :** A noncellular entity that consist minimally of protein and nucleic acid and then can replicate after
- **Wilt :** Loss of rigidity and drooping of plant part generally caused by insufficient water in the plant.
- **Yellows :** A plant disease characterized by yellowing and stunting of the host plant.

4.12 Self-Learning Excercise

Section -A (Very Short Answer Type Questions)

1. Name the organism in which RNA serves as a genetic material?
2. Name the type of nucleic acid present in TMV?
3. What genetic material is found in plant virus?
4. Define viriods?
5. Name the microorganisms having only one type of nucleic acid?
6. What is the name of the subunit of the protein coat in virus?

Section -B (Short Answer Type Questions)

1- What are the function of protein coat and nucleic acid virus?

2- Write any three systematic symptoms in plants infected with virus?

3- Give the structure of virus?

4- Explain if virus can be cultured artifically, and if yes what culture medium will you use for their culture?

Section -C (Long Answer Type Questions)

1. Describe the characteristics of virus?
2. Give an illustrated account of the morphology and chemical structure of viruses?
3. Describe the structure of tobacco moasic virus?
4. Give a brief account of moces of transmission of virus?
5. Give general account of virus?

4.13 References and further readings

- Singh, V., Pandey, P. C. and Jain, D. K. A Text book of botany, Rastogi Publication, Meerut.
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Unit - 5

Scope and Applications of Microbes

Structure of the Unit

5.0 Objectives
5.1 Introduction
5.2 Applications of Microbes in Industry
5.3 Agricultural Applications of Microbes
5.4 Applications of Microbes in Biotechnology
5.5 Application of Microbes in Degradation of Pollutants
5.6 Application of Microbes in Bio-control of Pests
5.7 Summary
5.8 Self-Learning Exercise
5.9 References and further readings

5.0 Objectives

After studying this unit you should be able to:

- Understand the uses of microbes in industries, agriculture, pesticide degradation of waste, pollution control and biocontrol of pests in agriculture,
- Knowledge of production methodologies of different metabolites in the field of microbiology,
- Uses of different microbial product produced through the biotechnological approach,
- To know about the latest research in the field of microbiology,

5.1 Introduction

Microorganisms are used in production of several products as in alcohol, organic acids, different antibiotics, amino acids, several enzymes; vitamins and applications in agriculture (biofertilizers, toxins of different microbes). By using biotechnology microbes are used in Recombinant DNA technology, in waste

treatment, steroids biotransformation, dairy products, in pesticide degradations and microbial plastics production. The microbes used in bio-control of pests by antagonistic interactions (antagonism), amensalism (antibiosis and lysis), competition, parasitism and predation. Microbes are used in degradation of pollutants as deterioration and spoilage of wine, sewage (wastewater) treatment, microbial leaching, petroleum (hydrocarbon) and microbial degradation of xenobiotics. The microbes helps in biodeterioration of stored plant food material, leather, stone and building materials, paper and other cellulosic materials, fuels and lubricants, metals, plastics, cosmetics and pharmaceutical products and biofiltration.

5.2 Applications of Microbes in Industry

Wild strains of microorganism produce low amount of commercially important products so mutant forms are used to achieve the increased yield optimum. The potential productivity of the microorganisms is controlled or regulated by its genome. The modified microorganisms have; different nutritional requirements with different culture conditions. These factors provide benefits to the process of strain improvement of the microorganisms, followed by reappraisals of its cultural requirements.

For example a mutant requiring oleic acid for neomycin formation by *Streptomyces fradiae* showed a decrease in the intracellular level of neomycin precursors in the mutant. The supersensitive mutants of 5-lactam antibiotics are another example. Strains selected as obvious variants after exposure to mutagen are usually inferior in their capacity for accumulation of antibiotic.

Strain with enhanced altered morphology may be inherently better producers but may require considerable fermentation development.

1. Alcohol Production

From the ancient time, the alcohol was produced by fermentation process but now a day it is produced by the biochemical process means through the catalytic hydration of ethylene. In modern era, attention has been paid the production of ethanol for chemical and fuel purposes by microbial fermentation. Ethanol is now a day produced by using sugar beet, potatoes, corn, cassava, and sugar cane (Fig. 5.1).

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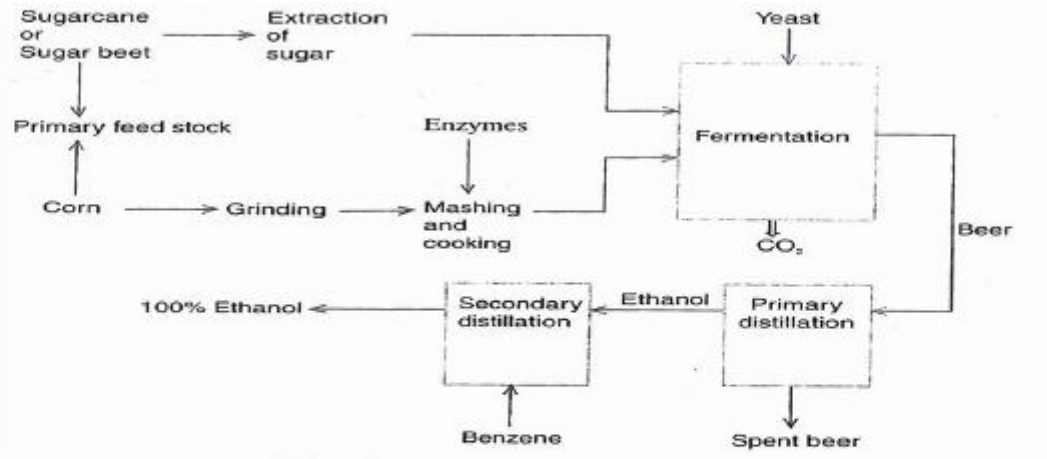


Fig. 5.1 : Ethanol Production from Molasses

Saccharomyces cerevisiae, S. uvarum, S. carlsbergensis, Candida brassicae, C. mills, Klebsiella fragilis (K. lactis) and bacteria (*Zymomonas mobilis*) have been employed for ethanol production in industries. The commercial production is carried out with *Saccharomyces cerevisiae*. The *Candida utilis* is used for the fermentation of waste sulphite liquor since it also ferments pentose. Recently experimentation with *Schizosaccharomyces* has shown promising results. Strain of *Klebsiella fragilis* is recommended for the production of ethanol from milk whey. It is also found that *Fusarium, Bacillus* and *Pachysolen tannophilus* (yeast) can transform pentose sugars to ethanol. It is not worthy that the ethanol at high concentration inhibits the growth of yeast. The concentration of ethanol reduces the yeast growth rate that affects the biosynthesis of ethanol. It can produce about 10-12 % ethanol but the demerit of yeast is that it has limitation of converting whole biomass derived by their ability to convert xylulose into ethanol. The *Zymomonas* has a merit over yeast that it has osmotic tolerance to higher sugar concentration.

Other fermented malt products-

(a) **Bock Beer-** prepared from roasted germinated barley seeds.

(b) **Pilsener-** lager type beer light in colour contains little fermentable carbohydrate.

(c) **Lager beer-**The bottom fermenting yeast is used for the preparation of lager beer.

(d) **Ale-** It is made by *Saccharomyces cerevisiae*, requires comparatively high temperature.

(e) **Sonti-** Rice beer or wine in India is called sonti.

(f) **Sake-** Japanese origin rice beer or wine with an alcohol content varying from 4-17% by preparing a starter or Koji through *Aspergillus oryzae.*

(g) Ginger beer- produced by yeast (*Saccharomyces pyriformis*) and *Lactobacillus vermiformi.*

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Types of wine

On the basis of production of carbon dioxide, wines are of two categories.

(a) **Still wine-** Those wine in which no carbon dioxide is produced by the fermentation is called still wine.

(b) **Carbonated wine-** Wine considerable quantity of CO_2 is produced is called carbonated wine.

(c) **Sherry or French dry sherry-** Prepared by grapes of high sugar, infected with *Botrytis cinerea.*

Other distilled beverages or liquors

(a) **Rum-** Obtained by distillation of alcoholically fermented sugarcane juice, syrup, or molasses.

(b) **Whiskey-** Obtained by distillation of saccharified and fermented grain mashes prepared by using wheat, corn, rye etc. by novel strains of *Saccharomyces cerevisiae* var. *ellipsoideus.*

(c) **Brandy-** Obtained from grape wine or by apple, peach and apricot after distillation.

2. Production of Organic Acids

(i) Vinegar Production- The vinegar mainly depends upon the type of local alcohol production such as rice vinegar in Japan or sugarcane vinegar in India. There are mainly two steps in vinegar production. In the first stage yeast converts sugar into ethanol anaerobically while in the second step, the ethanol is oxidized to acetic acid aerobically by *Acetobacter* and *Gluconobacter* and process is called acetification. The *Saccharomyces cerevisae* var. *ellipsoideus* carried out of the sugar into ethanol in the first step, while the species of *Acetobacter* or *Gluconobacter* convert ethanol into acetic acid. The animal pests such as

mites, fruit flies, vinegar eel (*Anguillula aceti*) attack the film of acetic acid bacteria which cause it to sink and deteriorate vinegar. Some times *Leuconostoc, Lactobacillus* contaminates the vinegar imparting off flavour.

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(ii) Production of Lactic Acid

Lactic acid was first discovered by Scheele (1789) from sour milk. Pastur (1857) identified the microorganism involved in lactic acid production. Lactic acid production by using chemical process was not economical, the recovery and purification were also not up to the mark. Lactic acid is produced by several microorganisms by fermentation which differ in their ability to produce either D (-) lactic acid, L (+) lactic acid or the racemic mixture. *Rhizopus oryzae* produces only L (+) lactic acid. There are mainly two important processes based on end product formation (a) Homofermentative process and (b) Heterofermentative process.

(a) Homofermentative process- *Lactobacillus delbruckii, L. bulgaricus, L. pentosus, L. leichrnanii, L. casei, Streptococcus lactis* more involves in the process. These bacteria utilize the BMP pathway to produce pyruvic acid which is then reduced by the lactate dehydrogenase to lactic acid. All the microbes are considered to be anaerobic and the end product is lactic acid with traces of others.

(b) Heterofermentative process- involves the action of *Leuconostoc esenteroides* which produces lactic acid, carbon dioxide, ethanol, acetic acid, water and few other products.

(iii) Production of Citric Acid

This acid was first produced commercially by John and Edmund in UK in 1826. Scheele (1789) reported the isolation and crystallization of the four constituents of lemon juice. Millard (1922) recorded accumulation of citric acid in culture of *Aspergillus niger* under condition of nutrition deficiency. Aeration is required for the continuous fermentation. The addition of copper ion is must to ensure that the new growth is of the right biochemical type.

3. Production of Antibiotics

Antibiotics (Fr. Anti = against; bios = life) are the chemical substances secreted by some microorganisms that inhibit the growth and development of other microbes. Most of antibiotics are introduced by Actinomycetes as *Streptomyces* and filamentous fungi (Table 5.1, 5.2). Antibiotics can be classified as-inhibitor of cell wall synthesis, able to damage the cell membrane, protein synthesis inhibitor, interference of nucleic acids and inhibitor of specific enzymes.

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(i) Production of Penicillin

The study of antibiotics began by the discovery of penicillin in 1929, when Alexander Fleming proved that the filtrate of a broth culture of *Penicillium notation* has antibacterial properties in Ration to Gram-positive bacteria. E. Chain and H. Florey (1940) obtained a relatively stable preparation of penicillin. Clutterbuck (1932) studied the chemistry of penicillin and observed that it can be extracted from organic acid solvents from aqueous solution of low pH, and it was heat labile. Morphological differentiation has been studied in relation to cephalosporin synthesis in *Cephalosporium acremonium* by causing mutation for elucidation of the biosynthesis pathways for antibiotics cephalosporin synthesis.

Streptomycete has the ability to produce aerial mycelium is sometimes associated with production of antibiotics. The biosynthetic pathway for butirosins using blocked mutants of *Bacillus circulans*. Corynesin (Chloramphenicol analog) is produced by *Corynebacterium hydrocarboclastus*. A mutant requiring oleic acid for neomycin formation by *Streptomyces fradiac* showed a decrease in the intracellular level of neomycin precursors in the mutant.

(ii) Production of Tetracyclines and Chloramphenicol

These tetracyclines are broad spectrum antibiotic and showed activity (Gram-positive and Gram-negative bacteria, Rickettsia, and some large viruses). The tetracyclines are also valuable for relatively low toxicity. There are three important actinomycetes namely, *Streptomyces aureofaciens, S. ramosus* and *Nocardia sulphurea* which form

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tetracyclines. *Streptomyces aureofaciens* produces aureomycin as observed by Duggar (1948, 1949) (Table 5.1).

Table 5.1: Representative natural Antibiotics, their producers and the target group

Producing Organism	Antibiotic	Target Group
Fungl		
Penicillium notatum	Penicillin	Mainly Gram-positive bacteria
P. chrysogenum	(Benzyl	(Bacteriolytic)
P. griseofulvin	penicillin)	Fungi (Fungistatic)
Cephalosporium	Griseofulvin	Gram-positive/negative bacteria
acremonium	Cephalosporin C	including *Pseudomonas* app.
		(Bacteriolytic)
Bacteria		
Bacillus licheniformis	Bacitracin	Gram-positive bacteria
B. polymyxa	Polymyxin	Gram-negative bacteria
B. brevis	Tyrothricin	Gram-positive bacteria
Actinomycetes		
Streptomyces griseus	Streptomycin	Gram-negative and *Mycobacterium tuberculosis*
S. venezuelae	Chloramphenicol	Gram-positive/negative, *Salmonella typhosa*
S. aureofaciens	Chlorotetracyclin	Gram-positive/negative bacteria
Streptomycis rimosus	Tetracycline	Gram-positive/negative bacteria
S. erythreus	Erythromycin	
S. tradiae	Neomycin	Mainly Gram-positive bacteria
S. orientalis	Vancomycin	For Gram-negative bacteria
S. mediterranei	Rifamycins	Gram-positive bacteria including clostridia
S. kanamyceticus	Kanamycin	
S. noursei	Nystatin	*Mycobacterium tuberculosis*

S. tenebrarius	Tobramycin	Gram-positive/negative bacteria
S. nodosus	Amphotericin B	Fungi
Micromonospora purpurea	Gentamicins	Gram-positive/negative bacteria Fungi Mainly Gram-negative bacteria

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(iii) Production of Streptomycin

It is effective against *Mycobacterium tuberculosis* and Gram-negative bacteria. The prolonged use of streptomycin in mass can produce neurotoxic effects and loss in hearing. So since it discovered by Schatz, Burgle and Waksman (1944) most of the strains of *S. griseus* are genetically improved.

Table 5.2: Antibacterial, Antibiotics and other Chemotherapeutic agents

Group	Agent	Mode of action	Antibiotic spectrum	Toxicity
Sulfonamides (synthetic)	Sulfadiazine Sulfathiazole Sulfaguanidine Sulfamethoxazole Sulfasixidine Sulfisoxazole	Inhibition of folic acid containing coenzymes	Bacteriostatic. Both Gram-positive/negative bacteria. Combination with trimethoprim shows synergistic effect and reduces development of resistant mutants	Low toxicity, occasional skin rash
Trimethoprim (synthetic)	Trimethoprim	Inhibition of folic acid	Combination with	Occasional toxicity

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		synthesis in a step different from that inhibited by sulfonamides	sulfamethoxazole is effective against *Pneumocystis* pneumonia in AIDS patients	
Nalidixic acid and fluroquinolones (synthetic)	Nalidixic acid, norfioxacin Ciprofloxacin Ofloxacin	Inhibition of DNA synthesis. Bind to DNA-gyrase	Mainly Gram-negative bacteria. Fluroquinolones are broad-spectrum agents	Fluoroquinolones are less toxic than nalidixic acid
β-lactam antibiotics (Natural and semi-synthetic)	Penicillins Benzyl penicillin Phenoxymethyl penicillin Ampicillin Amoxycllin Oxacillin Cloxacillin Carbenicillin Ticarcillin **Cephalosporins** Cephalexin Cephalothin Cefoxitin Cefotaxime	Inhibition of bacterial cell-wall synthesis. Transpeptidation of peptide side chains of murein is inhibited Similar to penicillins	Bacteriolytic Benzyl penicillin is mainly active against Gram-positive cocci. Semisynthetic penicillins are broad-spectrum antibiotics Broad-specrum. Also active against penicillin-	Generally non-toxic. May cause anaphylaxis in very rare cases Low toxicity

			resistant bacteria	
Aminoglycosides (Natural and semi-synthetic)	Streptomycin Gentamicin Kanamycin Neomycin Tobramycin Amikacin	Inhibition of protein synthesis. Interfere with condon-anticodon recognition by binding to the 30S subunit of prokaryotic ribosome	Bactericida, Broad-spectrum. Specially effective against *Mycobacterium tuberculosis, Pseudomonas* spp.	Toxic. Affect the hearing system. Some are used only for topical application
Tetracyclines (Natural and semi-synthetic)	Oxytetracycline Chlorotetracycline Doxycycline Minocycline	Inhibition of protein synthesis. Bind to 30S subunit of ribosome and prevent binding of aminoacyl t-RNA to ribosome	Bacteriostatic. Broad-spectrum Active also against intracellular pathogens like rickettsiae and chlamydiae	Low toxicity
Chloramphenicol (Natural but now synthetic)	Chloramphenicol	Inhibition of protein synthesis. Binds to 50S subunit of ribosome and inhibits peptidyl	Bacteriostatic Broad-spectrum. Active against *Salmonella, Haemophilus* and	Toxic Aplastic anaemia

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		transferase reaction	*Rickettsiae*	
Macrolides (Natural and semi-synthetic)	Erythromycin, Azithromycin, Clarithromycin	Inhibtion of protein synthesis. Bind to 50S subunit of ribosome and interfere with transpeptidation and translocation	Bacteriostatic. Mainly active against Gram-positive bacteria and some Gram-negative ones, like *Neisseria, Legionella, Chlamydia*	Essentially non-toxic
Rifamycins (semi-synthetic)	Rifampicin, Rifabutin	Inhibit bacterial transcription by binding to the β -subunit of RNA polymerase	Highly active against Gram-positive bacteria incluidng *Mycobacterium tuberculosis* and *M. leprae*	Relatively non-toxic

4. Production of Amino acids

Initially amino acids have been produced in Japan by bacterial fermentation (1950). The biosynthesis is now possible by genetically manipulating and physiologically altering the microorganism. *Corynebacterium glutamicum* and *Brevibacterium flavum* are involved in synthesis of L-lysine and L-threonine from a common intermediate, aspartic acid.

(i) Production of L-Lysine

Escherichia coli and *Enterobacter aerogenes* are used for the formation of diaminopalmelic acid and for the decarboxylation of the diaminopalmelic acid by an enzyme DAP decarboxylase (*E. aerogenes*)

respectively. *E. aerogenes* is an auxotroph requires L-homoserine or a mixture of L-threonine and L-methionine. The lysine-histidine are double auxotrophic mutant of *E. coli* produces diaminopalmelic acid on a molasses medium

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(ii) Production of L-Glutamic acid

Kinosita *et al* (1957) observed that L-glutamic acid is produced by using bacterial isolate, *Micrococcus glutamicus* isolates. This organism is not an auxotroph and requires biotin in the medium for growth. The amino acid is present both intracellular as well as leaked out in the medium subjected to optimum biotin level available for fermentative production of L-glutamic acid. If excess of biotin is present in the medium, there is heavy cell growth but lactic acid production starts. Some microorganisms such as *Corynebacterium herculis, C. lilium, Arthrobacter globiformis, Microbacteriurn salicinovorum, Brevibacterium divaricatum, B. aminogenes, B. flavum, Bacillus megaterium* are other microbes that produce glutamic acid.

5. Production of Enzymes

(i) Pectinases

It was studied that certain soft-rot causing bacteria produced pectolytic enzymes as *Fusarium* species which is wilt producing also produced pectinases as enzyme was observed. Scheffer *et al* (1950) contributed that *Verticilluim* species produces pectolytic enzymes that final plugging of xylem of infected plants. The production of appropriate pectolytic enzymes may not be the only characteristics needed to make a wilt inducing fungus pathogenic to a particular species of plant. The pectic substances, maker of middle lamellae are polymers of galacturonic acid.

(ii) Invertase or saccharose or sucrase

The enzyme sucrase splits sucrose into glucose and fructose. *Saccharomyces fragilis, S. cerevisiae* and some other species of *Saccharomyces* sp. are the richest source of enzyme invertase. Invertase is produced in industries from baker's or brewers yeast.

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(iii) Proteases

Enzymes of this group are catalyzing the hydrolysis of the protein molecule. The enzyme is actually a mixture of protenses and peptidases. These hydrolyze polypeptide fragments as amino acids. Various bacteria, such as *Bacillus, Pseudomonas, Clostridium, Proteus, Serratia,* species and fungi, namely *Aspergillus niger, A. oryzae, A. flavus,* and *Penicillium nquefortii* are the sources of various bacterial species that produce proteolytic enzymes.

(iv) Lipases (Glycerol esterhydrolase)

A large number of microorganisms are capable of using natural oils and fats as a carbon source for their growth. The enzyme responsible for the breakdown of the oils and fats prior to their digestion by microorganisms is extracellular lipases which catalyse the hydrolysis of triglycerides to free fatty acids, partial glycerides and glycerol. The Microorganisms used in extracellular lipase production are *Candida cylindracae, Candida rugosa. Aspergillus niger, Penicillin cyclopium, Humicola langinosa, Mucor javanicus, Rhizopus arrhizus* and *Geotrichum candidum.* The extraction of extracellular lipase from *Pseudomonas aeruginosa* was studied Jalger *et al.* (1992).

(v) Cellulases

The cellulases are synthesized by a large number of microorganisms such as fungi, bacteria, actinomycetes etc. Many bacteria utilize cellulose by cell bound enzymes, but fungi secrete cellulase into the growth medium. The extracellular cellulases secreted by *Trichoderma ressei, T. koningii, Penicillum pinophiluns, Fusarium solani* and *Phanerochaete chrysosporium*. The aerobic cellulolytic bacteria are *Cellulomonas* sp., *Cellubrio* sp., *Microbispora bispofa,* and *Thermomonospora* sp. *Acetovibrio cellulolyticcus, Bacteroids cellulosovens, Clostridium thermocelluns, Ruminococcus albus* are some anaerobic cellulolytic bacteria.

6. Production of Vitamins

(i) Riboflovin (Vitamin B2)

Riboflavin (also called lactoflavin) from whey of milk was isolated by Kuhn, Gyorgy and Wagner Jauregg (1933). It is present in free riboflavin

form. It is also present in other foods (liver, heart, kidney, or eggs) as flavoproteins which contain the prosthetic group FMN or FAD. Several microorganisms namely, *Clostridium acetobutylicum, Mycobacterium smegmatis, Mycocandida riboflavina, Candida flareri, Eremothecium ashbyii* and *Ashbya gossypii* are used in commercial production. *A. gossypii* has got an ability to resist against riboflavin accumulation. Riboflavin is produced also by chemical synthesis but biotransformation of glucose to D-ribose by mutants of *Bacillus pumilus* and subsequent chemical conversion to riboflavin produced 50% of worldwide production (Table 5.3).

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(ii) Vitamin B12 (Cyanocobalamine)

Minot and Murphy (1926) studied that liver extracts cure pernicious anaemia in human beings. Ricke and Smith (1948) isolated and crystallized vitamin B-12 from liver extracts. This vitamin is present in a very small amount in every animal tissue including human blood. It is synthesized *Butyribacterium rettgeri, Bacillus megaterium, Streptomyces olivaceus, Micromonospora* sp., *Klebsiella pneumoniae* etc. High yields of these vitamins have been obtained from *Propionibacterium freudenreichii, P. shermanii* and *Pseudomonas denitrificans.* The molecular biology and genetic engineering techniques have improved strains of *Rhodopseudomonas protamicus* (hybrid between *Propionibacter ruber* and *Rhodopseudomonas spheroides*) produces 135 mg/litre vitamin B-12. Vitamin B-12 analogue having other heterocyclic bases (purines or substituted benzimidazoles) either spontaneously produced by microorganisms or are produced after the addition of these substances in the culture medium (Table 5.3).

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Table 5.3: Major products of classical microbial fermentations showing the producing organisms and the important use of the products

Producing organism	Product	Uses
Yeasts and fungi		
Ashbya gossypii	Riboflavin	Component of Vitamin-B
Eremothecium ashbyii	Riboflavin	Component of Vitamin-B
Blakesleea trispora	Carotenoids	Precursor of vitamin A
Choanephora circinans	Carotenoids	Used in pharmaceuticals
Claviceps purpurea	Ergometrin and	Alkaloids used as
Fusarium monilifome	ergotoxin	medicines
Gibberella fujikuroi	Gibberellic acid	Plant hormone; used for
Aspergillus niger	Gibberellic acid	fruit setting and seed
	Citric acid, oxidases,	production
	gluconic acid, lipase	Food products, soft
Aspergillus terreus	and pectinase	drinks and
A. aureus		pharmaceutical (Citric
Mucor sp.	Itaconic acid	acid), bleaching of
	Protease and amylase	paper
Rhizopus nigricans	Renin (chymosin)	Wetting agent for resins
R. nigricans and *R.*		Meat softener, tanning
aureus	Fumaric acid	Curdling of milk in
	Transformation of	cheese manufacture
	steroids	Wetting agent for resin
		Preparatoin of 17-δ-hydroxy corticosterone
Bacteria		
Acetobacter xylinum	Cellulose microfibrils	Thickening agent in food
Alcaligenes faecalis	Curdlan	products
Azotobacter vinelandii	Microbial alginate	Pharmaceutical
Bacillus subtilis	Surfactin; amylases,	preparations
	proteases	Sizing agent
B. polymyxa		Surface active agent
B. thuringiensis	2, 3-Butanediol	paper and textile

B. popillae	Bio-insecticide	industries
Clostridium acetobutylicum	Bio-insecticide	Solvent
Lactobacillus delbruckii and *L. bulgaricus*	Acetone, butanol Lactic acid	Protection of crop plants from Insect infestation
Gluconobactor suboxydans	Alpha-Ketogluconic acid and sorbose	Solvents Used in food products, in
Methylophilus methylotrophus	SCP from methanol Cyanocobalamine	textile, tanning and laundry industries
Propionibacterium freudenreichii	Trehalose tetradiether	Intermediates of tartaric acid and ascorbic acid.
Rhodococcus erythropolis	Cyclodextrins Xanthan gum	Animal feed Food and feed
Thermoanaerobacter sp		supplement and in
Xanthomonas campestris		pharmaceutical preparations
		Surface-active agent
		Pharmaceutical products
		Food-stabilizer, thickening agent in syrup and ice-cream

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5.3 Agricultural Applications of Microbes

Microbial inoculants are a formulation that contains one or more beneficial microbial strains (or species) in an easy-to-use and economical carrier material, organic, inorganic or synthesized from defined molecules. The desired effects of the inoculants showed on plant growth include nitrogen fixation, enhancement of mineral uptake, weathering of soil minerals, biocontrol of (mainly) soil-borne diseases and nutritional or hormonal effects. In a microbial consortium or mixed inoculants, the combination of microorganisms interacts with other synergistic microorganisms. All of them provide nutrients, remove inhibitory products, and stimulate each other through physical or biochemical activities. A mixture of

Azospirillum (provides nitrogen) and *Cellulomonas* (degrades cellulose into glucose and this glucose) acts as Carbon source to *Azospirillum*.

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(i) Biofertilizers for nitrogen

The agricultural lands deprived of either one mineral or the other effects the growth of plants. Biofertilizers are the formulations of living microorganisms which are able to fix atmospheric nitrogen in the available form for plants (nitrate form) either by free living in the soil or associated symbiotically as *Anabaena azollae*. The nitrogen fixing as *A. azollae* and *A. variabilis* when immobilized in polyurethane foam and sugar cane waste have significantly increased the nitrogen fixing activity and ammonia secretion.

Other nitrogen fixing cyanobacteria as *Aulosira, Calothrix, Hapalosiphon, Scytonema, Tolypothrix* and *Westiellopsis* are used to increase fertility of the tropic rice fields. Several non-leguminous (particularly graminaceous species) have registered tremendous interest in nitrogen fixation and number of diazotrorphic bacteria such as *Azospirillum, Herbaspirillum* and *Acetobacter* has been reported. The facultative endophytic diazotrophs as *Azospirillum* spp. *Anabaena* considered important with non-legume plants, obligate endophytic diazotrophs as *Acetobacter diazotrophicus* and other bacteria as *Alcaligens, Burkholderia,* and *Klebsiella* substituted Nitrogen fixation has been observed in rice inoculated with *K. oxytoca*.

(ii) Biofertilizers for Phosphorus

Tropical soils are deficient in phosphorus and most of the microorganisms solubilize Phosphorus make it available for plant growth. *Aspergillus awamori, Penicillium digitatum* and bacteria like *Bacillus polymyxa, Pseudomonas striata* solubilize unavailable form of phosphorus to available form of rock phosphate deposits. Vesicular-arbuscular-mycorrhizal (VAM) fungi as *Glomus, Gigaspora, Acaulospora* and *Sclercystis* help plant growth through improved phosphorus nutrition and protect the roots against pathogens. The production of mycorrhizal biofertilizers inoculum differs with respects to

their nature depending upon their types as ectomycorrhizal or endomycorrhizal.

Waste water containing high concentration of nitrate can lead to eutrophication (algal or water blooms) when released directly without treatment into natural water bodies. To remove nitrates, anaerobic bioreactors have been designed in which denitrifying bacteria convert nitrate into molecular nitrogen. These escapes into the atmosphere like such bioreactor, *Melhylophilus methylotorophus* is employed which uses methanol as substrate and denitrify nitrate.

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(iii) **Toxins produce by *Bacillus thuringiensis*-** The Bt produces several toxins out of it, four alpha-exotoxin (heat-labile toxin); beta-exotoxin (fly-factor or heat-stable exotoxins); delta endotoxin (crystalline toxin or just crystal or parasporal body) and louse factor. The alpha exotoxin identifies as lecitherase C water soluble, heat labile and toxic to insect while the beta exotoxin defined as adenine nucleotide and ATP analogue thuringiensin (water soluble heat-stable toxin). The beta endotoxin in the crystal of Bt has a limited activity spectrum. The toxicity to lice (causal agent of mammals) was due to louse factor (new chemical).

(iv) **Bacteria associated with nematodes-** Nematode larvae entering an insect body cause septicaemia by dissolving the insect gut wall and thus introducing Bt bacteria in the haemolymph. *Achromobacter nematophilus* (an entomocidal-insect-killing) bacteria was described initially from the nematode *Neoplectana carpocapsae* and regarded as a commensal symbiont of the nematode. The nematode genera, *Neoplectana* and *Heterorhabditis* carry in its gut bacterial species named *Xenorhabdus nematophilus* and *X. fluorescens.* It is surprising that even one bacterium from each species is enough to kill insect.

(v) **Virus Insecticides-**There is viruses or their products commercially exploited in place of chemical insecticides. Viruses of the family Baculoviridae are pathogenic to arthropods restricted in their host ranges and they do not infect vertebrates, non-arthropod invertebrates, microorganisms or plants. Indeed baculoviruses infect only a few

arthropod species. Viruses most frequently considered for control of insects (usually saw flies and lepidoptera) are the occluded viruses, namely cytoplasmic polyhedrosis (CPV), granulosis (GV) and entomopox viruses (EPN).

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(vi) Entomopathogenic Fungi- These fungi overcome their hosts only after limited growth in the haemocoel so toxins are presumed to cause host death. The toxin production in the host must be preceded by activities as attachment of the infective unit on the cuticle, germination of infective unit, peneteration formation of germ tube and appearance of infection pegs from like appressoria, multiplication of hyphal bodies in the haemocoel, production of toxic metabolites, growth in the mycelial phase with invasion of all host organs, penetration of hyphae from the interior through the cuticle to the exterior of the insect and production of infective units on the exterior of the insects.

The fungus *Metarhizium anisopliae* produces destruxin B and desmethyl destruxin B in silk worm larvae and toxins are known as vivotoxins. Infection of *Entomophthora* species cultures into *Galleria mellonella* larvae caused blackening similar to that noted in infected larvae. Beauvericin is a depsipeptide and isolated from mycelium of *Paecilomyces fumosoroseus.* Fungi as *Beauveria bassiana* and *B. brongriartii* attack on insects. *Verticillium lecanii,* is non-fastidious fungi frequently recorded hosts are scale insects and aphids or sometimes hyperparasitizes phytopathogenic fungi on rusts and powdery mildews. *Hirsutella thompsonii,* is a potential killer of citrus rust mite (*Phyllocoptrula oleivora*). The fungal strains have also been reported from the citrus bud mite *Eriophyes sheldone* and coconut flower mite *E. guerreronis*. *Nomuraea rileyi* usually found to induce extensive epizootics in caterpillar pests on cabbage, clover, soybean and velvet beans and thus is a potential agent for use as a microbial insecticide. The natural epizootics were observed on *Bombyx mori, Peridroma saucia, Leptinotarsa decemlineata*. The other fungal species as *Aspergillus ochraceus, Paecilomyces fumosoroseus, Fusarium solani, Trichoderma*

harzianum, T. reesei, Gliocladium virens have also been reported as microbial pesticides.

(vii) Microbiology of lignocellulose degradation in the rumen

Lignocellulose (fodder) degradation in the rumen is a complex succession of reactions. A number of rumen microorganisms are cellulolytic and hemicellulolytic. These organisms act in consortium of mixed culture to hydrolyse the plant cell wall polymers. Small plant fragments are engulfed intact by the larger rumen ciliates such as *Eudiplodimuim maggii*. Large, fresh fragments are subjected to invasion cellulolytic chytridiomycetes fungal zoospores, such as *Neocallimatrix frontalis* and motile cellulolytic bacteria namely, *Butyrivibrio fibrisolvens, Eubacterium cellulosolvens* etc.

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(viii) Biodegradation of pesticides

Pesticides are synthetic complex organic compounds used in modern agriculture against controlling insect pests, pathogenic fungi and nematodes insect vectors of human diseases. Insecticides, fungicides, nematicides, herbicides are used in modem agriculture to eradicate undesirable pests and herbs in fields.

These man-made xenobiotic compounds are often highly recalcitrant to microbial decomposition and they may persist for a long time or amplified in food chain. Accumulation of the pesticides in soil and natural water bodies leads to pollution endangering the flora and fauna.

The interactions of different species for degrading a complex chemical compound may be of several different types. In cooperative interaction, one species attacks the compound to yield another compound which is utilized by a second species as a substrate and this may continue till the compound is fully degraded to produce inorganic products. In synergism two different species may be involved but neither of the two can individually degrade the compound. Co-metabolism is observed in decomposition of a compound, when a species grows at the expense of a substrate and simultaneously transforms another compound without deriving any direct benefit from the process.

5.4 Applications of Microbes in Biotechnology

NOTES

(i) Applications in Waste Treatment

The major use of biotechnology or rDNA technology is to detect the pathogens and to increase biodegradation of xenobiotics in waste water treatment plants. The major tools of rDNA technology are the nucleic acid probes and PCR to detect pathogens in effluents of wastewater plant. Some pathogens detected by PCR are *E. coli, Shigella flexneri, Salmonella, Legionella pneumophila, Pseudomonas aeruginosa, Yersinia,* Hepatitis A virus, HIV and *Giardia*.

(ii) Applications in steroids biotransformation- Steroids are complex organic compounds and require long step reactions for formation of steroids. Presently, soybean for stigmasterol, diosgenin from the *Dioscorea* plant was found to be easy and economical sources. Microbial preparations of many steroids by their enzyme action at the specific site led to the synthesis of novel varieties of steroids. Steroid transformation is different with that of microbiological process due to the fact that in later those organic acids, solvents, antibiotics are synthesized from the ingredients in the medium which also serve as substrate for growth and reproduction of microorganisms. Several fungal species as *Rhizopus nigricans, Curvularia lunata, Aspergillus, Penicillium, Gliocladium, Fusarium solani* and yeasts are some of the important organisms used for steroid biotransformation. *Corynebacterium simplex*, and actinomycete *Nocardia restrictus* are bacteria species known for biotransformation.

Table 5.4: Some Selected Products obtained From Genetically Engineered Bacteria and Yeast

Genetically engineered organism or cell	Product	Uses
Escherichia coil	Human insulin	Diabetic patients
E. coli	Somatostatin	Human hormone
E. coli	Human growth hormone	For growth deficiency in

		children suffering from hypopitutary dwarfism
E. coli and *Saccharomyces cerevisiae*	Alpha-interferon	Therapy of viral diseases and cancer
E. coli	Gamma-interferon	Therapy of chronic granulomatous diseases.
Escherichia coli	Tumor necrosis factor (TNF)	Used for disintegration of tumour cells in cancer therapy
E. coli	Interleukin-2	Stimulation of immune system (cancer therapy)
E. coli	Epidermal growth factor	Therapeutic use in healing of wounds and ulcers
E. coli and Saccharomyces cerevisae	Colony stimulation factor (CSF)	Leukaemia and resistance of infections in AIDS patients.
E. coli and S. cerevisae	Prourokinase	Anticoagulant, therapy of heart attack
	Relaxin	Easing of child brith
E. coli	Taxol	Treatment of ovarian cancer
E. coli	Hepatitis B surface glycoprotein Superoxide dismutase	Vaccine against hepatitis B virus Antioxidant
S. cerevisae and *Pitchia pastoris*		

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(iii) Applications in dairy products- Dairy or lactic streptococci, defined as strains of *S. lactis, S. cremoris* etc utilized for centuries in the production of fermented milk products. The main role of microbes is to produce lactic acid from lactose (milk sugar). The quality of fermented products is also dependent upon the ability of starter organisms to produce flavour or aroma compounds. Fermented milks are produced by inoculating pasteurized milk with a known culture of microorganisms as a starter

culture as *Streptococcus thermophilus* and *Lactobacillus bulgaricus* used as starter cultures in the preparation of yoghurt (Table 5.5).

Table 5.5: Microorganisms associated with Fermented Milk Production

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Fermented milk	Microbe involved
Cultured butter milk	*Streptococcus lacti, S. cremoris* with aroma producing bacteria, *Leuconostoc* spp
Acidophilous milk	*Lactobacillus acidophilus*
Yoghurt	*Streptococcus thermophilus, L. bulgaricus, S. lactis*
Kefir	*L. bulgaricus,* Lactose-fermenting yeast

Rennin or milk-coagulating enzyme rennet has its importance in cheese production. Certain commonly used cultures which have an ability to convert lactose to lactic acid are *Streptococcus lactis, S. cremoris, S. thermophilus, Lactobacillus helventicus* and *L. bulgaricus*. These organisms bring the desired curd structure and flavour with minimum gas production. Rennet is an extract from the fourth stomach of 3 to 4 week old calves which have been fed on milk. The enzyme purified and called rennin, chymase or chymosin. Rennin production of microbial origin is now widely recommended due to good coagulation of casein without hydrolysis, good odour and structure of cheese, nontoxic, low protein denaturation in order to prevent the development of bitter taste during ripenning process and low lipase activity to check the ranicidity development. Species of *Aspergillus, Candida, Coriolus, Rhizopus, Mucor, Penicillium, Torulopsis* etc. *Mucor pusillus, M. miehei* and *Endothica parasiticus* are widely used to produce rennin.

(vi) Applications as in Rumen Bacteria

Genetic modification of rumen bacteria by using rDNA technology may improve the rate or extent of lignocellulolysis digestion complex in animal. It is then necessary to develop effective vectors and transformation system to develop methods to monitor both the survival of the gene in the host cell and its survival in the rumen and finally to

measure its effect on in vivo digestibility of lignocellulose. Gene cloning in rumen bacteria may provide valuable into our understanding of the process operating in rumen. Genetic mutation technique used to produces greater quantities of ratelimiting enzymes. Mutagenesis in *Ruminococcus albus* causes regulation of cellulose enzymes. Genomic DNA libraries of *Bacteriodes silccinogens, Ruminococcus albus, Butyrivibrio fibrisolvens* have been constructed of fragments from the cellulolytic rumen bacteria.

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(v) Applications in pesticide degradations

The interactions of different species for degrading a complex chemical compound may be of several different types as cooperative interaction, synergism and co-metabolism. The insecticide parathion (diethyl paranitrophenol phosphorothionate) is slowly degraded by a microbial community consisting of *Pseudomonas slulzeri, P. aeruginosa* and *Corynebacterium.* These organisms act on parathion in coordinated manner. The initial attack is made by *P. stutzeri* converts parathion slowly to diethyl thiophosphate and p-nitrophenol. Now *P. aeruginosa* breaks down p-nitropherol and the products are used by the other two bacteria. An enzyme parathion hydrolase found in *Flavibacterium* species and *Pseudomonas diminuta*. This enzyme can also hydrolysed insecticides like diazinon, fenitrothin and cyanephos. The popular insecticide DDT is one of the highly recalcitrant xenobiotics which can persist for more than 15 years in nature and biologically amplified. This DDT has been shown to be slowly dechlorinated by *Aerobacter aerogenes* (= *Enterobacler aerogenes*) under anaerobic conditions producing dichlorophenyl methane. The latter can be converted to chlorophenyl acetic acid and chlorinated ketoenol compounds by *Alcaligene* sp. under aerobic conditions.

Organic sulfur compounds like dibenzothiophenes are degraded by *Rhodobacter* sp. This ability of these bacteria has been practically employed for removal of organo-sulfur compounds from diesel. The purified diesel does not emit sulfur dioxide in the burnt emissions of automobiles. For removal of chlorinated hydrocarbons from effluents of pesticide manufacturing plants, *Pseudomonas cepacia* has proved effective. Azo dyes in the effluents of textile factories. These dyes are

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removed by a strain of *Acetobacter liauefaciens* which is capable of degrading these dyes.

An ingenuous method of monitoring bioremediation has been developed by cloning the *lux-genes* controlling bioluminescence into some degrading bacteria, like *Pseudomonas fluorescence* capable of degrading naphthalenes. In this organism the *lux-genes* was cloned in such a way that it is expressed by the same promoter which controls also the naphthaline-degrading gene. The transgenic organism emits light when it is actively degrading the substrate (naphthalene). This makes the detection of active bacteria in the biodegradation plant much easier. As bioluminescence requires presence of oxygen, transgenic organisms containing the *lux-gene* can also be used for detection of oxygen in a bioremediation system. The transgenic bioluminescent bacteria can also be utilized in various other ways. Bioluminescent in *E. coli* has been employed for detection of toxic pollutants in waste waters because in presence of such substances, the bacteria are inactivated or killed failing to emit light.

Mercury out of the other two forms, Hg^{+} is more toxic than Hg^{+}. Many bacteria belonging to a wide range of genera like *Proteus, Providencia, Pseudomonas, Serratia, Shigella, Klebsiella, Staphylococcus* carry plasmid-borne genes conferring resistance to Hg^{++} as well as to organo-mercurial compounds. Such resistance has been found to be due to their ability to reduce mercuric ion ($Hg+^{2}$) to metallic mercury, catalysed by the enzyme, mercuric reductase which uses $NADPH_2$ as electron donor. Microorganisms may also cause aggravation of mercury toxicity and can convert metallic mercury to a methylated derivative (CH_3Hg^{+}) under anaerobic conditions. This organic mercury compound is 100 times more toxic than mercuric ion.

(vi) **Applications in microbial plastics production-** Certain bacterial species naturally synthesize polymers such as poly-p -hydroxybutyrate (PHB) as a raw material for plastic production. The bacterial plastics are substitute for synthetic polymers which are not only nuisance to environmentalist but also responsible for animal death. Genetically engineered microorganisms (GEMs) are recently developed to tackle this problem. The phenomenon of co-metabolism also called fortuitous oxidation, has been observed in pesticide degradation. A species *of*

Nocardia utilizes n-hexadecane, as substrate can simultaneously oxidise p-xylene, an aromatic hydrocarbon to produce 2, 5-dimethyl muconic acid. Another bacterium capable of utilizing diphenylmethane as substrate has been found to co-metabolise p-chlorobenzhydrol. The remedial measures to remove the ill-effects of pollutants on the environment by biological means constitute bioremediation. The self-purifying processes of nature operate spontaneously to keep the environment clean and healthy. The environment becomes sick when it is burdened with an overload of degradable, difficulty degradable or nondegradable materials produced through human activities. The bioremediation involves biodegradation at a more rapid rate than it normally occurs which can be achieved either by creating conditions or encourage acceleration of biodegradable.

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(vii) Applications in GMEs production- Still this technology is at the stage of infancy due to the lack of knowledge and fear in the society for release of genetically engineered microorganisms (GEMs).

5.5 Applications of Microbes in Degradation of Pollutants

(i) Microbial deterioration and spoilage of wine

Defects in wine are mainly due to metal and other reactants used for wine processing is not commercially used and discarded. White wines may turn brown and red wine may have precipitation by peroxidases or oxidizing enzyme of certain molds. *Acetobacter, Lactobacillus, Leuconostoc*, wild yeasts, molds. spoil wine. The species of *Acetobacter aceti* or *Gluconobacter oxydans* impart an undesirable process called acetification in which glucose may oxidise and may give mousy or sweet sour taste to wine.

(ii) Sewage treatment

Sewage is the used and wastewater consisting of human excreta, wash waters, industrial and agricultural wastes (wastes from live stock, chicken, cattle, horse etc) that enter the sewage system. In the sewage a variety of the microorganisms are found as bacteria, fungi, protozoa, algae, nematodes, amoebae and viruses. This sewage in general contains about 95.5% water and 0.1 to 0.5% organic and inorganic materials. The celluloses, lignocelluloses, proteins and fats are found in colloidal form

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in water. The industries disposed wastes consist of detergents, antibiotics paints, biocides etc. The pulp and paper industries discharge cellulosic and inorganic chemicals.

Biochemical oxygen demand (BOD) consequently develops anaerobic conditions in water which results in death of water animals and emitting foul smell due to incomplete oxidation of organic materials in sewage. The wastes have now high (BOD) requirement by aerobic bacteria which the sewage has no more oxygen to bring about oxidation process. BOD is the amount of oxygen required by organisms in water under certain standard conditions and sewage of high organic material has high BOD value and vice versa.

Septic tank for sewage treatment, the material is degraded (butyrate, propionate, lactate, succinate, ethanol) produced during fermentation are utilized as substrate by several acetogenic bacteria viz. *Synnitrophobacter* and *Acetobacterium*. The products produced as a result of acetogenic reactions by acetogenic reactions are acetate, H_2 and CO_2.

The products of acetogenesis are utilized as substrate by methanogenic bacteria. Acetate is used to produce $CH_4 + CO_2$ by *Methanosarcina* and *Methanothrix*. H_2 and HCO_3 are used to produce methane by several bacteria as *Methanobrevibacter, Methanomicrobium, Methanogenium, Methanobacterium, Methanococcus* and *Methanospirillum*. The final product of anaerobic digestion, is a mixture of gases (70% CH_4, 30% CO_2), microbial biomass and non-biodegradable residues (heavy metals, polychlorinated biphenyls)

(iii) Microbial leaching

Algae and oligotrophous, nonspore forming bacteria belonging to the genera *Pseudomonas, Corynebacterium and Arthrobacter* predominate in the rocks. Rocks disintegrate mainly along cracks and at the surface. Accumulation of organic substances, leaching of elements and formation of clayey minerals occur through weathering of rock-crust which are accompanied by large deposits of bauxites, kaolinite clays and nickel, are more complex land microenvironments. The weathering crusts are characterised by general distribution of autotrophic bacteria which oxidise reduced compounds of nitrogen, sulphur and iron. Non-spore

forming bacteria prevail among heterotrophs *Arthrobacter, Corynebacterium* and *Mycobacterium* in a pure culture which assimilate phenols, ethanol and other alcohols besides growing on nitrogen-poor rocks.

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(iv) Biodegradation of hydrocarbons

It is a microbiological process where the complex polymers are broken down into simple less harmful forms and in turn utilized by them as a source of energy. Petroleum (hydrocarbons) is a rich source of organic matter and oxidised when comes in contact with air and moisture. Some microorganisms cleave the hydrocarbons into simpler molecules. Oil or other pollutants are utilized by microorganisms if added with inorganic nutrients. The importance of bioremediation in oil spill of marine (sea) environment is widely studied. Besides cyanobacteria, yeast and algae (shown to oxidise hydrocarbons), fungi and bacteria also are the main agents which decompose oil and oil products. The simplest hydrocarbon pollutant is methane that degraded by bacteria called methanotrophic bacteria. Hydrocarbon-oxidising microorganisms develop rapidly in such films. Oil is present both in anoxic (absence of O_2) as well as oxic (presence of O_2) environment as is evidenced by the presence of natural oil deposits.

Many pseudomonad, cyanobacteria and mycobacteria are able for degradation of petroleum products. Initially the nonvolatile components are oxidised by bacteria and in the later process, certain fractions of branched-chain and polycyclic hydrocarbons are degraded slowly. It has an impact on fisheries.

Significant quantities of Si, Al, Fe and Mg were reported to be solubilized by *Penicillium simplissimum* from dunite, peridotite, basalt, granite and quartzite rocks due to the production of citric acid. The destruction of apophyllite, olivine and Ca and Zn silicate by Pseudomonas and other soil organisms was found to be accompanied by the releases of ketogluconic acid and other organic acids.

(v) Microbial degradation of xenobiotics

Xenobiotics are man-made compounds those do not exist in nature such as pesticides. Pesticides are toxic chemicals which act by interfering with microbial reactions in the target organisms. Most of the time these are

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added in soil and may affect those microorganisms which are important in maintaining soil fertility. Such organisms also detoxify pesticides in soil. So chemicals seriously affects the soil microflora may harm soil fertility and crop production. Pesticide loss can also occur by volatilization, leaching or spontaneous break down.

Table: 5.6 The microorganisms used to metabolize pesticides and herbicides

S.No.	Name of Microbe	Chemical	Degradation product
1.	*Closteriduim sporogenous*	γ - BHC	1,2,3,5 – tetrachlorobenzene
2.	*Pseudomonas putida*	γ - BHC	γ - BTC and α - BHC
3.	Yeast	DDT	1,1- dichloro-2-2 bis (p-chloropheny leithane, TDE)
4.	*Proteus vulgaris*	DDT	TDE
5.	*Aspergillus niger, Penicilluim chaysogenum*	Aldrin	Dieldrin
6.	*Trichoderma viridae, Mucor plumbeus*	Malathion	Dyfoxon

(vi) Microorganisms in abatement of heavy metal pollution

The metals and their compounds no doubt are indispensable to the safety and economy of most of the nations. Heavy metals cadmium, vanadium, manganese, arsenic, lead, iron, mercury, zinc, nickel, chromium, copper, antimony are toxic to the biological system, not only due to their inert nature but also due to their persistence and long run cumulative effects.

Fungi, bacteria, actinomycetes, algae are the major microorganisms reported to tolerate heavy metals which universally occur in diverse ecosystems with meaning frequency. Algal species as *Chlorella, Anabaena inaequalis, Westiellopsis prolifica, Stigeoclonium tenue, Synechococcus* species, *Selenastrum capricomutum* tolerate heavy metals. Bacteria resistant to heavy metals were frequently isolated from

environmental sources such as soil and water. *Staphylococcus aureus* was intermediate in heavy metal sensitivity between *E. coli* and *Pseudomonas aeruginosa.* The other bacterial genera as *Bacillus cereus, Mycobacterium scrofulaceum, Streptococcus agalactiae, Streptornyces lividans, Thiobacillus ferrooxidans, Pseudomonas aeruginosa, Yersinia enterocolitica, Staphylococcus aureus* were reported to tolerate both cadmium and mercurry. *Arthrobacter, Bacillus, Brevibacterium, Corynebacterium, Nocardia* and *Serratia* absorb mercury and lead along with other heavy metals in the solution *Alcaligenes faecalis* tolerate zinc and cadmium when grown in nutrient broth.

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Actinomyces flavoviridis and several species of *Streptomyces* exhibited high ability to absorb mercury and lead along with the other heavy metals from mixed metal solution of manganese, cobalt, nickel, copper, zinc, cadmium, mercury, lead and uranium. *Actinomyces levoris and S. viridochromogenes* were shown to accumulate a large amount of uranium from aqueous systems. Fungi also have the tolerance for heavy metals. Lead and copper were more readily accumulated by fungi and Actinomycetes in comparison to zinc, managenese, cobalt, nickel and cadmium which make selective accumulation of these heavy metals by fungi different from many bacteria and yeasts. *Trichoderma viride, Aspergillus niger* and *A. giganteus* tolerate nickel concentration but showed prolonged growth and inhibited spore formation and spore germination, reported the selective absorption of mercury and lead from a mixed metal solution along with the other heavy metals by *A. niger, A. oryzae, Chaetomium globosum, Fusarium oxysporum, Giberrella fujikuroi, Mucor hiemalis, Neurospora sitophila, Penicillium chrysogenum, P. lilacinum* and *Rhizopns oryzae* by sides yeast species of the genera *Candida, Hensenula, Saccharomyces* and *Torulopsis*. *Macrophomina phaseolina* has tolerent to 500 ppm of cadmium *in vitro* conditions. Cadimum toxicity increased with increase in pH and decreased with increase in concentration of Zn and Mn. Microalgae as green alga, *Chlorella,* blue green alga, *Anabaena* marine, masses, and macrophytes have been used for heavy metal removal. The naturally occurring cells showed higher efficiency for Ni^{2+} and Cd^{2+} biosorption as compared to laboratory cells.

(vii) Waste water pollution management

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The level of water pollution is increasing in large cities in many countries so efforts are being made to minimize water pollution levels and apply biotechnological tools for wastewater treatment. Japan has applied genetic engineering methods and improved bioreactors for wastewater and industrial waste treatment.

(viii) Bioaugmentation (Use of Blends of Microorganism) -Acceleration of biodegradation of specific compounds by inoculating bacterial cells is called bioaugmentation. Bacterial cells contain specific plasmid which encodes enzymes for degradation of those compounds. A variety of plasmids have been reported from *Alcaligenes, Acinetobacter, Arthrobacter, Beijerinkia, Klebsiella, Flavobacteriurn* and *Pseudomonas*. Several genetically engineered strains have been developed.

(ix) Metal removal

Generally physical and chemical methods are used for method of metal removal. Microorganisms utlised for metal removal is an alternative to physical and chemical methods. There are several microorganisms growing in marine water, fresh water and wastewater. *Bacillus licheniforrnis* and *Zooglea ramigera* have been isolated from activated sludge. They produce extracellular polymer which complex and accumulate metals such as iron, copper, cadmium, nickel or uranium. The accumulated metals are released from biomass upon treatment with HCl. Fungal mycelia (*Aspergillus* and *Penicillium*) also remove metals from wastewater and offer a good alternative for detoxification of effluents. Biosorption by *Aspergillus oryzae* can remove cadmium efficiently from solution.

(x) Biodeterioration of complex compounds

It is a phenomenon of reducing the quality of products by microorganisms through secretion of enzymes and other metabolites. It can be further classified as-

(1) Biodeterioration of stored plant food material

The stored or unprocessed plant materials like fruits, seeds are usually decayed by post-harvest attack of bacteria and fungi and

spoilage is called biodeterioration. Bacteria such as *Erwinia* sp., *Corynebacterium* sp. and fungi *Phytophthora* sp., *Streptomyces* sp., *Curvularia* sp., *Aspergillus* sp. developed dormant spores/mycelium that cause post-harvest spoilage resulting into deterioration of food, fruits, plant materials and seeds during storage. The most affected products are soft fruits and salad vegetables; grains, oilseeds and legumes are durable products and root vegetables and apples are of semi-perishable nature.

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(2) Biodeterioration of Leather

Leather is a product of animal hides which keratins, animal fats and proteins attacked by microorganisms. It is rapidly deteriorated by lipolytic and proteolytic microorganisms which secrete lipases and proteases. Leather production from animal hides involves soaking process in water where several bacilli (*B. subtalis, B. megaterium. B. punilis*) attack it. They secrete several extracellular enzymes that may remain active long after the death of their producer organism. During leather deterioration microbial damage may cause tensile strength and colouration. Finished leather is quite acidic, hence *Rhizopus, Mucor, Cunninghamella and Aspergillus* deteriorate it and bacteria are secondary colonizers. Wool, fur, and feathers mainly contain cystein rich proteins (keratin) which is degraded by keratinophilic fungal species as *Trichophyton, Chryosporium, Streptomyces* etc.

(3) Biodeterioration of stone and building materials

Old ancient monuments, natural rocks are attacked by various *Pleurococcus, Oscillatoria, Botrytis, Penicillium* and *Trichoderma* sp. and lichens. Various biocides in washes, bleaching compounds, phenolics and organo-tin compounds are being used to save the building materials. *Desulfovibrio desulfuricans* reduce sulphur compounds and produces H_2S which is then oxidized to sulphuric acid by *Thiobacillus thiooxidans*. Various nitrifying bacteria as *Nitrobacter, Nitrosomonas* also solubilise calcium associated with building material. They oxidize ammonia to nitrite leading in the formation of soluble form of calcium i.e. calcium nitrite. A large number of

pseudomonads corrode steel and iron structures used in building construction.

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(4) Biodeterioration of paper and other cellulosic materials

The plant cells are composed of cellulose, hemicellulose, lignin and pectic substances. So, the plant cell biomass derives paper and card. A large number of factors are responsible for the microbial spoilage of paper as deterioration of paper occurs by various cellulolytic fungi (*Trichoderma, Chaetomium, Aspergillus*) and bacteria (*Cellulomonas*). These microorganisms secrete cellulases (endo-p-glucanases,) exo-p-glucanases and (3-glucosidase) convert cellulose into glucose the simplest manner.

(5) Biodeterioration of fuels and lubricants

Fuels and lubricants are the products of petroleum are attacked only if water is present. Lubricants deteriorate more quickly as they consist of an emulsion of soil finely dispersed in water, in the presence of emulsifying agent. Large number of fungal species *Aspergillus, Cladosporium resinae* often found to be associated with oil sludge. These soil fungi degrade linear and branched alkanes to aromatic rings. Biodeterioration of these hydrocarbons containing materials may be controlled by adding biocides (organoboron, isothiazolones, etc.). The necessity of bioremediation for removing pollutants was felt acutely when accidental spillage of very large quantities of crude petroleum occurred and covered wide areas of sea surface killing marine animals and birds.

Different methods have been tried to minimize the detrimental effects of large-scale oil-spills. The removal of the deposited oil, use of surface-active agents to disperse the oil, stimulation of petroleum-degrading microorganisms *in situ* and addition of genetically engineered bacteria capable of degrading the major fractions of crude petroleum. Ananda Mohan Chakrabarty of the University of Illinois, USA, developed genetically engineered strains of *Pseudomonas putida* which proved highly efficient in degrading crude petroleum and claimed for patenting them in 1974. Although these bacteria were very effective in laboratory

tests, they proved to be of not much value when exposed to natural conditions.

(6) Biodeterioration of metals

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Microorganisms are known to corrode metals and they make biofilm by colonization of cells, which release corrosive metabolic products resulting in removal of hydrogen by sulphate reducing bacteria. The microbial concentrations of the cells appear from an oxygen gradient that develops as a microbial colony, in contact with the metal, utilizes the available oxygen. These colonies have both oxygen-accessible (border) and oxygen-limited zone (centre), which are having negative and positive charge particles respectively. This leads to metal ion formation by producing insoluble hydroxides. Iron corrosion occurs mainly due to a bacterium, *Gallionella* (chemolithotroph) that oxidizes ferrous ions to ferric ions and forms insoluble ferric hydroxide deposits at the site of microbial attack. Various organic and inorganic acids are of microbial origin for example *H. resinae* produces sulphuric acid to sulphide. The organism comes in contact of steel/iron resulting in corrosion and breakage/leakage of water pipe lines.

(7) Biodeterioration of plastics

Polymeric materials like polyethylene, polystyrene, poly vinyl chloride (PVC) and polyesters are resistant to microbial attack addition of various other materials makes the plastics prone to microbial attack. *Streptomyces rubireticidi* and *Penicillium* sp. are reported to deteriorate PVC and polyamides (nylon) respectively. Polyesters, polycaprolactone and polybutylene adipate are degraded by bacteria and fungi.

(8) Biodeterioration of cosmetics and pharmaceutical products

Cosmetics are being manufactured in the form of lotions, creams, liquids, solids and powder forms, used externally for cleaning and decorative proposes. Various lipids (oils, fats) are susceptible to microbial attack when dispersed in aqueous formulations after degradation. These allow various microbes to grow and secrete amylases, cellulases, etc. responsible for degradation of such

carbon containing microbial nutrients. Shampoo and detergents contain sodium dodecyl sulfate which act as substrates for enzyme alkyl sulphatases. The species of *Pseudomonas, Citrobacter* and *Aerobacter* secrete enzymes that breakdown the finished items and may generate unpleasant odour, particularly H_2S. Various disinfectants contain ammonia compounds; *Pseudomonas aeruginosa* contaminates eye drops, washes and mascara. Some injectables contain Gram-negative bacteria, fungi and produced endotoxins (pyrogens) that directly induce fever. The active ingradients may also become ineffective due to microbial contamination. It leads to breakdown of antibiotics (for penicillin is attacked by p-lactamases). Aspirin is broken down by *Adnetobacter iwoffii*, Atropine is degraded by *Pseudomonas* and *Corynebacterium* spp., and *Cladosporium herbarum* causes spoilage of hydrocortisone. The microbial activity within a product may also be confirmed from changes occurring to the pH, viscosity, stability etc. Spoilage may also occur due to the presence of dangerous metabolite products of microbial origin and some fungi are responsible for the mycotoxins production. Many hydrolysate enzymes (cellulase) can pose to product storage life. To test the efficacy of preservatives challenge test examine their effectiveness by utilizing biodeteriogens, or a group of standard organisms such as *P. aeruginosa, Staphylococcus aureus, Candida albicans* and *Aspergillus niger*.

(xi) Biofiltration of pollutants

It is a low cost technology gradually becoming popular due to simple operational and waste-removal efficiencies. Biofiltration is a new technology used to purify contaminated air evolved from volatile organic and inorganic compounds by involving microorganisms. Biofilters were used to remove odorous compounds from waste water treatment plants or animal farming. It could be achieved by digging, trenches, laying an air distribution system and refilling.

This process is not suitable for highly haloginated compounds (trichloroethylene, trichloroethane and carbon tetrachloride) due to its low aerobic degradation, and the size of a biofiltration is inversely proportional to the degradation rate. Microorganisms present in

biofiltration are mainly aerobic ones and most of them present in biofilters are bacteria (especially coryneforms and endospore formers) pseudomonads, protozoa, few actinomycetes (*Streptomyces* spp.) and some fungi (*Alternaria, Aspergillus, Botrytis, Cladosporium, Fusarium, Rhizopus, Penicillium, Trichoderma*). Biological gas treatment systems employ biofilters. A biofilter consists of a column packed with inert supports coated with biofilms. Some of the organic pollutants present in industrial emission are formaldehyde, styrene, isopropanol, ethanol, toluene, propane etc. Emissions containing H_2S and other sulfur compounds are purified by using *Thiobacillus ferrooxidans* which oxidise H_2S to elemental sulfur. The gas mixture is passed through acidic ferric sulfate solution resulting in formation of elemental sulfur and ferrous sulfate.

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5.6 Applications of Microbes in Bio-control of Pests

There are different ways by which the microorganisms derive nutrition for their growth and development. These may survive as saprophytism, parasitism and symbiosis. Saprophyte shown by species of *Aspergilius Penicillium, Rhizopus, Mucor* etc produce extracellular enzyme, parasitism may be obligate parasite or facultative saprophytes while symbiosis (both microbes and hosts are benefited) as in lichens, mycorrhiza, root nodules of legumes and non-leguminous plants on the basis of nutrition. The biological control mechanism may be classified as (i) microbial interactions and (ii) plant interactions.

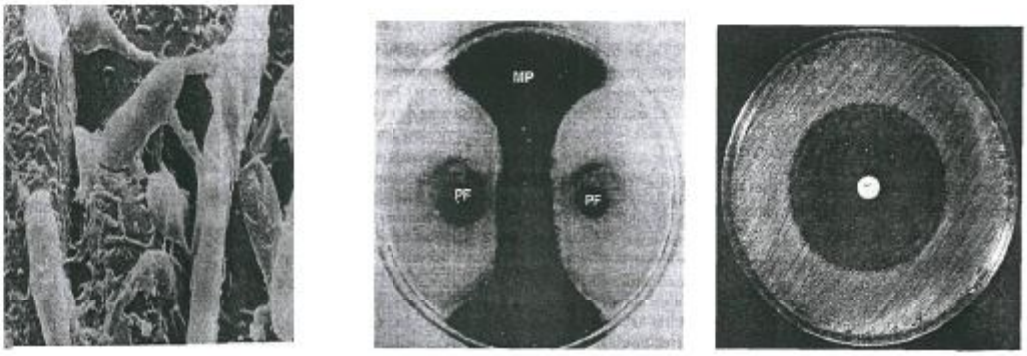
A. Microbial Interactions

Microorganisms are ubiquitous in their occurrence and interact to its surrounding. Baker and Cook (1974) reported that a microbe may not affect the other, or may affect by one or more of the following ways as stimulation of growth and development of associate, inhibition of growth and development of the associate, stimulating the formation of resting bodies by the associate, inhibiting the formation of resting bodies by the associate, enforcing the dormancy of the associate, lysis of the associate, harming the population of plants, directly benefiting the plants and getting influenced by its own micro environmental factors. On the basis of relative advantage to each partner (hosts and microorganisms) the relationships known as neutralism (host remains unaffected by the microbe) mutualism (both partners get benefits from the

association) and parasitism (where one partner gets benefits and the second suffers from damages).

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The clay minerals get adsorbed and bind with proteins, amino acids, small peptides and humic substrates. Microorganisms utilize the nutrients for their growth and activity directly from clay- protein, clay-amino acids or peptides and clay-humic substrate complexes. The clays and humic colloids influence the distribution and activity of *Streptomyces, Nocardia* and *Micromonospora*. Clay particles as kaolinite, is known to reduce the toxicity of cadmium (Cd) on *Macrophomina phaseolina.* The above ground (phylloplane) and below ground (rhizosphere) plants are constantly interact with a large number of microorganisms like bacteria, actinomycetes, fungi, amoebae, nematodes algae and viruses that develop several types of interrelationships.



A B C

Fig. 5.2. Plant-microbe interactions: (A) Plant roots release nutrients that allow intensive development of bacteria and fungi on and near the plant root surface (left), (B) Antibiosis between *Macrophomina* sp (MP) and *Pseudomonas fluorescens* (PF) showing the zone of inhibition and (C) showing the growth inhibition of pathogenic fungi by antagonist *Trichoderma harzinium*.

B. Plant-Microbe Interactions

(i) Antagonistic interactions (Antagonism)

The composition of the microflora/microfauna of any habitat is governed by the biological balance created through interactions and associations of all individuals present in a community. Any inhibitory effect of an organism created by any means to the other organism(s) is known as antagonistic interaction and phenomenon is called antagonism.

(ii) Amensalism (Antibiosis and Lysis)

In this phenomenon one microbial species is adversely affected by the other species, whereas the other species remains unaffected by first one. It is accomplished by secretion of inhibitory substances, such as antibiotics. The metabolites secreted (antibiotics, siderophores, enzymes etc.) by one organism inhibit the growth of another (fig. 5.2). These metabolites penetrate the cell wall and inhibit its activity by chemical toxicity. The potent antagonists as *Trichodema harzianum* and *T. viride* are known to secrete cell wall lysing enzymes, β-1, 3-glucanase, chitinase etc. and lysis of fungal mycelium occurs due to secretion of enzymes.

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Siderophores are the other extracellular secondary metabolites secreted by bacteria (*Aerobacter aerogenes, Arthrobacter pascens, Pseudomonas cepacia, P. fluorescens*), Actinomycetes (*Streptomyces* spp.), yeast (*Rhodotorula* spp.), fungi (*Penicillium* spp.), and dinoflagellates (*Prorocentrum minimum*). Siderophores are low molecular weight compounds commonly known as microbial iron-chelating compounds because these have a very high chelating affinity for Fe^{3+} ions and very low affinity with Fe^{2+} ions. Kloepper *et al* (1980) were the first to demonstrate the importance of siderophore production by PGPR in enhancement of plant growth. Siderophores chelate Fe^{3+} and make Fe^{3+} deficient condition for other microorganisms and growth of microbe is inhibited. When the siderophore producing PGPR is present on root surface, it supplies iron to plant so plant growth is stimulated.

(iii) Competition

Among the microorganisms, competition exists for nutrients, including oxygen and space but not for water potential, temperature or pH. Garrett (1950) suggested characteristics likely to contribute to the competitive saprophytic ability are rapid germination of fungal propagules and fast growth of young hyphae towards a source of soluble nutrients, appropriate enzyme equipment for degradation of carbon constituents of plant tissue, secretion of fungistatic and bacteriostatic growth products like antibiotics, and tolerance of fungistatic substances produced by competitive microorganisms.

(iv) Parasitism and Predation

Parasitism (one organism consumes another organism in a subtle and non-debilitating relationship) and predation (antagonism where a living organism is attacked by the other with the consequences of death of the former) are the

another relationship of microorganisms. Predation is commonly dealt with fungi, amoebae and nematodes (Table 5.6). It included following interactions-

(a) Mycoparasitism (Fungus-fungus interaction)

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In this process one fungus is parasitized by the other fungus the phenomenon is called mycoparasitism. The parasitizing fungus is called hyphae parasite and the parasitized fungus as hypoparasite. The inter-fungus interaction may be due to several events lead to predation coiling, penetration, branching, sporulation, resting body formation, barrier formation to check the entry of pathogen and lysis of host cell(s) (Table 5.6).

Table 5.7 Examples of Predation and Parasitism (Dubey, 2005)

S.No.	Mode of Antagonism	Plant Pathogens	Antagonists	Post-infection events
1.	Mycophagy	*Cochliobolus sativus,*	soil amoebae	Perforation in conidia
		Gaeumannomyces graminis var. *tritici*	soil amoebae	Penetration and hyphal lysis
2.	Mycoparasitism	*Botrytis alli*	*Gliocladium roseum*	Penetration of hyphae
		Cochliobolus sativus	*Myrothecium verrucaria*	Antibiosis and penetration
		Rhizoctonia solani and *Fomes annosus*	*Trichoderma viride*	Coiling, cytoplasm coagulation
		Sclerotium rolfsii	*T. harzianum*	Coiling, penetration lysis
3.	Nematophagy	*Heterodera rostochiensis*	*Phialospora heteroderae*	Cyst penetration and egg killing

(b) Mycophagy

It is the phenomenon of feeding upon fungi by amoebae. The antagonistic soil amoebae are *Arachnula, Archelle, Gephyramoeba, Geococcus, Saccamoeba,*

Vampyrella interact with fungal hyphae and make perforations in *Cochliobolus sativus, Gaeumannomyces graminis* var. *tritici, Fusarium oxysporum, Phytophthora cinnamomi*. On the lysed hyphae of these fungi amoebae develop round cysts. Chakraborty et al (1983) have described 3 major steps of feeding on fungal propagules by soil amoebae as attachment (trophozoites of amoebae attach to fungal propagules as conidia, hyphae, chemotaxis or thigmotaxis), engulfment (fungal propagules engulfed by amoebae, small trophozoites makes hyphal wall or spore perforations) and digestion (completely or partially engulfed propagules digested by a large central vacuole formed inside the cysts).

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(c) Nematophagy

The phenomenon of eating upon nematodes by fungi is known as nematophagy. Fungi are mechanically involved in attacking and killing the nematodes resulting in consumption of nematodes. The predaceous fungi are widely distributed in the surface litter and decaying organic matter. Over 50 species of fungi are known that attack nematodes and different developmental stages of nematodes are susceptible to attack by different types of fungi. The nematophagous fungi are of three main types on the basis of ecological habit (a) nematode-trapping fungi, (b) endoparasitic fungi and (c) egg parasites. The nematode-trapping fungi capturing nematodes using evolved structural adaptations to trap or penetrate their prey by predation or endoparasitism. There are varieties of ways by which fungi trap nematodes resulting in their death.

Adhesive hyphae contact of mycelium with nematode, production of yellowish chemical, an outgrowth similar to appressorium formed. When the nematode is trapped, it becomes inactive first and killed in the last after penetration of hyphae. Adhesive branches (most primitive and simple organ of capture), over the whole surface of branch a thin film of adhesive material is coated as in fungi *Dactylella cionopaga* and *D. gephyropaga,* adhesive nets (nets formed of adhesive nature like single hoop-like loop in *Arthrobotrys musiformis*, networks in *A. oligospora,* penetration by infectious hyphae), adhesive knobs (distinct adhesive cell, globose to sub-globose in structure, produced in *Dactyleria candida, Dactylella* and *Nematoctonus,* non-constricting rings (*Dactylaria candida* and *D. lysipage*) and constricting rings (sophisticated ring formed by *Arthrobotrys anchonia, Dactylaria brachopaga, Dactylella*).

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The body of nematode consists of a low molecular weight peptide (or possibly a single amino acid) which is called nemin which is water soluble and potential stimulant for trap-formation. The enzyme collagenase is secreted by the fungus which dissolves collagen protein of nematode cuticle. The hyphae which have penetrated the nematode digest the body content and translocated to rest of the parts of hyphae for fungal growth and reproduction.

(d) Endoparasitic fungi

These produce many modifications brought about in conidia in the predator. The endoparasitic fungi are species of *Cephalosporium, Meria, Verticillium, Catenaria, Meristacrum* etc. Another fungi *Catenaria anguillulae* produces zoospores which track down nematodes by swarming, eventually encyst near nematode body orifice (anus, vulva and buccal cavity), penetrate and colonize the prey. *Meristacrum asterospermum* forms adhesive conidia which attach to the cuticle of nematode. It germinates to form the hypha which swells and acts as infectious thallus. Similarly adhesive spores are also produced by species of *Meria, Cephalosporium* and *Verticillium.*

(e) Egg Parasites

When a fungal hypha comes in contact of an egg, a swollen structure at terminal portion develops at the point of contact and after penetration; the infectious hyphae swell up form a post-penetration bulb like appressorium. From this structure there develops numerous irregularly branched absorption hyphae that consumes egg nutrients as *Dactyllela oviparasitica* and *Paecilomyces lilacinus* that penetrate root-knot or cyst nematode.

5.7 Summary

Microorganisms are used in production of several products which are useful for our life. Mutant strain with enhanced better products but may require considerable fermentation development. Step wise selection implies small increment in productivity, the increased productivity and the probability of getting hyper producing strains decreases. The microbes are used in different types of alcohol production as beer, wine, whisky, rum etc., and organic acids as lactic Acid, citric acid. Different antibiotics produced by microbes are used as inhibitor of cell wall synthesis, able to damage the cell membrane, protein synthesis inhibitor, interference of nucleic acids and inhibitor of specific enzymes. These antibiotics are penicillin, tetracyclines/chloramphenicol and streptomycin. The production of amino acids as L-lysine, L-glutamic acid is

important. Vitamin B12 (cyanocobalamine) and riboflovin (vitamin B2) are also produced by microbes. In Agriculture the microbes used as biofertilizers for nitrogen, biofertilizers for phosphorus, toxins produce by *Bacillus thuringiensis* against insects, bacteria attack on nematodes, viral insecticides, entomopathogenic fungi etc. In biotechnology microbes are used in Recombinant DNA technology in waste treatment, steroids biotransformation, dairy products, in pesticide degradations and microbial plastics production. The microbes used in bio-control of pests by antagonistic interactions antagonism, amensalism, competition, parasitism and predation as mycoparasitism, mycophagy, nematophagy, endoparasitic fungi and egg parasites.

The application of microbes in degradation of pollutants as deterioration and spoilage of wine, sewage (wastewater) treatment, microbial leaching, petroleum (hydrocarbon), microbial degradation of xenobiotics, abatement of heavy metal pollution, waste water pollution management, bioaugmentation. The biodeterioration of stored plant food material, leather, stone and building materials, paper and other cellulosic materials, fuels and lubricants, metals, plastics, cosmetics and pharmaceutical products and biofiltration.

5.8 Self-Learning Excercise

1. What do you know about plant-microbe interactions? Discuss in brief destructive associations.
2. Write an extended note on plant-microbe interactions with emphasis on symbiosis.
3. Discuss the role of microorganisms in environmental microbiology.
4. Write a note on biodegradation of pesticides.
5. Name few microorganisms and associated biodegradation process of pollutants.
6. Write a critical account on biodegradation of industrial waste containing heavy metals.
7. Describe the process of solid waste conversion process.
8. "Microbes are essential in agricultural practices" explain it.
9. Write short notes on:

   (a) Organic fertilizer (b) Bioremediation

(c) Xenobiotics (e) Microbial plastics (f) Sewage treatment

10. Describe the process of liquid waste treatment by microorganisms.
11. Write a short account on:

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(a) BOD (b) Sludge

(c) Methanogens

12. Discuss the process of Biodeterioration of the following:

a) Leather (b) Paper

(c) Lubricants (d) Metals

(e) Plastics (f) Cosmetics

(g) Pharma products (h) Bioaugmentation

5.9 References and further readings

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Unit - 6

Algae: An Introduction

NOTES

Structure of the Unit

6.0 Objectives

6.1 Introduction

6.2 Algae in Diversified Habitat

6.3 Thallus Organization

6.4 Ultrastructure

6.5 Reproduction

6.6 Criteria of classification as Pigmentation, Reserve food, flagella

6.7 Summary

6.8 Self-Learning Exercise

6.9 References and further readings

6.0 Objectives

After studying this unit you should be able to:

- understand the diversified habitat of algae in different areas,
- knowledge of thallus organization in different types of algae,
- differentiate the cells on the basis of ultra structure of cells in algae,
- know the criteria of classification used in systematic of plants,
- Know about different types of reserve foods pigmentation flagella types in algae.

6.1 Introduction

NOTES

Algae are a group of chlorophyllous, photosynthetic thalloid plants with universal occurrence. These are found in water or on terrestrial. They may be-aquatic algae, terrestrial algae and algae of unusual habitats. Algae show a progression in thallus unicellular (microscopic) to multicellular (macroscopic). The unicellular forms may be motile or non-motile. The algae may proliferate vegetatively, asexually and sexually. The prokaryotic cell has no organized nucleus Prokaryotic cell is smaller than the eukaryotic cells. Cell wall made up of glucosamine and muramic acid. The algae have been classified on the basis of stored food, pigments, flagella etc. There are two types of cells as Prokaryotic and eukaryotic cells in algae.\

6.2 Algae in Diversified Habitat

Algae comprise a group of chlorophyll containing thalloid plants and differ from fungi in the presence of photosynthetic pigment-chlorophyll and in their mode of nutrition. Algae are of universal occurrence, found in a variety of habitats such as freshwater, sea water, on snow, on rocks and on/or within the plant and animal bodies. On the basis of habitat, they may be classified into the following three groups:

(1) Aquatic algae, (2) Terrestrial algae, and (3) Algae of unusual habitats

(1) Aquatic algae

The aquatic or hydrophilous algae are either free-floating (*Chlamydomonas, Volvox, Spirogyra*), attached on substratum by holdfast (*Oedogonium, Ulothrix*) or free-floating or in colonial form on the surface of water (water blooms or phytoplanktons). Algae like *Dictyosphaerium, Fragilaria, Cosmarium, Volvox, Asterionella* and *Golenkinia* are commonly found in fresh water planktons, whereas *Actinocyclus, Chaetoceros* and *Coscinodiscus* are common in marine planktons. Many algae are found attached to rocks along the edges of lakes and seas and these forms are called phytobenthos. the phytoplankton or planktophytes may be free floating in early steges of life called Tychopplanktophytes (*Oedogonium, Cladophora, Sargassum, Nostoc*) or some of remain free-floating throughout their life and are called Euplanktophytes

(*Chlamydomonas, Volvox, Closterium*). Aquatic forms are found in fresh water or in saline water of the sea.

1. Fresh water forms- These forms occur in fresh water or in low salinity water of ponds, pools, lakes, rivers etc. They may found in slow running water (*Cladophora, Oedogonium, Ulothrix Vaucheria* and *Chara*) or stagnant water (*Chlamydomonas, Volvox, Hydrodictyon, Spirogyra, Zygnema, Oedogonium, Chara* and *Rivularia*).

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2. Marine forms- These forms occur in saline water of the sea and are represented mostly by the members of Phaeophyceae (*Ectocarpus, Sargassum, Fucus*) and Rhodophyceae (*Polysiphonia*).

(2) Terrestrial algae

Such algae found in terrestrial, edaphic algae or edaphophytes or terrestrial algae habitats like soils, rocks, logs etc. the algal forms like *Vaucheria, Botrydium, Fritschiella* and *Euglena* are found on the surface of the soil known as saphophytes, or under the soil as blue-green algae (members of *Cyanophyceae- Nostoc, Anabaena; Vaucheria, Oedogonium, Fritschiella*) known as cryptophytes. A few algae are found on tree trunks and moist walls; they absorb carbon dioxide and water from the atmosphere (*Protococcus, Scytonema*).

(3) Algal species of unusual habitats

In addition to aquatic and terrestrial habitats some algae also occur in uncommon habitats as given below-

1. Benthic algae- These attached to any substratum in the bottom of water bodies are called benthic algae or benthophytes may be fresh water (*Chara, Nitella, Cladophora*) or marine water living (*Sargassum, Fucus*).

2. Epactic algae- Found attached to the substrata along the shores of fresh water bodies are called epactic algae or epaciphytes (*Oedogonium, Spirogyra, Rivularia*).

3. Thermophilic algae- Such algae living in hot springs at around 55°C or above (*Oscillatoria brevis, Synechococcus elongatus, Heterohormogonium* sp., *Haplosiphon lignosum* spp). They are able to survive such high temperatures

possibly due to the absence of well organized nucleus. Most hot springs are alkaline so some phycologists believe that tolerance to high temperature may be associated with this factor.

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4. Phytoplankton- Algae float on the surface of water are called phytoplankton or planktophytes may be free floating in early stages of life called Tychopplanktophytes (*Oedogonium, Cladophora, Sargassum, Nostoc*) or some of remain free-floating throughout their life are called Euplanktophytes (*Chlamydomonas, Volvox, Closterium*).

5. Epizoic or epizoophytes algae- These grow on animals like snails, fishes and tortoise known as epizoic. *Cladophora crispata* grows on snails, species of *Stigeoclonium* are found in the gills of fishes. Similarly the species of *Characiopsis* and *Characium* are found on the legs of *Branchipus.*

6. Epiphytic algae- They grow on larger algae or on bryophytes and angiosperms. The species of *Bulbochaete, Oedogonium* and *Microspora* are found attached to the larger species of *Cladophora, Rhizoclonium* and *Vaucheria.* Algae with mucilagenous thalli like *Chaetophora, Oedogonium* and *Zygnema* are epiphytic on *Achnanthes, Eunotia, Synedra* etc.

7. Halophytic algae- Algae living in salty water as salt water lakes, sea-shores, estuaries, seas and oceans (*Chlamydomonas ehrenbergii, Scenedesmus, Enteromorpha*, *Dunaliella* and *Stephanoptera*) known as halophytic algae.

8. Endozoic algae- Algae species occur in the tissues or inside the animals are known as endozoic as species of *Zoochlorella* are found in *Hydra viridis.* The *Zooxanthellae* is found in fresh water sponges. There are some 15 species of the family Oscillatoriaceae (blue-green algae) which occur in the respiratory and digestive tracts of vertebrate animals. *Characium* is seen in the body of some insect larvae in water.

9. Symbiotic algae- Several members of Chlorophyceae and Cyanophyceae form symbiotic association with fungi, bryophytes, gymnosperms and angiosperms. In lichen thallus both algal and fungal components are benefited due to the symbiotic association. As in lichens their algal components belong to Cyanophyceae (*Nostoc, Gloeocapsa, Microcystis*) or Chlorophyceae (*Coccomyxa, Chlorella, Protococcus*) are found in symbiotic association.

Colonies of *Nostoc* and *Anabaena* are found in symbiotic association in the thallus of *Anthoceros* and *Notothylas* (Bryophytes) and the coralloid roots of *Cycas*. The blue-green alga *Anabaena azollae* occurs in the leaf tissues of aquatic fern *Azolla* as well as *Chlorochythrium* is found inside the *Lemna* and *Ceratophyllum* (aquatic angiosperms).

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10. Cryophytic algae- Such forms growing on ice or snow are called cryophytic which provide attractive colours to snow covered mountains. The alpine and arctic mountains become red (*Haemotococcus nivalis*), green snow in Europe (*Chlamydomonas yellowstonensis* and species of *Mesotaenium*), black snow (*Scotiella nivalis* and *Raphidonema brevirostri*), red snow (species of *Scotiella, Gloeocapsa* and diatoms) and brownish purple snow (*Ancyclonema nordenskioldii*) due to the growth of different algal species. *Gloeocapsa* and *Phormidium* live on ice temporarily while *Cylindrocystis* and *Trochiscia* can live both in ice and snow. *Ulothrix* and *Nostoc* cause yellow or yellow green snow.

11. Lithophytic algae- Algae growing on moist rocks and stones as many blue green algae (*Nostoc, Rivularia* and *Gloeocapsa*) commonly grow on moist and shady rocks. *Scytonema* is commonly grown on moist walls during rainy season.

12. Parasitic algae- Algae grow as parasites on many plants and animals as *Cephaleuros virescens* (Chlorophyceae) which causes red rust in tea and coffee plantations. *Phyllosiphon* (Chlorophyceae) grow as parasite on the leaves of *Arisarum vulgare* and *Polysiphonia fastigiata* (Rhodophyceae) a semiparasite on *Ascophyllum nodosum.*

13. Aerial Algae- The living forms on terrestrial plants and animals, walls, fencing wires and rocks are known as aerial algae or aerophyte may be of four types namely Epiphyllophytes, Epiphloeophytes, Epizoophytes and Lithophytes.

Epiphytic algae living on leaves of large trees are called epiphyllophytes (*Phyllosiphon*), bark of trees called epiphloeophyte (*Trentepohlia, Phormidium*), on the body of terrestrial animals said epizoophytes (*Chaetophora*) on rocky substratum or terrestrial habitat are called lithophytes (*Nostoc, Vaucheria, Scytonem*).

6.3 Thallus Organisation

NOTES

Algae show a progression in thallus construction from unicellular (microscopic) to multicellular (macroscopic) forms. The unicellular forms may be motile or non-motile. Some algae are colonial while others are filamentous. The filamentous forms may be branched or unbranched. In higher forms the thallus possesses rhizoids, pseudo stems and leaves. On the basis of thallus organisation, algae are divided into the following five groups:

(1) Unicellular forms

(2) Colonial forms

(3) Filamentous forms

(4) Siphonaceous forms

(5) Advanced types of thalli

(1) Unicellular forms

Simple unicellular forms are found in all groups of algae except Charophyceae and Phaeophyceae. These forms are sometimes referred to as a cellular since they function as complete living unit without any cellular differentiation. There are four types of unicellular algae as (i) Flagellated forms (ii) Coccoid forms, (iii) Rhizopodial forms, and (iv) Spiral filamentous forms

(i) Flagellated forms

These are unicellular flagellated, freely moving in water by flagella and found in all classes except Cyanophyceae and Rhodophyceae. These cells may be spherical, oblong, pear-shaped or circular (*Chlamydomonas*) or dorsiventrally differentiated (*Phaeus*). In few forms there is no true cell wall so that the shape of the cells is flexible called periplasts or naked forms or amoeboid forms (*Heterochloris mutalis*). Motile cells of algae, after shedding their flagella develop long delicate cytoplasmic process called rhizopodium or rhizopodial forms (*Synura*). Some motile unicells are enclosed by thick, variously shaped envelop called encapsulated forms (*Phacotus*). Flagellated unicells may be periplastic without cell wall (*Euglena*) or with a distinct cell wall (*Chlamydomonas*) but in *Phacotus* there is a thick calcareous covering (capsule) around the cell wall.

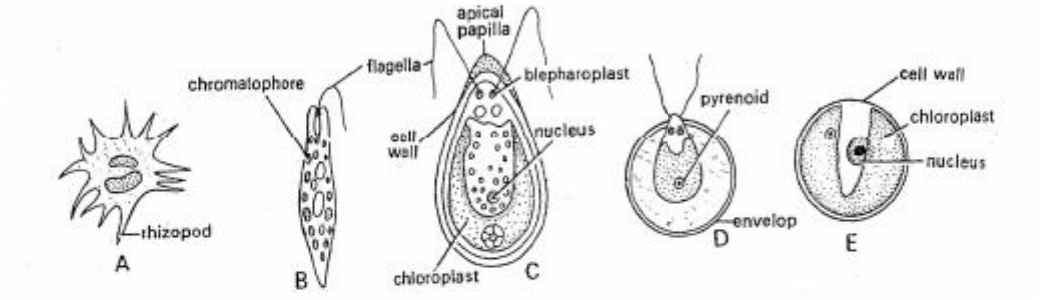


Fig. 6.1 : A-E Unicellular algae: A. *Chrysamoeba*, B. *Euglena*, C. *Chlamydomonas*, D. *Phacotus*, E. *Chlorella*.

(ii) Coccoid forms- These are unicellular, non-flagellated forms, more or less round and bounded by rigid cell wall (*Chlorella, Chroococcus*). The cell may be enclosed by sculptured calcareous scales called coccolith and form is called cocosphere (*Calcidiscus* and diatoms) (Fig. 6.1 E).

(iii) Rhizopodial unicells- These forms lack a rigid cell wall, possess cytoplasmic projections for amoeboid movement (*Rhizochrysis, Rhizochloris, Chrysamoeba*) (Fig. 6.1 A).

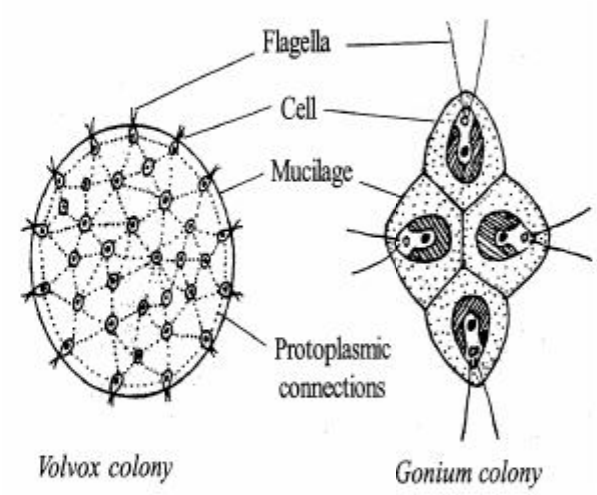
(iv) Spiral filamentous unicells- Algae form spiral or coiled structures. The cell is elongated and spirally coiled (*Spirulina*) or spindle-shaped (*Closterium*).

(2) Colonial forms

Multicellular may be colonial forms, filamentous forms, siphonaceous forms and parenchymatous thallus. The colonial habit is achieved by aggregation of the products of cell divisions within a mucilagenous mass, associations are usually loose or colony are connected with each other by cytoplasmic connections; so they cannot break into segments (*Volvox*). The colonial forms are of four types namely

(i) **Coenobial form-** A coenobium is a colony in which the number and manner of aggregation of cells remain constant at juvenile and mature stages. The coenobium may be motile or non-motile. The colony may be motile coenobium and all its cells are uninucleate and flagellated (*Volvox, Gonium, Pandorina*). A *Volvox* colony has 500-20,000 Chlamydomonad type of cells interconnected by protoplasmic connections.

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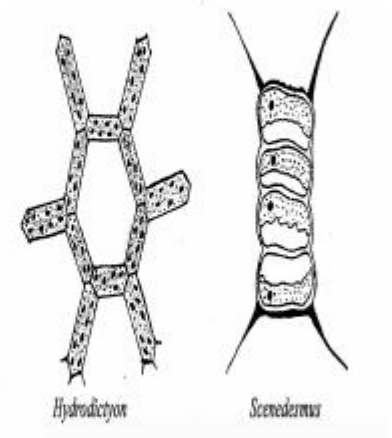


Fig. 6.2 : Motile coenobia **Fig. 6.3 : Non-motile coenobia**

Gonium colony consists of 4-32 closely arranged Chlamydomonad type cells surrounded by mucilage-lamella (Fig. 6.2). *Pandorina* colony has 16-32 cells covered with a common mucilage sheath. The individual cells are non-flagellated, non-motile called non-motile coenobia (*Hydrodictyon, Pediastrum, Scenedesmus*) (Fig. 6.3). In *Scenedesmus*, the colony consists of 4-8 variously shaped cells which are parallely arranged one above the other as a stack of coins.

(ii) Palmelloid forms- An algal colony in which non-motile cells are embedded in an amorphous gelatinous matrix is called palmelloid colony or palmelloid form (Fig. 6.4). The gelatinous matrix may be secreted by protoplasts of the individual cells of the colony or produced by gelatinization of walls of daughter cells. Palmelloid form is the permanent feature in *Tetraspora, Chlorosaccus* and *Phaeocystis*. In some palmelloid forms it is a temporary phase (*Chlamydomonas*), whereas in others it is a permanent feature (*Tetraspora, Aphanotheca*, Fig.6.4 A-B).

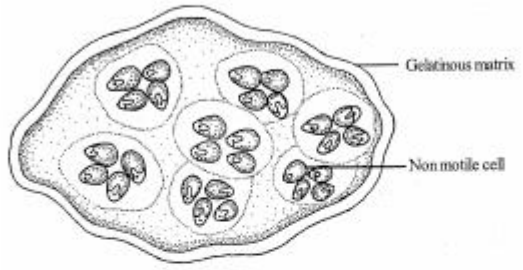


Fig. 6.4 : Palmelloid form (*Tetraspora*)

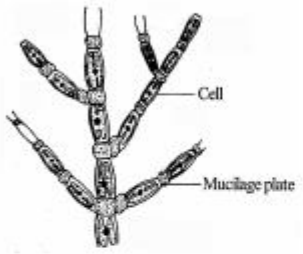


Fig. 6.5: Dendroid form (*Prasinocladus*)

(iii) Dendroid form- the colony looks like a microscopic tree and the number, shape and size of the cells is also indefinite in dendroid colonies. It gives a tree like appearance to the whole colony (*Chrysodendron*, *Prasinocladus*) (Fig.6.5).

(iv) Rhizopodial form- In such type of colony the cells are united through rhizopodia (*Chrysidiastrum, Chrysophyceae*; Fig. 6.8 D).

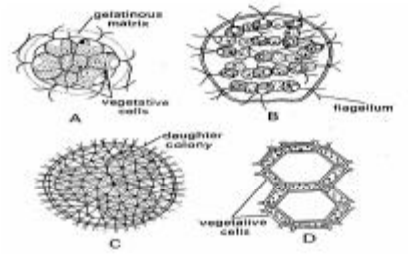


Fig. 6.6 A-D. Colonial algae: (A) *Pandorina*, (B) *Eudorina*, (C) *Volvox*, (D) *Hydrodicotyon*.

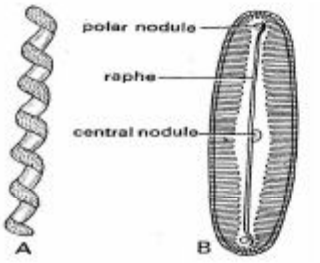


Fig. 6.7 A-B. Unicellular algae: (A) *Spirulina*, (B) *Pinnularia*

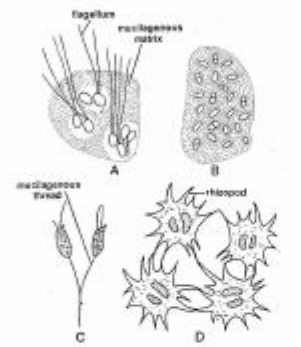


Fig. 6.8 : A-D Colonial algae:
A. *Tetraspora*, B. *Aphanotheca*,
C. *Chrysodendron*, D. *Chrysidiastrum*

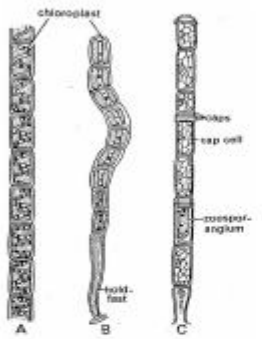


Fig. 6.9 : A-C Filamentous algae:
A. *Spirogyra*,
B. *Ulothrix*, C. *Oedogonium*

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(3) Filamentous forms

In such type of forms the cells of algal thallus are arranged in linear row and are joined end-to end by middle lamella is called a filament or filamentous form. If the filament is made of single row of cells, it is called uniseriate filament (*Ulothrix, Oedogonium*) (Fig. 6.9 B-C). If the cells are arranged in more than one linear row, then the filament is termed multiseriate filament (*Ulva*). These developed by repeated transverse divisions of cells and for separate and they remain attached one upon the other in a definite sequence to form a filament may be branched or unbranched or uniaxial or multiaxial.

(i) Unbranched filaments- In simple unbranched filaments are found only in a few groups of algae may be free floating (*Spirogyra*; Fig. 6.9 A) or attached to substratum (*Zygnema; Ulothrix, Oedogonium*; Fig. 6.9 B-C) or form colony (*Nostoc, Oscillatoria*; Fig. 6.10 A-B).

(ii)Branched filaments- In branched filaments, the filament formed by repeated transverse divisions of lateral outgrowths of cells and branching of filaments may be false or true. A false branch does not arise as lateral outgrowth, but the trichome may break either due to death or decay of intercalary cells or at the point of heterocyst. The broken end emerges out of the mucilagenous sheath in the form of a branch (*Scytonema*, Fig. 6.14A).

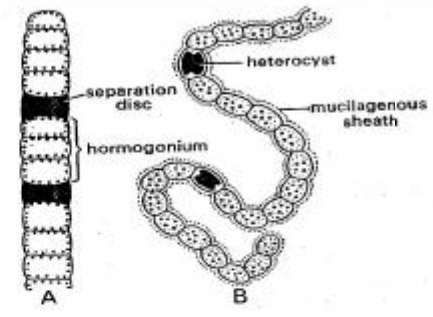


Fig. 6.10. A-B. Filamentous algae: A. *Oscillatoria*, B. *Nostoc*.

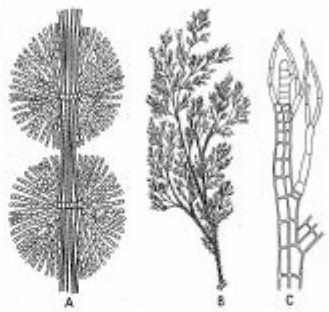


Fig. 6.11. A-C. Pseudoparenchymatous alg A. *Batrachospermum*, B-C. *Polysiphonia*

True branches, which arise as lateral outgrowths, may result in the following three types of filaments-

(a) **Simple filaments-** Branched filaments remain attached to the substratum by a basal cell. In *Cladophora* branches arise just below the septa between two adjacent cells (Fig. 6.13 B).

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(b) **Heterotrichous filaments-** It is characteristic feature of the order Chaetophorales of Chlorophyceae. In *Fritschiella* both erect and creeping systems are equally developed but in *Coleochaete scutata*, the creeping system is well developed and disc-like, but the prostrate system is poorly developed and filamentous. In *Drapernoldiopsis*, the prostrate system is well developed but the creeping system is poorly developed. Thallus is very much evolved and differentiated into prostrate and erect systems (*Fritschiella, Ectocarpus, Draparnaldiopsis, Coleochaete, Stigeoclonium*) (Fig.6.13C-F), both the prostrate and the erect systems may be well developed (*Fritschiella, Ectocarpus*; Fig. 6.14 C, F) or there is progressive elimination of prostrate (*Draparanaldiopsis*) or erect (*Coleochaete*) system (Fig. 6.14 D, E).

(c) **Pseudoparenchymatous filaments-** One or more central or axial filaments, together with their branches, form a parenchymatous structure. In this form, if a pseudoparenchymatous thallus is formed by the branches of only one filament it is called uniaxial (*Batrachospennum*), and if branches of more than one filaments are involved called multiaxial (*Polysiphonia*; Fig. 6.12A,B).

(iv) Siphonaceous forms

The thallus is made up of branched, aseptate, coenocytic, tubular filaments (*Vaucheria, Botrydium*) (Fig.6.12 A-B). In *Vaucheria*, the thallus contains numerous nuclei, chromatophores, peripheral cytoplasm and a central narrow vacuole. The thallus is branched and coenocytic in *Vaucheria* and is unbranched in *Protosiphon*.

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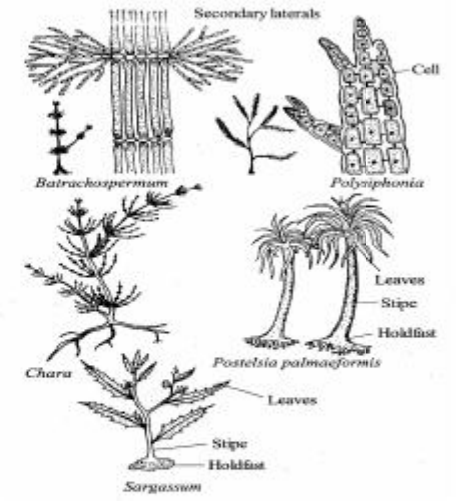


Fig. 6.12.A-E. Pseudoparenchymatous A.*Batrachospermum,* B. *Polysiphonia, C. Chara,* D. *Sargassum,* E. *Postelsia*

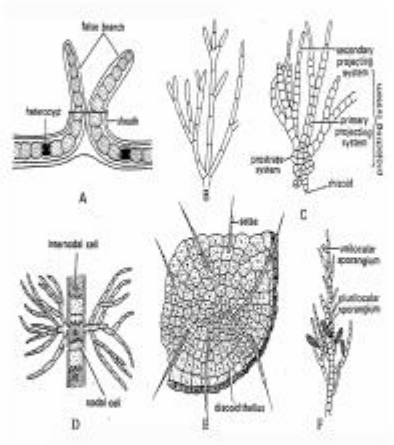


Fig. 6.13 A-F. Branched filamentous algae: A. *Scytonema* (false branching), B. *Cladophora* (simple branching), C. *Fritschiella* (heterotrichous), D. *Draparnaldiopsis* (heterotrichous), E. *Coleochaete* (heterotrichous), F. *Ectocarpus* (heterotrichous)

5. Advanced types of Thallus

In these advanced types, the thallus consists of a combination of filaments and parenchyma cells. In these cases the thallus may be uniaxial (*Batrachospermum*) or multiaxial (*Polysiphonia*). In *Chara,* thallus bears rhizoids to attach it with the substratum and the branched erect system consists of branches of limited and unlimited growths. *Sargassum* thallus is differentiated into root-like, stem-like and leaf-like structures consisting of parenchymatous cells whereas in *Postelsia palmaeformis* the thallus is palm-like with parenchymatous cells. The daughter cells do not separate from the parent and give rise to parenchymatous thalli of various shapes, like flat (*Ulva*), tubular or complex (*Sargassum*; Fig. 6.12). The growth of such thalli is apical (*Fucus, Dictyota*), intercalary (*Laminaria*) or trichothallic (*Porphyra*).

6.4 Ultrastructure

Although the structure of algal cells varies considerably among themselves, they share some common characters in the features of cell wall, cytoplasm, photosynthetic pigments and genetic materials and so on. Algal cells may be differentiated into prokaryotic, mesokaryotic and eukaryotic types.

NOTES

1. Prokaryotic Cells- The cell has no organised nucleus is called prokaryotic cell. These prokaryotic cells are smaller than the eukaryotic cells. Each cell is bound by a thick cell wall without cellulose composed of amino sugars, glucosamine and muramic acid. The cell wall is surrounded by a layer of mucilage sheath and inner to the cell wall there is a plasma membrane made of proteins and lipids. The plasma membrane may have some invaginations called mesosomes.

Membrane bound cell organelles such as true nucleus, mitochondria, chloroplasts, lysosomes, endoplasmic reticulum, golgi complex and vacuoles are absent in prokaryotic algal cells. The nuclear materials remain in the cytoplasm and are not bound by chloroplast membrane as in eukaryotic cells. The ribosomes of prokaryotic cells are 70 S type. The genetic material is a double stranded circular DNA (Cells of blue-green algae are examples of the prokaryotic cells). Cyanophyceae (BGA) is characterized by presence of incipient nucleus, absence of membrane bound organelles like plastids, endoplasmic reticulum, Golgi bodies and mitochondria, absence of basic proteins-the histones in DNA, presence of mucopeptide in the cell wall and absence of mitosis.

2. Eukaryotic Cells

The cells contain an organised nucleus are called eukaryotic cells and algal cells are very much similar to the cells of higher plants. Protoplasm of adjacent cells remains connected by plasmodesmatal connections. The protoplasm is a viscous substance containing cell organelles and reserve foods. The nucleus has distinct nuclear membrane which divides the protoplasm into the outer cytoplasm and inner nucleoplasm, the nucleoplasm contains nucleolus and chromosomes. DNA is protected by histone proteins. The ribosome present in the cytoplasm are 80s

type. The photosynthetic apparatus called thylakoids are surrounded by chloroplast membrane called chloroplast or plastid.

NOTES

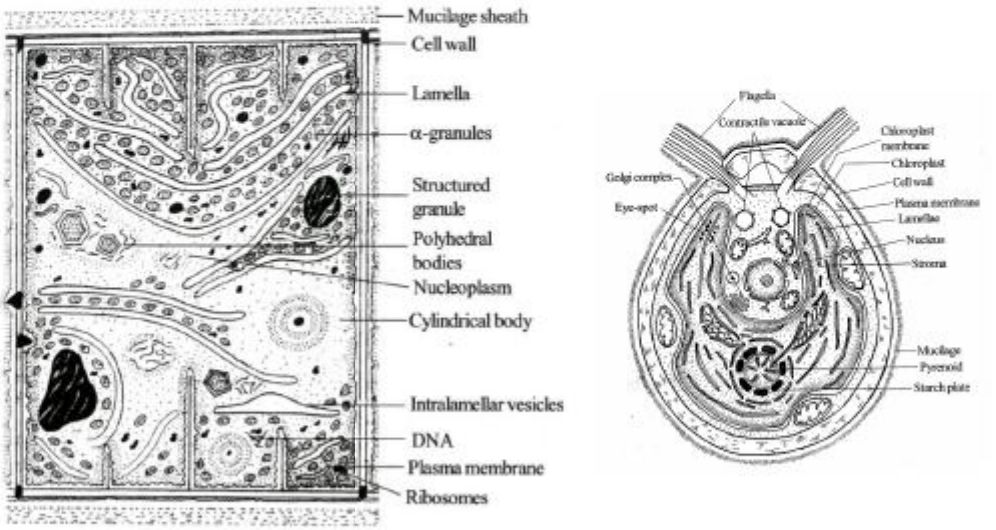


Fig. 6.14 : Prokaryotic and Eukaryotic cell

A eukaryotic cell, on the other hand, is characterized by the presence of a well organized nucleus and membrane bound organelles like plastids, mitochondria and Golgi bodies (Fig. 6.22). An intermediate type of cell organization, i.e., mesokaryotic is found in the members of Dinophyceae, where although the nucleus has a nuclear membrane and chromosomes (eukaryotic characters), basic proteins are absent (prokaryotic character).

(i) Cell wall

Most of the non-motile unicellular and multicellular algae possess a typical cellulosic cell wall of non-living matter outside the cytoplasmic membrane. It is composed of pure or mixed carbohydrates (cellulose, mucilage, pectin, etc.) and substances like alginic acid, fucoidin, fucin and hemicelluloses are present in brown algae (Phaeophyceae), pectin in red algae (Rhodophyceae), calcium carbonate in Coralline algae (red algae) and silica in diatoms (Bacillariophyceae). They may be arranged in two layers at right angles to each other, in three layers or in a random manner. The cell wall of diatoms is more complex, having pores with perforated membranes.

In blue-green algae (Cyanophyceae), the cell wall is mucopolymeric, mainly consisting of glucosamine, amino acids, muramic acid and diaminopimelic acid. A true cell wall is absent in some algae like *Euglena, Gymnodinium* and *Pyramimonas.* They simply have a bounding membrane of cytoplasm, known as pellicle.

NOTES

(ii) Nucleus

Almost all algae, except Cyanophyceae have a well organized eukaryotic nucleus. The nucleus in Dinophyceae is also not truely eukaryotic, although it is membrane bound, but well organised chromosomes are not present. In uninucleate algae the nucleus generally lies alongside the cell wall but sometimes it is suspended in the centre of the cell by fine cytoplasmic threads (*Spirogyra, Zygnema).* In multinucleate members the nuclei usually occur between the vacuoles and the plastids in the cytoplasm.

The nuclear membrane is two layered and in some members the two unit membranes are separated by a perinuclear space.

There is a great variation in the morphology of chromosomes. They are small and spherical in desmids and elongated or thread like in *Oedogonium.* The size of chromosomes varies form 0.25 mm or less (Ulotrichales) to more than 12 mm (Oedogoniales and Charales). The number of chromosomes also shows variation, the lowest number, n=2, is found in *Porphyra linearis* (Rhodophyceae) and the highest, n=592, in *Netrium digitalis* (Chlorophyceae).

(iii) Golgi bodies or dictyosomes

Golgi bodies are present in all algal cells except blue-green algae and can be seen under electron microscope. They may be found in the region of the nucleus (*Chlamydomonas),* near plastids (diatoms and *Bulbochaete),* associated with the flagellar bases (*Chlamydomonas*) or without any apparent association with any particular organelle (*Euglena, Fucus).* Golgi bodies are composed of 2-20 flat vesicles which are arranged in stacks. Each stack is called a dictyosome (all dictyosomes collectively form the Golgi apparatus). The exact role of Golgi bodies in algae is not known. They are associated with the synthesis of cell metabolites and have also been shown to contribute to the plasma membrane as in higher plants.

NOTES

(iv) Mitochondria

Well organised mitochondria are present in all algal cells with the exception of blue green algae. A mitochondrion is bound by a double membrane. The inner membrane has cristae. There are usually few cristae in Chlorophyceae and many in Chrysophyceae, Phaeophyceae and Xanthophyceae. The lumen, surrounded by bounding membranes, is filled with a granular matrix which contains nucleic acids (RNA and DNA). There are more than one mitochondria per cell but in *Micromonas* (Chlorophyceae) each cell contains a single mitochondrion act as respiratory centres of the cell. Mitochondria arc also the sites of enzyme action in protein synthesis and amino acid interconversions.

(v) Endoplasmic reticulum (ER)

The cytoplasm of the algal cell is traversed by a system of interconnecting tubules, known as endoplasmic reticulum. It is connected with the outer membrane of the nuclear envelope but does not penetrate other cell organelles like chloroplast or pyrenoid. The surface of ER is studded with ribosome, the sites of protein synthesis in the cell.

(vi) Eye-spot or Stigma

It may be located in the anterior, middle or posterior part of the cell. On the basis of their position and structure five types of eye-spots are recognized.

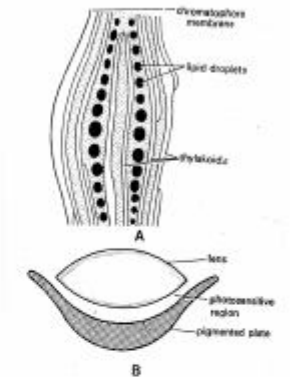


Fig. 6.15 : eye spot of *Phalacroma* cell

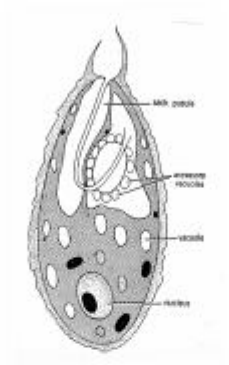


Fig. 6.16 : Vacuolar apparatus of *Phalacroma* cell

Type A: Eye-spot is located in the chloroplast without association with flagella (Chlorophyceae, Cryptophyceae) (Fig. 6.15),

Type B: Eye-spot is located in the chloroplast and associated with a swollen flagellum (Chrysophyceae, Phaeophyceae and Xanthophyceae),

Type C: Eye-spots are independent clusters of osmophilic granules and are situated at the anterior side of cell near the flagellar swelling (Euglenophyceae),

Type D: Eye-spots having osmophilic granular structure with membranous lamellae situated near flagellar bases (Dinophyceae) and

Type E: Eye-spot is made up of a lens, retinoid and pigmented cup. These are the largest and most complex type of eye-spots (Dinophyceae).

The eye spot is considered to be a light sensitive organelle which directs the movements of swimming cells, certain mutants of *Chlamydomonas* lack eye spot and are still phototactic. Some workers consider the eye spot as a shading organelle which possibly modifies the optical quality of transmitted light before it is focussed on the flagellar swelling means flagellar swelling, rather than eye spot, is the primary receptor of light.

(vii) Vacuoles

Except Cyanophyceae, mature cells of almost all classes of algae possess one or more vacuoles bounded by tonoplast. Vacuoles act as the main osmoregulatory organ in the cell and help in regulating the absorption of water and solutes. In holozoic forms, the cytopharynx of complex vacuoles serves as gullet. It also store reserve food materials such as laminarin and chrysolaminarin. Motile algal cells may have the following two types of vacuoles:

Simple or contractile vacuoles- Such vacuoles, found in the members of Chlorophyceae, show periodic contractions and throw out the waste products out of the cell.

Complex vacuoles- A complex vacuole consists of: (i) a tube like cytopharynx, (ii) a large reservoir, and (iii) a group of vacuoles of varying sizes (Fig. 6.24). These vacuoles are characteristic of Dinophyceae and Euglenophyceae.

(viii) Gas vacuoles

These gas containing cavities are characteristic of the mature healthy cells of Cyanophyceae. Their walls are freely permeable to gases. They render buoyancy to planktonic forms and also act as a screen against intense light.

NOTES

(ix) Plastids

Plastids are membrane bound cell organelles found in the cytoplasm of algal cell and specialised for different functions as leucoplasts are colourless plastids which do not contain any pigments in them but storage of reserve foods such as starch, oils and proteins. Chloroplasts are green plastids contain chlorophyll-a, b and other pigments help in photosynthesis and temporary storage of starch. Chloroplasts are seen in green algae. Those plastids which contain chlorophyll-a, other pigments except chlorophyll-b called chromatophores or chromoplasts. They have excess of pigments other than chlorophylls.

There is no plastid in Cyanophycean cells so thylakoids are not protected by membranous envelop and thylakoids are freely dispersed in the protoplasm.

Mostly only one chloroplast is found in most algal cells but in *Chara, Vaucheria, Spirogyra,* etc. more than one chloroplast is seen in a cell.

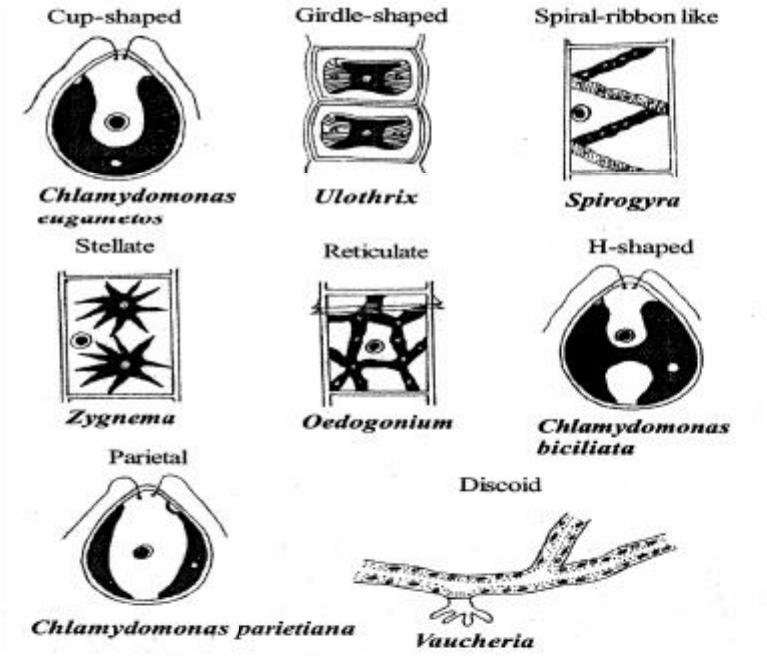


Fig. 6.17 : Cells of Algae showing Different types of Chloroplasts

The various shapes of chloroplasts in algae- There is a great variation in the shape of chloroplasts in different species of algae. Some important shapes of chloroplasts are given below:

Cup shaped chloroplast (*Chlamydomonas eugametos, Volvox, Chlorella*), girdle shaped chloroplast appears as a semicircular parietal band (*Ulothrix*), reticulate vast net work found in the cytoplasm and Pyrenoidse found in the junction points of the reticulum (*Oedogonium, Cladophora, Hydrodictyon, Chlamydomonas reticulata*), H-shaped (*Chlamydomonas biciliata*), stellate star-shaped chloroplast, may be one or two chloroplasts in a cell (*Zygnema, Chlamydomonas arachne*), discoid small disc like chloroplast with Pyrenoids (*Chlamydomonas alpina, Chara, Vaucheria*), spiral chloroplast like spiral band bears many pyrenoids (*Spirogyra*) and parietal chloroplast chloroplast looks like a thin plate and occupies a parietal position in the cell (*Chlamydomonas parietiana*) (Fig.6.25).

NOTES

Structure of chloroplast

A chloroplast is bounded by two unit membranes, outer membrane and an inner membrane separated by a periplastidial space. Interior of the chloroplast membrane is filled with a colourless fluid called stroma or matrix. Many closely pressed membranous sacs called thylakoids are found in the stroma. Many thylakoids are arranged one above the other to form grana. Two adjacent grana are connected by a membranous tube called fret lamella.

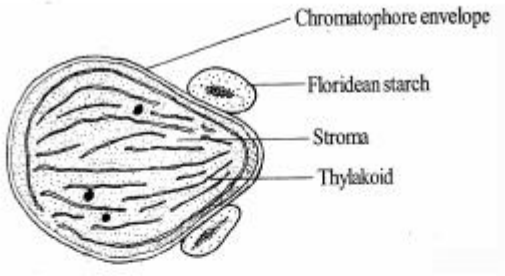


Fig. 6.18 : A Chromatophore of Red Algae

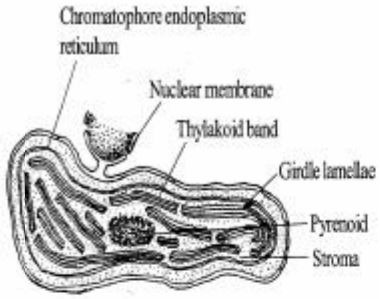


Fig. 6.19 : A Chromatophore of Chrysophyceae

The chloroplast contains circular double stranded DNA which is not protected by histone proteins capable in formation of mRNA for protein synthesis. The ribosomes of chloroplasts are smaller in size and are of 70S- 80S type with pyrenoids seen in the chloroplasts.

Chromatophores of different Classes

NOTES

In the Chromatophore of Rhodophycean algae thylakoids are not stacked one above the other to form grana and are freely distributed in the stroma as individual thylakoids. Floridean starch granules remain attached to the membrane of the chromatophore. In Cryptophycean algae, chromatophore membrane is surrounded by another double layered membrane called chromatophore endoplasmic reticulum. In Crysophyceae, the chromatophore membrane is surrounded by endoplasmic reticulum and the thylakoids are closely arranged to form bands (**Fig. 6.26, Fig.6.27**).

In Pyrrophyta, there are 2-4 discs of thylakoids stretching the full length of the chromatophore. Starch grains are deposited on the pyrenoid. In Phaeophyceae, the disc bands are separated by a clear uniform space. In Eugtenophyceoe, the entire length of chloroplast is traversed by 10-45 stacks of thylakoids, each of which consists of 4 or 5 closely arranged thylakoids. Paramylon grains are und attached to the membrane of the chloroplast. The pyrenoids are traversed by some bands and oil globules are seen in the stroma.

(x) Pyrenoids

Pyrenoids are proteinaceous bodies present in chromatophores considered to be associated with synthesis and storage of starch. In members of Chlorophyceae, pyrenoids are surrounded by starch plates but in some algae (diatoms), they accumulate lipids instead of starch. A chromatophore may have one (*Chlamydomonas*) or more than one (*Oedogonium*) pyrenoids embedded in the chromatophore (*Chlamydomonas*) or attached on its surface with help of a stalk (*Ectocarpus*). The pyrenoids consist of crystals of proteins embedded in a colloidal matrix. Pyrenoid is a food storage containing a small round protein granule surrounded by an arch sheath. The pyrenoid may be found within a chloroplast or found attached to the surface of chloroplast membrane. They are found in all classes of algae, except in the members of *Cyanophyceae.*

Pyrenoids may arise from pre-existing one or arise independently within four hours when the cell is continuously exposed to bright light. The storage of reverse foods is the main function of the pyrenoids. There may be one pyrenoid in a chloroplast as in *Chlamydomonas* or many pyrenoids as in *Oedogonium.*

The size of the pyrenoid decreases when the cell suffers from starvation and it increases while the cell is well-nourished. There are three views regarding the nature of pyrenoids. The first view is that pyrenoids are crystalloid in nature, the second view states that they are masses of proteinaceous fibrils surrounded by starch plates and this nature is called pyrenocrystal.

NOTES

6.5 Reproduction

In algae the propagation takes place by vegetative, asexual and sexual methods.

(I) Vegetative reproduction

In vegetative reproduction, includes all those processes of propagation in which portions of the plant body become separated off to give rise to new individuals without any obvious changes in the protoplast means there is no rejuvenation of the protoplasts. It is the most common method of reproduction in algae and takes place by the following means:

(i) Cell division or fission- Simplest method of propagation, found in unicellular algae (*Euglena, Chlamydomonas*), desmids and diatoms. The unicellular algal cell divides mitotically to form two daughter cells. The cell divides at midnight or early morning *Euglena, Diatoms, Desmids, Pleurococcus* etc.

(ii) Fragmentation- In filamentous forms (*Ulothrix, Nostoc, Spirogyra, Dictyosphaerium, Zygnema, Oedogonium*) the thallus often breaks into small fragments and each fragment grow independently to forms a new thallus. This fragmentation may be due to mechanical pressure, dissolution of transverse walls or difference in turgor pressure between adjoining cells or in colonial forms as blue-green

(iii) Hormogonia- It is a characteristic method of reproduction in blue-green algae. In unfavourable conditions, the trichome breaks into motile segments of varying length called hormogonia (Fig.6.15). The formation of hormogonium is due to intercalary biconcave dead cells called necridia, heterocyst or akinetes or hormogone or hormogonium, and by the germination the hormogone generate a new thallus. eg *Nostoc, Oscillatoria* and *Cylindrospermum.*

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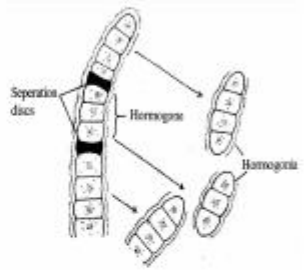


Fig. 6.20 : *Oscillatoria* – Hormogone formation

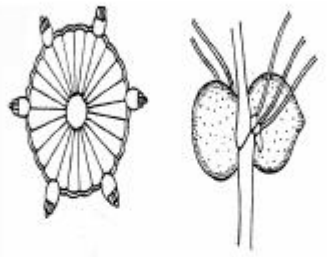


Fig. 6.21 : *Chara* - Amylum star and bulblis

(iv) Formationof adventitious branches - Adventitious branches are formed in some large thalloid forms of algae. These branches, detached from the parent thallus, develop into new plants (*Dictyota, Fucus*). Adventitious branches like protonema, formed on the internodes of *Chara* or stolon of *Cladophora glomerata* are found.

(v)Tubers- On the rhizoids and the lower nodes of *Chara* some tuber like structures are formed due to storage of food material. A tuber is a round structure, made of a mass of cells rich in starch and other reserve foods. In *Cladophora* and *Chara* the tuber produces an independent plant, when detached from the parent plant.

(vi) Budding- In *Protosiphon,* vegetative propagation takes place by budding which formed due to proliferation of vesicles. They eventually get separated from the parent plant by the formation of the septum, and have the capacity to form plants.

(vii) Adventitious Thallus- An adventitious thallus, a special branch arising from any vegetative part of a thallus (*Dictyota* and *Chara*) called propagules or propagula (*Bryopsis, Sphacelaria, Nereocystis*).

(viii) Protonema- In some algae (*Chara*) vegetative structures arising from the main axis of the thallus called protonema. When they get separated off from the thallus, they develop into new plants.

(ix)Amylum Stars- These are star-shaped structures consisting of a mass of cells rich in starch which on germination give rise to a new thallus (*Chara*) (Fig.6.16).

(x) Bulbils- In *Chara,* small bud-like structures, developed on the rhizoids are called bulbils, after separation developing into new plants (Fig.6.16).

(II) Asexual reproduction

NOTES

In asexual reproduction, the protoplasm of a cell divides into many small protoplasts which in turn develop into spores. This reproduction involves in rejuvenation of the protoplasts and the reproductive bodies are either naked or provided with a newly synthesized wall of their own. When these spores are released from the mother cell, they develop into new plants. The spores are produced inside the specialized celled sporangia. In this reproduction a variety of motile or non-motile spores formed and these spores may be differentiated into the following broad categories on the basis of their structure-

(i) Zoospores

These are motile, naked structures with two (*Chlamydomonas, Ectocarpus*), four (macro zoospores of *Ulothrix)* or many (*Oedogonium, Vaucheria)* flagella. The zoospores bear nucleus, chromatophores, an eyespot, flagella and develop in zoosporangium (Fig.6.17). The protoplast of zoosporangium may form a single zoospore (*Oedogonium, Vaucheria)* or undergoes repeated divisions and each segment forms a zoospore (*Cladophora*). Zoospores are haploid or diploid. They are usually formed during the night and are liberated early in the morning. After liberation, they rest for some time and then germinate to form new individuals. In *Oedogonium* many short flagella are arranged in the form of a ring around a colourless region at its anterior end. This is known as stephanokontan type of flagella arrangement.

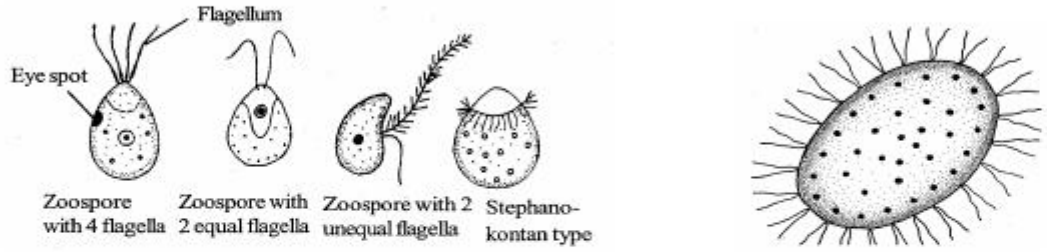


Fig. 6.22 : Different types of flagella occurs in algae (right) and synzoospore (left)

NOTES

In *Chlamydomonas*, the daughter protoplasts do not develop flagella and they are embedded in a mucilage matrix called Palmella stage in *Chlamydomonas tetraspora.* In *Vaucheria,* the zoospore is called synzoospore or ompound zoospore because all the zoospores produced in a zoosporangium remain together and fail to separate.

(ii) Aplanospores- These are non-motile spores, commonly found in terrestrial algae or in some aquatic algae (*Ulothrix, Microspora)* also form them during drought conditions. The aplanospore is produced in aplanosporangium formed at the tip of lateral branches. Aplanospores are non-flagellate, non-motile, multinucleate cells with thin cell wall, produced during unfavourahle condition (Fig.6.18).

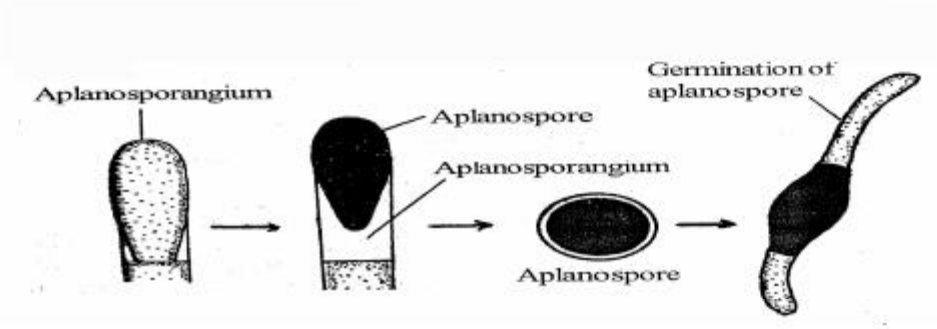


Fig. 6.23 : *Vaucheria*- Formation of Aplanospores, Endospores

(iii) Hypnospores- These are aplanospores like structure occur in *Pediastrum* and *Sphaerella* secrete thick walls to overcome prolonged period of desiccation and such thick walled aplanospores are called hypnospores. The hypnospores of *Chlamydomonas nivalis* are red in colour due to the deposition of a pigment haematochrome in their walls.

(iv) Tetraspores- Diploid thallus of some algae (*Polysiphonia*) form aplanospores is called tetraspores formed in tetrasporangium, by meiosis (haploid), germinate to form haploid plants.

(v) Autospores- The aplanospores with a structure similar to the parent cell are called autospores. In *Scenedesmus* and *Chlorella* the aplanospores acquire all distinctive features of the parent cell before their liberation from the sporangium. Autospores are infact replica of the parent cell; the only difference is that they are smaller in size.

(vi) Akinetes- Vegetative cells develop into thick walled spore like structure with abundant food reserves called akinetes (Fig.6.19). Unlike aplanospores, akinetes always have additional wall layers around the protoplast which are fused with the parent wall. The position of akinetes may be terminal or intercalary. They are resistant to unfavourable environmental conditions. Akinetes are rich in starch, fat and oils and they develop a thick wall around it. The formation of akinetes is affected by the availability of carbohydrates and light and found in many blue-green and green algae as *Oedogonium, Ulothrix* and *Cladophora.*

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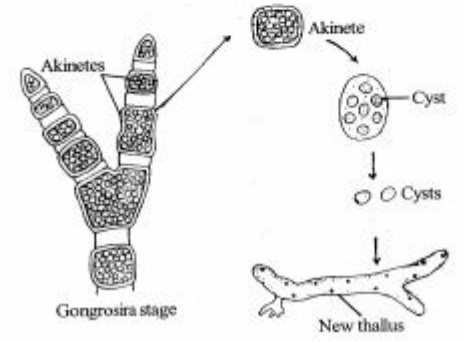


Fig. 6.24 : *Vaucheria*- Akinete formation

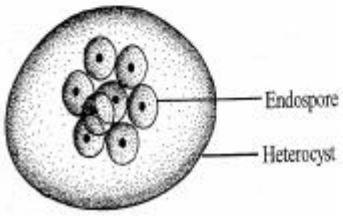


Fig. 6.25 : *Nostoc*- Endospores

(vii) Exospores and endospores- In many blue-green algae the protoplast divides to form special type of spores, known as exospores and endospores. The cell that produces endospores becomes somewhat enlarged and its contents divide successively in three planes, forming four to many endospores (*Dermocarpa*). The spores produced endogenously within the parent cell by the division of its protoplasm and nucleus is called endospores, common in blue-green algae and in diatoms. Tetraspores produced in red algae are a kind of endospore (*Polysiphonia, Gracilaria*) (Fig. 6.20). The exospores are formed externally; the protoplast of the cell comes out through a terminal pore and successively cuts spherical spores (*Chamaesiphon*). Exospores are spore, which produced outside by a constriction of protoplast of apical cell of a filament (*Chamaesiphon, Stichosiphon*).

NOTES

(viii) Auxospores- These are diploid spores formed by zygote of diatoms and secrete a thin membrane called perizonium around it. It forms an auxospore during unfavourable condition. In Bacillariophyceae, auxospores are produced during unfavourable conditions. The protoplasm of diatoms comes out of the frustules and grows into the maximum size.

(ix) Carpospores- A round, uninucleate, non-motile spore formed from the direct or indirect division of the zygote of the Rhodophyceae. The spores produced inside the carpogonium are called carpospores. They are diploid and they grow into diploid sporophytes. Carpospores are produced in red algae (*Polysiphonia, Gracilaria*).

(x) Monospores- A large four nucleate aplanospore produced by some brown algae is called monospore in monosporangium without cell division. Monospores develop into new individuals as in *Batrachospermum* and *Porphyridium.*

(xi) Paraspores- The spores produced from triploid sporophyte of some red algae are called paraspores. Paraspores are produced on the tetrasporophyte of Rhodophyta. They are diploid and always germinate to produce new tetrasporophytes.

(xii) Statospores- These are thick-walled resting spores produced in diatoms and in the members of Xanthophyceae and germinate into new individuals.

(xiii) Microspores- These are small spores produced in diatoms. Each protoplast develops a thick wall around it and becomes a microspore. The microspore on germination forms a new individual.

(xiv) Gongrosira stage- In *Vaucheria,* the protoplasm of a filament is partitioned by the formation of many septa and each compartment becomes a hypnospore or cyst. At this stage, the thallus looks like the alga *Gongrosira.* So this stage is called Gongrosira stage.

(xv) Cysts- These are the resting spore of certain algae to resist dry conditions. In dry season the protoplast divides into many small units eg *Protosiphon, Vaucheria.* When favourable season comes, the cysts germinate into new thallus.

(III) Sexual reproduction

All groups of algae except Cyanophyceae reproduce sexually when gametes fuse to form zygote. Sexual reproduction involves the fusion of two sex cells called gametes one male and another female and this fusion of gametes is either external or internal. The fusion may occur between two gametes from the same plant (monoecious or homothallic) or from different plants, (dioecious or heterothallic). The process of fusion of gametes is called fertilization and the produce zygote. The gametes participating in the fusion may vary in their morphology, physiology and behaviour. Gametes with flagella are called zoogametes and gametes without flagella are called aplanogametes.

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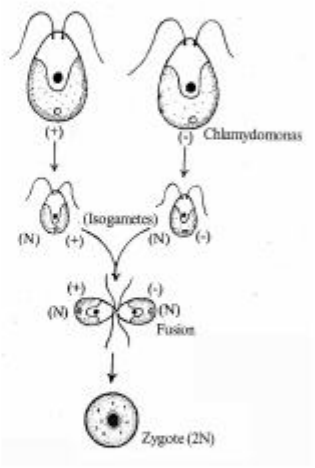
On the basis of the structure and physiological behaviour of sex organs and their complexity, the following six types of sexual reproduction are recognised in different groups of algae.

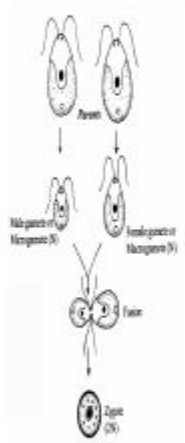
1. Autogamy- When two gametes of the same mother cell fuse to form a diploid nucleus called autogamy. The autogamy lacks incorporation of external genes so algae developing as a result of autogamy do not show new characters eg Diatoms.

2. Hologamy- In some unicellular forms (*Chlamydomonas, Dunaliella*) the vegetative cells of different strains (+) and (-) (female and male) behave as gametes and fuse to form zygote. From evolutionary point of view hologamy is more advanced than autogamy. It involves fusion of two cells having different genetic constitution.

3. Isogamy- In isogamy the two gametes which are morphologically and physiologically similar form zygote called. Such gametes are called isogametes, as they are indistinguishable into plus and minus strains *Ulothrix, Chlamydomonas eugametos*. The fusion of gametes of similar form, size and behaviour is called isogamy and these isogametes may be naked (gymnogametes) or they may have a wall (calyptogametes). The male gamete fuses with the female gamete produce a diploid zygote (Fig.6.21A). Isogamy is the simplest and most primitive type of sexual reproduction and seen in unicellular colonial and filamentous algae (*Chlamydomonas debaryanum, Ulothrix, Cladophora, Ectocarpus*).

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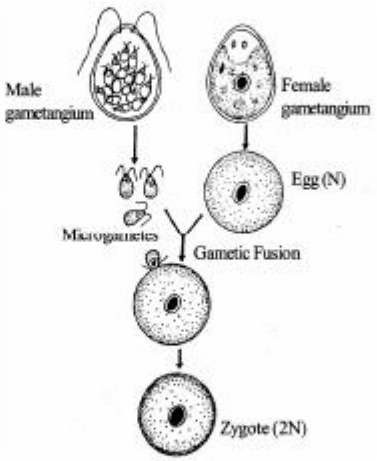


Fig. 6.26 : A. Isogamous reproduction

B. Anisogamous reproduction (*Chlamydomonas braunii*)

C. Oogamous reproduction (*Chlamydomonas coccifera*)

5. Anisogamy- In anisogamy fusion takes place between dissimilar and motile, morphologically and physiologically distinct gametes (anisogametes). The male or microgametes are smaller and more active, whereas the female or macro gametes are larger and sluggish eg. *Chlamydomonas braunii* (Fig.6.21B) and *Pandorina.* In *Spirogyra, Zygnema* and *Ectocarpus* gametes are similar in morphological characters, they show physiological variation with plus (+) and minus (-) strains. It is slightly advanced than isogamy.

6. Oogamy- This is the most advanced type of sexual reproduction. The fusion of a large, non-motile female gamete by a small motile male gamete is called oogamy. Egg is formed within the oogonium and sperms within the antheridium. In this process a large non-motile egg or ovum fuses with a small motile sperm or antherozoid (in Rhodophyceae, sperms are non- motile). *Volvox, Oedogonium, Chara, Vaucheria, Sargassum, Batrachospermum* and *Polysiphonia* are common examples of oogamy (Fig.6.21C). The fusion of the gametes may be external (*Dictyota* and *Fucus*) or internal (*Oedogomum* and *Vaucheria*). In *Rhodophyceae,* oogamy is the only type of sexual reproduction.

The advantages of sexual reproduction are that it gives a variety of offspring through new combination of genes. It prevents the degeneration of race which may result from continuous asexual reproduction. Without new combinations evolutionary process cannot survive.

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The disadvantages of Sexual reproduction are that it depends on chance. It involves locomotion of gametes and requires an aquatic medium. The main conditions favoring sexual reproduction are that light stimulates the production of gametes, Nitrogen deficiency induces gamete formation and deficiency of nutritive materials initiates sexual reproduction.

6.6 Criteria of Classification as Pigmentation, Reserve Food, Flagella

(I) Photosynthetic Pigments

Plastids are of the following two types as leucoplast (colourless plastids), chromoplast (coloured plastids); containing both chlorophyll a and chlorophyll b (chloroplasts) and those lacking chlorophyll b (chromatophores). The various types of pigments found in the algal cell are given below.

1. Chlorophyll- There are five types of chlorophylls viz. chl a, b, c, d and e. chlorophyll a is present in all groups of algae, chlorophyll b only in Chlorophyceae and Euglenophyceae, chlorophyll c largely in algae of marine habitats (Phaeophyceae, Cryptophyceae, Bacillariophyceae and Chrysophyceae), chlorophyll d in some red algae only as a trace constituent and chlorophyll e in certain Xanthophyceae such as *Vaucheria hamata* and *Tribonema bombycinum.*

2. Xanthophyll- More than 20 types of xanthophylls are known formed by the incorporation of molecular oxygen into carotene molecule. Many xanthophylls, common in higher plants (lutein, violaxanthin, and neoxanthin) are found in the members of Chlorophyceae and Phaeophyceae. Fucoxanthin is the main xanthophyll pigment of Phaeophyceae and diatoms whereas myxoxanthophyll, myxoxanthin and oscilloxanthin are found only in Cyanophyceae.

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They are soluble in chloroform and are orange or brown in colour. Lutein, Siphon in, Zeaxanthin, Siphonoxanthin, Astaxanth in, Neoxanthin, Cryptoxanthin, Violaxanthin, Lycopene, Diatoxanthin, Diadinoxanthin, Flavoxanthin, Myxoxanthin,. Dinoxanthin, Taraxanthin, Antheraxanthin, Oscilloxanthin, Myxoxanthophyll, Flavacine, Peridinin, Neofucoxanthin-a, -b and Fucoxanthin are important xanthophylls found in different classes of algae.

3. Carotenes- These are oxygen free alicyclic compounds, composed of isoprene units. The five types of carotenes occur in algae are: a-carotene in Chlorophyceae; Cryptophyceae and Rhodophyceae; b-carotene in all algal groups, except Cryptophyceae, c-carotene in Chlorophyceae; E-carotene in Bacillariophyceae, Cryptophyceae, Phaeophyceae and Cyanophyceae and flavacene in members of Cyanophyceae.

4. Phycobilins- These are water soluble complexes of protein and bile pigments, present in the photosynthetic tissue of plants. Phycobilins are red (phycoerythrin) and blue (phycocyanin) pigments which are confined to Rhodophyceae and Cyanophyceae respectively. They act as light harvesting pigments in photosynthesis and the light absorbed by them is transferred to chlorophyll a. Phycobilins are found only in three classes of algae namely Cyanophyceae, Rhodophyceae and Cryptophyceae.

Distribution of Pigments and reserve food in Different Algal Classes

The intermediate colour, even within the members of a species, is due to variations in the relative proportion of various pigments in their cells.

Cyanophyceae- Chlorophyll-a, b, Carotene- b, e, flavacine, echinenone, zeaxanthin, myxoxanthophyll, myxoxanthin, oscilloxanthin, phycocyanin-c and phycoerythrin- C.

Chlorophycene- Chlorophyll-a,-b, carotene-a,-b and -g, Leutin, Violaxanthin, Neoxanthin, Siphonaxanthin and Astaxanthin.

Charophyceae- Chlorophyll-a,-b, carotene-a, b- and-g, Lycopene, Leutin, Violaxanthin and Neoxanthin.

Xanthophyceae- Chlorophyll-a,-e, Violaxanthin and Neoxanthin.
Chrysophyceae- Chlorophyll-a, b-carotene, Fucoxanthin, Diatoxanthin and Diadinoxanthin.

Bacillarlophyceae- Chlorophyll-a,-c, carotene -b and -e, Fucoxanthin, Dinoxanthin and Diadinoxanthin.

Pyrrophyceae- Chlorophyll-a-c, b-carotene, Diadinoxanthin, Dinoxanthin and Peridinin.

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Crysophyceae- Chlorophyll-a,-c, a-carotene, Zeaxanthin, Diatoxanthin, Phycocyanin and Phycoerythrin.

Euglenophycea- Chlorophyll-a,-b, b-carotene, Echinenone, Zeaxanthin, Neoxanthin, Antheraxanthin and Astaxanthin.

Phaeophyceae- Chlorophyll-a,-c, b-carotene, Leutin, Violaxanthin, Fucoxanthin and Diatoxanthin.

Rodophyceae- Chlorophyll-a, -d, carotene- a, b, Leutin, Zeaxanthin, Violaxanthin, Phycocyanin-R, Phycoerythrin - R.

(II) Structure of Flagella

Flagella are whip-like structures present on the surface of cells. They are helpful for the movement. They are found in motile stage of all classes of algae, except in Cyanophyceae and Rhodophyceae. The number, position of insertion and the nature of flagella vary in different cells of algae.

Flagella arise from neuromotor apparatus present in motile cells. This apparatus consists of one or two dense granules called blepharoplasts. The number of blepharoplasts is equal to the number of flagella present in the cell. Only one flagellum arises from each of the blepharoplasts. The blepharoplasts are interred connected by a thread-like structure called paradesmos. One of the blepharoplasts is connected with a centrosome body found at the surface of nucleus by means of a long thread called rhizoplast fibril. The cross section of flagella shows 2 central fibrils surrounded by 9 fibrils arranged in the form of a circle. The outer 9 fibrils are called peripheral fibrils. The peripheral fibrils are surrounded by plasma membrane.

Types of flagella- They are mainly of the following two types:

(i) Whiplash or acronematic flagella- Such flagella have a smooth surface (Fig. 6.28. A, B).

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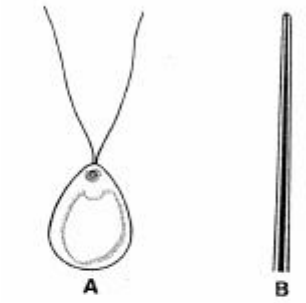


Fig. 6.27: A-B. Acronematic flagella: A. An algal cell with acronematic flagella, B. A single acronematic flagellum

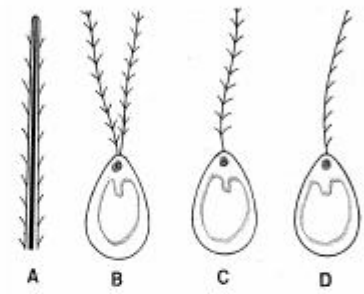


Fig. 6.28 : A-D. Pleuronematic flagella: A. A pleuronematic flagellum showing mastigonemes, B. A cell with two pantonematic flagella, C. A cell with pantocronematic flagellum, D. A cell with stichonematic flagellum.

(ii) Tinsel or pleuronematic flagella- The surface of these flagella is covered with mastigonemes or Dimmers (Fig. 6.29 A-D). The motile stages of Chlorophyceae possess two or four anteriorly inserted whiplash flagella of equal length, whereas the members of Phaeophyceae and Xanthophyceae have one whiplash and one tinsel flagellum of unequal length. Depending on the presence or absence of hairs on flagella, they are classified into two types, namely Acronematic flagella and Pantonematic flagella. In acronematic flagella, there is no flimmer hair on the surface so that the surface of the flagella is smooth. This type of flagellum is otherwise called whiplash flagellum. The pantonematic flagellum possesses fine arranged along the axis of the flagellum. This type of flagellum is otherwise called tinsel flagellum.

6.7 Summary

Algae are group photosynthetic thalloid plants with universal occurrence. These are found in water or on terrestrial. They may be aquatic, terrestrial and algae of unusual habitats. Algae show a progression in thallus unicellular (microscopic) to multicellular (macroscopic). These algae may be benthic, epactic, thermophilic, phytoplankton, epizoic or epizoophytes, epiphytic, halophytic, endozoic, symbiotic, cryophytic, lithophytic, parasitic and aerial Algae. The unicellular forms may be motile or non-motile. Further algae can be classify on the basis of thallus as unicellular forms, colonial forms, filamentous forms, siphonaceous forms and advanced types of thallus. The algae may proliferate vegetatively, asexually and sexually. Vegetative reproduction may be by cell division or fission, fragmentation, hormogonia, formation of adventitious

branches, tubers, budding, adventitious thallus, protonema, amylum stars and bulbils; asexual reproduction by zoospores, aplanospores, hypnospores, tetraspores, autospores, akinetes, exospores and endospores, auxospores, carpospores, monospores, paraspores, statospores, microspores, gongrosira stage and cysts; sexual reproduction1 by autogamy, hologamy, isogamy, anisogamy and oogamy.

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6.8 Self-Learning Excercise

Section -A (Very Short Answer Type Questions)

1. Write habitat of algae in diversified habitat.
2. What are the criteria of classification in algae?

Section -B (Short Answer Type Questions)

1. Write the cell ultra structure of algae.
2. Short note on-
   1. types of asexual reproduction
   2. zoospore
   3. akinetes
   4. hormogonia

Section -C (Long Answer Type Questions)

1. Write an essay on thallus organization in algae.
2. "Reproductions in algae" write an essay.

6.9 References and further readings

- Pandey SN, Mishra SP and Trivedi PS. 2012. A text book of Botany vol. 2nd Vikas Publishing housee pvt Ltd pp. 714.
- Singh V, Pandey PC and Jain DK. 2006. Diversity of microbes and cryptogams. Rastogi Pubication.
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Unit – 7

Classification and Salient Features of *Prochloron, Dunaliella, Nitella, Botrydium*

Structure of the Unit

7.1 Objectives
7.2 Introduction
7.3 Prochlorophyta
  7.3.1. Distinguishing Features
7.4 Prochloron
  7.4.1 Classification
  7.4.2 Structure of Cell
7.5 Chlorophyta
  7.5.1 Distinguishing Features
7.6 *Dunaliella*
  7.6.1 Classification
  7.6.2 Cell Structure
  7.6.3 Morphology and Characters
7.7 Charophyta
  7.7.1 Distinguishing Features.
7.8 *Nitella*
  7.8.1 Classification
  7.8.2 General Characters
  7.8.3 Vegetative Structure
  7.8.4 Reproduction
7.9 Xanthophyta
  7.9.1 Distinguishing Features.
7.10 *Botrydium*
  7.10.1 Classification
  7.10.2 General Characters
  7.10.3 Reproduction

7.11 Summary
7.12 Glossary
7.13 Self-Learning Exercise
7.14 References and further readings

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7.1 Objectives

After going through this unit you will be able to--

- Explain & List out the distinguishing features of Prochlorophyta, Chlorophyta, Charophyta, and Xanthophyta
- Describe the thallus structure of *Prochloron, Dunalilla, Nitella and Botrydium*
- Describe the structure and life history of *Prochloron, Dunalilla, Nitella and Botrydium.*
- Describe the reproduction in *Prochloron, Dunalilla, Nitella and Botrydium.*

7.2 Introduction

Prochlorophytes are very small microbes generally between 0.2 and 2 µm . They were formally known as Blue Green Algae due to their morphologically resemblances with Cyanobacteria.Chlorophyta (Green Algae), members of the largest phylum of the algae, numbering some 6000 to 7000 species. They are commonly known as green or grass-green algae because of their bright green color, which is imparted by two chlorophylls, a and b.This division is also called green algae. There are about 5700 species in this division. It has two classes namely. *Chlorophyceae* and *Charophyceae.* The unicellular algae of the genus *Dunaliella* belong to the *Chlorophyta* (green algae). They fall into the class *Chlorophyceae*. The Charophyta are a **division** of freshwater green algae and are commonly known as stoneworts or brittleworts. The Xanthophyta or Heterokontae commonly known as yellow-green algae include only one class

Xanthophyta. The division has close relationship with the Chlorophyta comprising both marine and fresh-water forms. Certain species grow on drying mud, on trunk of trees, on damp walls, and similar other habitat.

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7.3 Prochlorophyta

7.3.1 Distinguishing Features

1. Prochlorophyta are a photosynthetic prokaryote member of the phytoplankton group Picoplankton.
2. They are abundant in nutrient poor tropical waters and use a unique photosynthetic pigment, divinyl-chlorophyll, to absorb light and acquire energy.
3. Prochlorophyta was assigned as a new algal sub-class in 1976 by Ralph A. Lewin
4. Prochlorophytes are very small microbes generally between 0.2 and 2 μm . They morphologically resemble Cyanobacteria (formally known as Blue Green Algae).
5. Prochlorophyta were initially discovered in 1975 near the Great Barrier Reef and off the coast of Mexico.
6. Members of *Prochlorophyta* have been found as coccoid (spherical) shapes, like Prochlorococcus, and as filaments, like Prochlorothrix.
7. Prochlorophytes contain polyhedral bodies (carboxysomes) containing RUBISCO (Ribulose Bisphospate Carboxylase/Oxygenase, the enzyme that converts inorganic carbon to reduced organic carbon in all oxygen evolving photosynthetic organisms).
8. Prochlorophytes can be classified as obligate photoautotrophic organisms.
9. Reproduction in this divisions is strictly asexual, by simple cell division of fragmentation of the colony or filaments.

7.4 *Prochloron*

7.4.1 Classification

Kingdom : Bacteria

Division	:	Cyanobacteria
Order	:	Prochlorales
Family	:	Prochloraceae
Genus	:	***Prochloron***

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Prochloron was discovered in 1975 by Ralph A. Lewin of the Scripps Institution of Oceanography. *Prochloron* is one of three known prochlorophytes, cyanobacteria that contain both chlorophyll *a* and *b* bound to a special light-harvesting protein (La Roche et al., 1996)

7.4.2 Structure of Cell

The fine structure is described of *Prochloron*, a unicellular prokaryotic alga which contains both chlorophyll *a* and chlorophyll *b*. The cell wall resembles that of a blue-green alga. The thylakoids and cytoplasm together occupy a wide peripheral band. However, the thylakoids are present not as single lamellae, as in

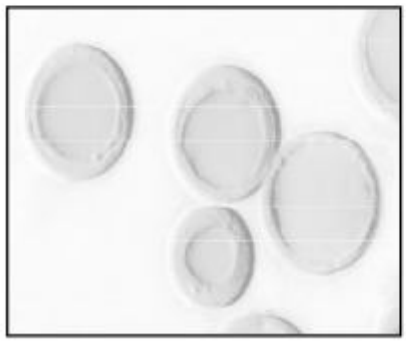


Fig. 7.1 ***Prochloron***

blue-green algae, but in pairs or, sometimes, in thicker stacks. Both thylakoids and cytoplasm are absent from a large central zone which is generally electron-transparent, but may contain electron-dense granules and fibrils. The function of the central zone is not known. *Prochlorons are distributed within the tissues of Didemnid ascidians,* mainly in the cloacal cavities under the upper tunic of the organism. Ascidians, or "sea squirts", are primarily known as a nusciance to humans. These sessile tunicates are found on most solid marine surfaces, including rocks, reefs, and algae.

7.5 Chlorophyta (Green Algae)

7.5.1 Distinguish Features

1. Green algae or chlorophyta (GK.; Chloros = green, Phyton = plant) include more than 7,000 species. About 90% of the total species grow in fresh water habitats and 10% are marine. The marine species (eg., Siphonales, Ulvaceae) are mainly found in the tropical seas.

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2. Green algae are cosmopolitan in distribution and occur in diverse habitats
3. Thallus may be unicellular, colonial, filamentous, siphonous or pseudoparenchymatous.
4. Green algae are distributed in freshwaters, salt waters and moist soils.
5. Cell wall is rich in cellulose.
6. The members of this class contain green chromatophores.
7. The chromatophores contain excess of chlorophyll – a and b.
8. Pyrenmoid is surrounded by starch plates.
9. Starch is the reserve food.
10. Flagella may or may not be present. If present, they are 2 or 4 in number and equal.
11. Chloroplasts have 2-20 thykaloid lamellae. They are usually associated with pyrenoids. Each pyrenoid has a central protein called 'pyrenocrystal' and a surrounding starch sheath. They serve the purpose of storing starch.
12. Photosynthetic pigments in chloroplasts are chlorophyll-a, chlorophyll-b, carotene and xanthophylls. The green color is due to presence of excess chlorophyll, chloroplastic pigments are the same as in land plants.
13. Motile forms, zoospores, gametes and other motile cells are flagellated. The flagella are usually 2, sometimes 4 or even more, attached at the anterior ends of the cells. They are whiplash type and equal in size.
14. Usually, the flagellated cell possesses a small dot like photosensitive, red, eye spot (or stigma) at the anterior end.
15. Reproduction takes place by vegetative, asexual and sexual methods.
16. Vegetative reproduction takes place by the cell division, fragmentation, status and tubers.
17. Asexual reproduction takes place by the formation of akinetes (eg., Phitophora), zoospores (eg., *Ulothrix),* daughter coenobia (*Volvox),* aplanospores (eg., *Dedogonium),* hypnospores and autospores

18. Sexual reproduction occurs by isogamous (*Ulothrix, Cladophora*), anisogamous (eg., *Chlamydomonous braunii)* and oogamous (eg., *Volvox, Oedogonium*) methods.

19. Zygote is generally the only diploid structure in the life cycle.

20. There is a regular alteration of haploid gametophytic and diploid sporophytic generations in the lifecycle of green algae. The alternation of generations maybe isomorphic (i.e. both gametophyte and sporophyte generation are morphologically dissimilar, eg., *Stigeoclonium spinosum*

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7.6 *Dunaliella*

The unicellular algae of the genus *Dunaliella* belong to the *Chlorophyta* (green algae). They fall into the class *Chlorophyceae*. Recently they were put into their own order of *Dunaliellales* and family of *Dunaliellaceae*. The genus *Dunaliella* consists of the two subgenera *Pascheria* (including five freshwater species) and *Dunaliella* (including 23 described saltwater species).

7.6.1 Classification

Domain	:-	Eukaryota
Kingdom	:-	Viridiplantae
Phylum	:-	Chlorophyta
Class	:-	Chlorophyceae
Order	:-	Chlamydomonadales
Family	:-	Dunaliellaceae
Genus	:-	***Dunaliella***

7.6.2 Cell Structure

Dunaliella tertiolecta is a marine green flagellate with a cell size of 9−12 μm. *Dunaliella* sp. are motile, unicellular, rod to ovoid shaped . The organisms are relatively simple to cultivate and do not clump or form chains This strain is reported to have oil yield of about 37% (organic basis). *D. tertiolecta* is a fast-growing strain and that means it has a high CO_2 sequestration rate as well The best-known species is the extremely salt tolerant *Dunaliella salina.*A new

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species of *Dunaliella* was discovered in the *Atacama desert* in 2010. It is believed that the algae is sustained by the condensation of water vapor on.

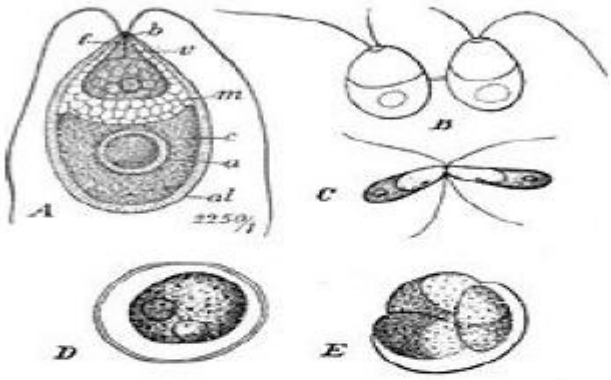


Fig. 7.2 : *Dunaliella salina* Teodor. A: Vegetative cell, B: Zoospores in cell dvision, C: Mating gametes, D: Ripe zygospore, E: Zygospore germination

7.6.3 Morphology and Characters

In the past 23 different species had been described. Many species are extreme halo-tolerant and propagate even in saturated salt (NaCl) solution. All species are unicellular and have two flagella in their motile vegetative phase. In addition, all species possess a cup-shaped chloroplast. For some species sexual reproduction has been reported with either homothallic or heterothallic behaviour. It is known that the cell morphology changes throughout the life cycle. Moreover, cell morphology depends on environmental conditions.

7.7 Charophyta

7.7.1 Distinguishing Features

1. Charophyta are commonly known as stoneworts or brittleworts.
2. They come from a monophyletic lineage, and are a paraphyletic group.
3. The Charophyta are a **division** of freshwater **green algae** .
4. There are five classes: Chlorokybales, Klebsormidiales, Coleochaetales, Charales, and Zygnematales.
5. It was commonly believed that Charophyta were related to embryophytes (land plants).
6. Karol *et. al.* (2001) performed a four-gene phylogenetic analysis, the results of which support this hypothesis.

7. Embryophytes can be classified within Charophyta. Their analysis also identified Charales as the closest living relatives of plants.
8. In addition, their research shows that the unicellular flagellate Mesostigma makes up the earliest branch of charophyte lineage.
9. Some of the characteristics between Charophyta and land plants are: homologous chloroplasts, as well as similarities in mitosis, sperm ultra structure, cell wall composition, peroxisomes, and genetic data
10. In some charophyte groups, such as **Zygnematophyceae** or conjugating green algae.
11. **Flagellae** are absent and sexual reproduction does not involve free-swimming flagellate sperm. Flagellate sperm, however, are found in **stoneworts**

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7.8 *Nitella*

7.8.1 Classification

Division	=	Chlorophycophyta
Class	=	Chlorophyceae
Order	=	Charales
Family	=	Characeae
Sub-family	=	Nitelloideae
Genus	=	*Nitella*

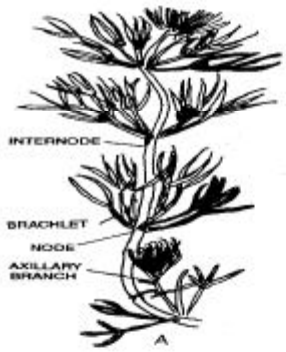


Fig. 7.3 *Nitella*

Branchosperm

7.8.2 General Characters

Occurrence

There are about to 40 species of the genus Nitella. All of them are found in clear and freshwater with the exception of *N. terrestris* which occurs on damp ground, are aquatic or sub-aquatic.

Organization of Thallus

The *Nitella* plant has jointed, central main axis a whorl of branches arising from each joint (node). It is anchored to the soft substratum by multicellular, branched, colourless rhizoids. The plant thus has the appearance of miniature

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horsetails (*Equisetum*). In their equisetoid habit *Nitella* and *Chara* differ from all green algae. The upright, tall main axis often called the stem varies in height in different species. The main axis (so-called stem) is differentiated into a series of well-marked alternating nodes and inter-nodes. The internode is a single, elongated, undivided cylindrical cell several times longer than broad.

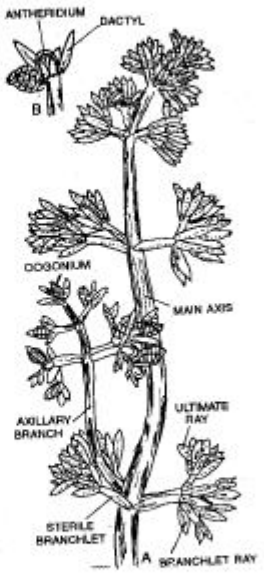


Fig. 7.4 ***Nitella terrestrial*** **: A. Part of thallus with fertile B. branchlet, B. A part of fertile branchlet**

The node consists of a ring of usually 6, rarely 7 or 8 peripheral cells enclosing two central cells. A whorl of branches of limited growth arise from each node. These branches are called by various names such as branchlets, laterals or leaves. In addition, growth in the inner side of the oldest branchlet in the whorl.. **There are no stipulodes at the nodes in** ***Nitella***.

The branchlets in *Nitella* have a characteristic furcated appearance. The furcations are called the rays or branchlet rays of first, second, third or may be one – celled or two-celled. They may be elongate but are abbreviated in some higher order depending on the species. The ultimate branchlate rays are called the *dactyls*.

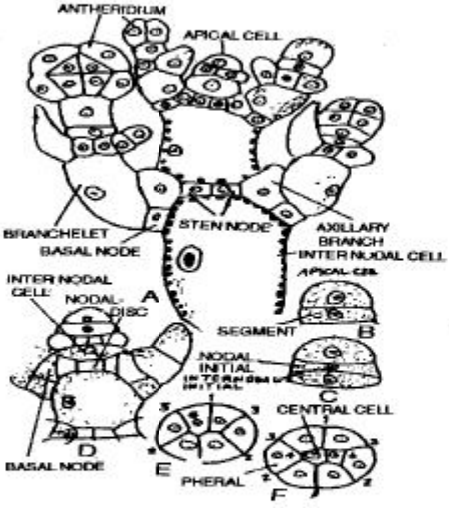


Fig. 7.5 ***Nitella*** **: Structure and sex organs**

Fig. 7.5 ***Nitella :*** **A : L.S. apical region showing structure of stem node and basal node of branchlet with an initial of axillary branch-developing sex organs and branchlets; B-C : successive stages of** ***segmentation of apical cell and differentiation of nodal and inter nodal initials; D. : L. Section through the apical region of main axis; E-F*** **: C.S. young nodes showing the sequence of walls (A based on Sundaralingam but slightly modified and diagrammatic E-F after Fritsch**

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7.8.3 Vegetative Structure

The nodal cells and young internodal cells have dense protoplasmic contents. The single nucleus is usually located in the centre of the cell. There are a number of small discoid chloroplasts, oval in shape and devoid of pyrenoids. They are uniformly distributed in the cytoplasm. The reserve food is stored as starch. The cell wall is cellulose in nature. It has more or less a gelatinous superficial layer of unknown composition external to it.

The elongated intermodal cell has a large central vacuole with the cytoplasm forming a lining layer within the cell wall. The nucleus which lies in the peripheral cytoplasm, at first, becomes lobed and then divides amitotically to form several nuclei. The resultant nuclei lie in the lining layer or cytoplasm and have large nucleoli and scanty chromatin. The peripheral cytoplasm of the multinucleate intermodal cell is distinguishable into two distinct regions, the outer or parietal denser region just within the cell wall and the inner less denser part. The forms is called *exoplasm* and the latter *endoplasm*. The exoplasm remains stationary. The chloroplasts are lodged in the stationary exoplasm. They are arranged in well-defined longitudinal series. The study of fine structure of the chloroplasts revealed that it is limited by a double membrane chloroplast envelope. Within the chloroplast envelope is the matrix which contains 40-100 discs or thylakoids. All of them may form a single stack or band occupying most of the volume of the chloroplast. The more fluid, less denser endoplasm is in a state of constant rotation. It flows up on one side and down on the other. The two cytoplasmic streams adjoin a colourless strip or streak of stationary cytoplasm on either flank of the cell. The regular contraction and expansion of these fixed fibrils cause the adjacent endoplasm to stream.

Growth

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The main axis and the axillary branches show indefinite growth. It takes place by the activity of a domeshaped (hemispherical) *apical cell* located at the tip fig. 7.6 (A). It cuts off a series of segments parallel to it posterior face (B). Each

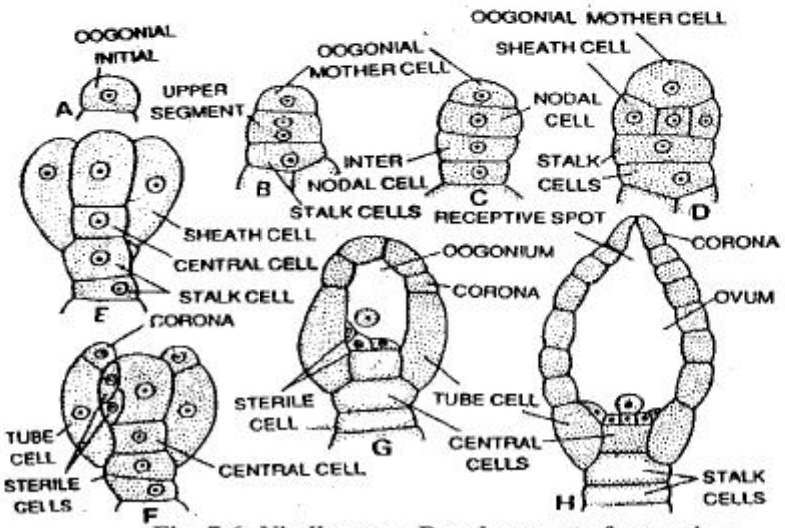


Fig. 7.6 *Nitella* spp. : Development of oogonium

segment divides by a curved transverse wall into two halves fig. 7.6 (C). The lower half which is known as the *internodal initial* is biconvex. It undergoes no division but elongates gradually during further growth to the length of a mature internode. The upper half, which is biconcave, is known as the *nodal initial.* It divides in a characteristic manner to form the nodal elements fig. 7.6 (D). The nodal initial first divides by a halving wall into two semi-circular cells fig. 7.6 (E). The subsequent divisions take place by curved septa occurring in planes intersecting the previous one. In this way a ring of usually 6 rarely 7 or 8 peripheral cells enclosing the two central ones is formed fig. 7.6 (F). This mass of cells constitutes the node.

7.8.4 Reproduction

Vegetative : Vegetative propagation may be effected by (i) *amylum stars* developed from the lower nodes, (ii) *bulbils* developed upon rhizoids and (iii) *protonema*, developed from a node.

Sexual Reproduction

It is an advanced type of oogamy. Some species are *monoecious* and some are *dioecious*(*N. acuminate, N.furcata, N. terrestris* and *N. hyaline*).

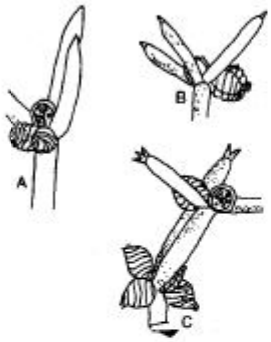


Fig. 7.7 *Nitella*: Position of sex organs. A. *N. acuminate* ; B. *N. terrestris*; C. *N. furceta*

In the monoecious species the antheridium is terminal at the centre of furcation and ooganium lateral in position below the antheridium . The antheridium is developed from the apical cell of the branchlet at the furcation. The oogonia are developed from the adaxial peripheral cells of the upper node of the branchlet. It is also called the basal node of the antheridium. Thus morphologically the oogonium is a modified branchlet ray of the higher order than that of the antheridium. In monoecious forms with more than one furcation (*N.terrestris)* all the furcations may bear both the sex organs (B). *N. furcata* which is also monoecious, however, has only oogonia at the first furcation and both antheridia and oogonia on other furcations above the first (C). The final furcation is sterile. The dioecious species (*N. flagelliformis*) bears either an antheridium or an oogonium at each furcation.

Antheridium

In monoecious species of *Nitella* the antheridium is above the oogonium at the node. It consists of a jacket layer of 8 closely fitting shiel cells. From the middle of each shiel projects inwards towards the centre of the antheridium an elongated cell, the manubrium. The later at its distal end bears a terminal cell known as the primary capitulum. The primary capitulum buds about six secondary capitula. Each secondary capitula. Each secondary capitulum terminally

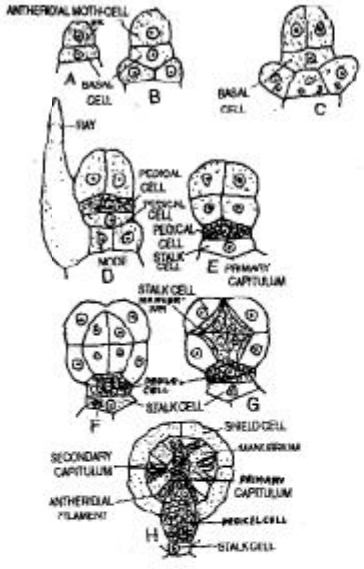


Fig. 7.8 (A-H) *Nitella*: Successive stages in the development of antheridium

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develops a pair of long filaments called the antheridial filaments. Each cell of the antheridial filament produces a single antherozoid. The mature antheridium appears stalked. The stalks consists of a pedicel cell which partly projects into the cavity of the antheridium and the stalk cell. The antheridium with a jacket of 8 shields and corresponding number of manubria and head cells is called octoscutate. In *N.terrestris* there are only 4 shields with a corresponding number of manubria and head cells. Such an antheridium is called quadriscutate.

Development of Antheridium

The antheridium primordial cuts off a cell at its base (A) and then assumes a spherical form to function as an antheridial mother cell (B). The latter undergoes two longitudinal divisions at right angles to one another. The resultant four cell constitute the quadrant stage (C). In section only two cells are seen. Each quadrant divides transversely to form the octant stage (E). In section only four cells are seen. Each octant undergoes a periclintal division (F). The outer segment divides again by a periclinal wall. In this way a row of three cells is formed in each octant (G). The outer cell of each row grows laterally to form a shield cell. The middle one elongates radially and projects inwards to form the manubrium. The innermost cell of the row constitutes the primary capitulum or head cell. The latter cuts of secondary capitular cells which form antheridial filaments (H).In *Nitella*, as development of the antheridium proceeds the basal cell divides transversely into two segments upper and lower (D). The lower segment remains short and discoid to form the stalk cell. The upper sister segment grows and elongates to form the pedicel cell. A part of the latter remains outside the antheridium.

Oogonium

Oogonium is oval in form and is enclosed by a sheath of five long cells spirally wound around it in a clockwise direction. There are ten small closely fitting cells capping the mature oogonium. They are arranged in two tiers of five cells each and constitute the *corona.* The corona in *Nitella* is colourless, small, persistent or deciduous and two-tiered. Within the sheath is the oogonium. The protoplast of the oogonium forms a single ovum packed with starch and oil. The nucleus lies at the base. As the apex of the ovum is a colourless, granular cytoplasm constituting the receptive spot.

Development of Oogonium

It is develops from the adaxial peripheral cell of the node below the antheridium.

Fertilization

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As the sperms mature, the shield cells separate from each other exposing the antheridial filaments. The sperms usually escape in the morning into the surrounding water in which they may continue to swim until the evening. Within the ovum the sperm nucleus moves down the fuse with the female nucleus at its base. How do the sperms escape from the sperm mother cells is a matter of dispute.

Oospore

The fertilized egg or zygote enlarges and secretes a thick wall around it to become an oospore. It varies in colour from light yellow to black and is rounded to ellipsoid in form.

Germination of Oospore

After a period of rest which may extend over weeks or months the zygote, germinates and divides into four daughter nuclei. It is presumed that the division is meiotic. The division of the nucleus is followed by asymmetrical division of oospore into a small, uninucleate distal cell and a large, basal trinucleate cell packed with food reserve materials. The basal cell later degenerates. The oospore bursts at the apex exposing the uninucleate cell which now divides vertically to form a rhizoidal initial and a protonematal initial. The two grow in opposite directions, the former developing into a colourless, filamentous first rhizoid and the latter into an erect, green filamentous primary protonema. Both are differentiated into nodes and inter nodes. The adult plant arises as a lateral branch from the second node of the protonema.

7.9 Xanthophyta

7.9.1 Distinguishing Features

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1. The Xanthophyta or Heterokontae are commonly known as yellow-green algae.
2. Certain species grow on drying mud, on trunk of trees, on damp walls, and similar other habitat.
3. There are varied forms of vegetative body ranging from unicellular coccoid, siphonaccous to filamentous condition.
4. Each vegetative cell has a wall composed chiefly of pectic substances which, depending on species, may be impregnated with silica.
5. The cell contains one to several discoid chromatophores. Except in the siphonaccous forms each vegetative cell is uninucleate.
6. Due to the presence of excess of carotinoids, the colour of chromatophores is yellow-green.
7. The two flagella are normally of unequal length, being tinsel type and whiplash type.
8. The food storage products are oil and fat, but never starch.
9. A cell wall is frequently absent and when present it generally has a higher content of pectic material than the walls of Chlorophyta.
10. A cell contains one or more chromatophores, which usually lack pyrenoids.
11. In some forms, the thallus in coenocytic.
12. Vegetative reproduction occurs by fragmentation.
13. Asexual reproduction in most species is by zoospores with a few exceptional cases where aplanospores are formed for asexual reproduction .
14. Sexual reproduction ranges from isogamy (eg. *Botrydium* spp.) to anisogamy (eg. *Botrydium* spp.) and oogany (*Vaucheria*).

7.10 *Botrydium*

7.10.1 Classification

Class	:	Xanthophyceae
Order	:	Heterosiphonales
Family	:	Botrydiaceae
Genus	:	*Botrydium*

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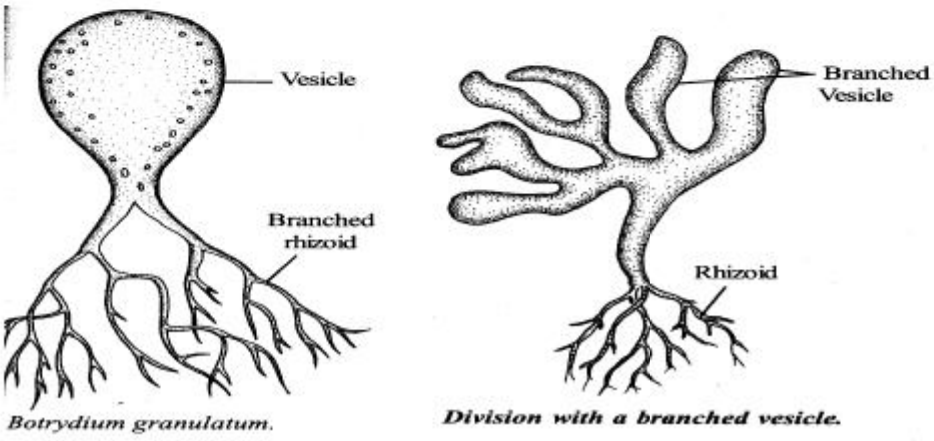


Fig. 7.9 *Botrydium*

7.10.2 General Structure

Botrydium is yellow-green alga. The plant body is siphonaceous.It is widely distributed in terrestrial habitats. It grows on muddy soils near the streams and ponds. There are about six species in Botrydium, few species are commonly found in India. (*Botrydium granulatum, Botrydium tuberosum)*

7.10.3 Reproduction

In *Botrydium,* reproduction takes place by two methods(.A)Asexual reproduction(B)Sexual reproduction

Asexual Reproduction

Zoospores

Zoospore are uninucleate, biflagellate, asexual spores.

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The multinucleate cell of vesicle divides into many uninucleate piecesand develops into a biflagellate zoospore. At the anterior end, the zoospore bears two unequal flagella, namely whiplash type and tinsel type.

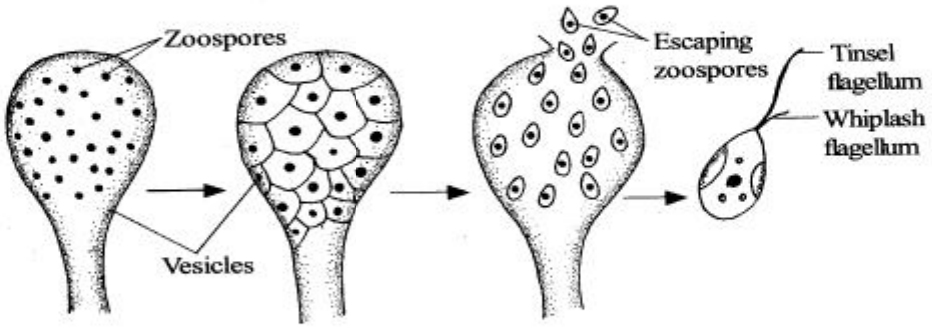


Fig. 7.10 *Botrydium* : Zoospore

The zoospores are liberated from the anterior end of the vesicle and they germinate into new thalli. Zoospores are developed, when the plants are submerged under water.

Apanospores

The apanospores are thin-walled, multinucleate, non-flagellate, asexual spores. The protoplast of the cell divides into several uninucleate or multinucleate pieces and develops into an aplanospore.Aplanospores are liberated from the vesicle and they germinate into new plants.

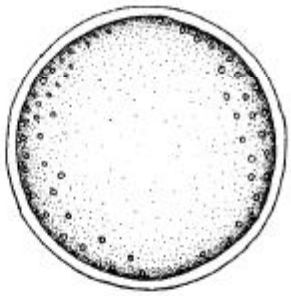


Fig. 7.11 Aplanospores

Hypnospore

Hypnospores are thick-walled, non-motile, non-flagellate cells. They develop during adverse condition. Hypnospore may be uninucleate or multinucleate. When favourable condition returns, hypnospores are liberated from the cell and they germinate into new haploid plants.

Cysts

Cyst is a thick-walled resting spore. It develops during dry conditions. They develop from the vesicle and rhizoids. There are four types of cysts. They are :

(A)Macrocyst(B)Sporocyst(C)Rhizocyst(d)Tuberous cyst

Sexual Reproduction

The sexual reproduction in *Botrydium* is isogamous or anisogamous.The multinucleate cell of vesicle divides into many uninucleate pieces. Each piece develops into a biflagellate gamete. At the anterior end, the gamete bears two unequal flagella, namely whiplash type and tinsel type.

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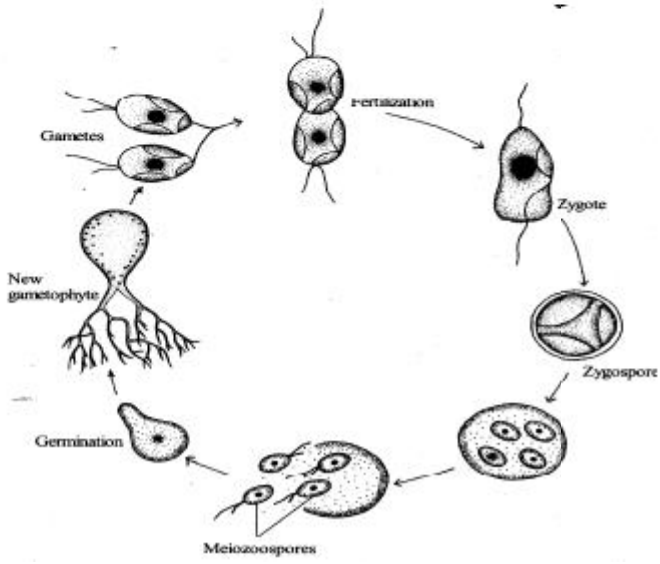


Fig. 7.12 : *Botrydium* : Sexual reproduction

Uninucleate and biflagellate gametes are liberated from the anterior end of the vesicle. .The fusion takes place between two haploid gametes by their non-flagellated posterior ends to form a diploid zygote. The zygote secretes a thick wall around it to become a zygospores.The nucleus of the zygospore undergoes meiosis to form 4 haploid nuclei. Each haploid nucleus develops into a biflagellate meiozoospore. The meiozoospore escapes from the zygospore and germinates into a new haploid gametophyte.

The multinucleate cell of vesicle divides into many uninucleate pieces. Each piece develops into a biflagellate zoospore. At the anterior end, the zoospore bears two unequal flagella, namely whiplash type and tinsel type.

The zoospores are liberated from the anterior .

7.11 Summary

In this unit we studied the distinguishing features of Prochlorophyta, Chlorophyta Charophyta, and Xanthophyta.The unit further elaborated on the

salient features of some genera like *Prochloron,Dunalilla,Nitella and Botrydium* In this unit we discussed the nature of *Prochloron,Dunalilla,Nitella* and Botrydium.We also discussed the life cycle, reproduction methods found in *Prochloron, Dunalilla, Nitella and Botrydium.*

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7.12 Glossary

- **Aplanospores :** The alanospores are thin-walled, multinucleate, non-flagellate, asexual spores.
- **Cryophytes :** Grow in the polar regions on ice and snow.
- **Cysts :** Cyst is a thick-walled resting spore. It develops during dry conditions
- **Epizoic :** Grow inside the body of animals .
- **Epiphytes :** Grow on other plants such as tree trunks, damp wood work and shady leaves.
- **Endophytes :** Grow inside the other plants .
- **Hypnospore :** Hypnospores are thick-walled, non-motile, non-flagellate cells. They develop during adverse condition.
- **Macrocyst :** Macrocyst is a large multi nucleate cyst developing from the vesicle without division. The macrocyst develops during adverse condition
- **Rhizocyst :** Rhizocyst is a thick walled, multi nucleate, asexual cyst developing from the rhizoid
- **Sporocyst--**Sporocyst is a thick-walled, multi nucleate cyst. It is also called hypnospore.
- **Terrestrial :** Grow anywhere on moist soil, walls and rocks in the form of sheets.
- **Thermophilic :** species are found growing in hot springs .
- **Tuberous cyst :** Tuberous cyst is a thick-walled, multi nucleate, asexual cyst.
- **Zoospores :** Zoospore are uninucleate, biflagellate, asexual spores.

7.13 Self-Learning Exercise

NOTES

Section-A (Long Answer Type Questions)

1 Discuss the characteristics of green algae.

2 Explain the life cycle pattern in green algae.

3 Describe the thallus structure on Chlorophyta.

4 Write an illustrated account of the sexual organs of *Nitella* and the germination of its oospores.

5. Discuss the characteristics of Charophyta

6 Describe the structure and development of sex organs of *Nitella*.

7 Give an account of habitat and structure of thallus of *Botrydium*.

8 Give a complete account of structure and life history of *Botrydium.*

9 Discuss the characteristics *of Dunalilla.*

10 Discuss the characteristics of Prochlorophyta.

11 Give a complete account of structure Prochloron.

Section -B (Short Answer Type Questions)

1 Explain the Habital-variation in Chlorophyta.

2 Briefly mention the type of pigments in green algae.

3 Summerize the classification of green algae.

4 Write short notes on :

(i) Asexual reproduction in green algae.

(ii) Sexual reproduction in green algae.

(iii) Thallus structure in *Nitella*.

(iv) Sexual reproduction in *Nitella*.

5 Comment upon the features of special interest of *Nitella*.

6 Describe the salient features of *Botrydium*.

7 Summerize the classification *Dunalilla.*

8 Write short note on Cell Structure of Dunalilla. Q.11.Describe the salient features Prochloron.

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Section-C (Very Short Answer Type Questions)

1 What is the 'algal bloom'?

2 Explain the haplodiplontic life cycle.

3 Name the type of reserve food in green algae.

4 Fill in the blanks :

(i) Fusion between gametes of unequal sizes is called ……..

(ii) A motile flagellated asexual cell is known as …….

(iii) Stonewort is the common name for ……

(iv) Botrydium belongs to family ……

(v) The zoospores in *Botrydium* is ……

(vi) In *Botrydium* sexual reproduction is ……

(v) *Dunalilla* belongs to family ……

5 Select the correct answer :

(i) Reserve food is starch in

(a) Chlorophyceae (b) Myxophyceae (c) Phaeophyceae

(d) Rhodophyceae

(ii) Asexual spores which are motile and have two flagella are called

(a) Zoospores (b) Synzoospores (c) Zygospores

(d) Chlamydospores

(iii) Which of the following has reserve food as starch ?

(a) Volvax (b) Vaucheria

(c) Ectocarpus (d) Batrachospromum

(iv) *Botrydium* belongs to class :

(a) Chorophyceae (b) Charophyceae

(c) Xanthophyceae (d) Bacillariophyceae

(v) In *Botrydium* the sexual reproduction is

(a) Isogamous (b) Anisogamous (c) Heterogamous

(d) Oogamous

6 Name the type of reserve food in green algae.

7.14 References and further readings

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NOTES

Unit - 8

Classification and Salient Features of *Navicula, Laminaria, Gelidium*

Structure of the Unit

8.1 Objectives

8.2 Introduction

8.3 Bacillariophyta

8.3.1. Distinguishing Features

8.4 *Navicula*

8.4.1 Classification

8.4.2 Structure of Cell

8.4.3 Protoplast

8.4.4 Reproduction

8.5 Phaeophyta

8.5 .1 Distinguishing Features

8.6 *Laminaria*

8.6.1 Classification

8.6.2 Structure

8.6.3 Internal Structure of Thallus

8.6.4 Reproduction

8.7 Rhodophyta

8.7.1 Distinguishing Features.

8.8 *Gelidium*

8.8.1 Classification

8.8.2 Structure

8.8.3 Reproduction

8.9 Summary

8.10 Glossary

8.11 Self-Learning Exercise

8.12 References and further readings

8.1 Objectives

After going through this unit you will be able to--

- Explain & List out the distinguishing features of Bacillariophyta Phaeophyta and Rhodophyta
- Describe the thallus structure of *Navicula Laminaria. and Gelidium*
- Describe the structure and life history of *Navicula, Laminaria. and Gelidium.*
- Describe the reproduction in *Navicula, Laminaria. and Gelidium*

NOTES

8.2 Introduction

The Bacillariophyta are popularly called diatoms. They play a very important role particularly in the aquatic vegetation of the world, forming an important part of the plankton, the basic food of aquatic fauna. Diatoms have been very appropriately named as the "***Jewels of the plant world***", for their diverse forms and very delicately designed walls with ornamentation being the objects of great beauty..A special branch of phycology known as **Diatomology**, the science of diatoms has developed dealing with the various aspects of the huge number of diatom species and their unique structure. The group contains 250 genera and about 1,00,000 species.

The phylum Phaeophyta includes the single Fuciphyceae, formerly known as Phaeophyceae popularly called the brown algae. A large number of brown algae popularly as 'Sea weeds'. Some of them are the largest sea plants. The gaint brown algae are called kelps .The Rhodophyta (Red algae) owe their colour to the presence of excess of γ-phycoerythrin in their chromatophores and this red pigment masks the colour of other photosynthetic pigments.

8.3 Bacillariophyta

8.3.1 Distinguishing Features

Diatoms are the members of the largest group of algae in the golden algae phylum. Diatoms are unicellular but may occur as stalk-like or branching

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colonies. Their cell walls consist of almost identical halves, which fit together much as a box fits into its lid. The walls contain some cellulose, but are primarily composed of silica, which gives them rigidity and also produces elaborately sculpted patterns of grooves that often serve as identifying features The cytoplasm contains the green pigment chlorophyll, but other pigments, especially the yellowish xanthophylls, give the organisms a golden-brown appearance.

Reproduction is usually by cell division. The shell separates, and each half secretes a slightly smaller shell that fits inside the old one. Successive cell divisions result in ever smaller daughter cells until a minimum size is reached. Periodically, sexual reproduction by means of fertilization of haploid gametes produces cell that are the original size of the organism.

More than 8000 species exist, mostly in fresh ponds or on the surface layers of the oceans, where they are a major component of the plankton on which marine life depends. The fossil remains of diatom shells are called diatomaceous earth.

- The members of Basillariophyta are popularly known as the diatoms.
- They are mostly single called, like tiny boats, microscopic, variously coloured and found in fresh (Mesosira, Nitzchia, navivula and Cocconeis) and salt water.
- Morphologically they are seen as triangles, rectangles and circles of bilateral or radial plan.
- The photosynthetic pigments are chlorophyll a and c but not, together with fucoxanthin as the photosynthetic pigments. They appear yellow brown, golden yellow or olive green in colour. The colour is due either to the presence of a very large proportion of the carotenoids (normal constituents of cholorophyll). The other pigments are xanthophylls (funcoxanthin or isofucoxanthin or diatomin).
- The thallus is diploid , cell wall silicified, with two overlapping halves bearing characteristic secondary structures.

- The storage food reserves are oil and chrysolaminarin or a protein like food material called voluntine.
- They produce auxospores.
- The motile stage (sperms) with a single pantonematic (tinsel) flagellum (rarely two).
- The diatom cell wall is composed of two parts, an inner continuous pectin membrane and an outer highly silicified, armour of hydrates silica. The silica envelope shows characteristic secondary structure. It is often called the shell or frustules. A completely enclosing wall of silica (frustules) would hinder cell division. Hence it is made up of two overlapping halves. One of these is the older of the two. The older half fits closely over the younger half like the lid of a box 9. The overlapping side walls of the two halves are called the girdles. The word diatom literally means "cut into two" this refers to the characteristic double nature of silica wall.
- Auxospores are specialized enlarged spore, also known, as the growth spores. They are zygotic in nature and serve to restore to the normal, the reduction in the size of the diatom cell occurring during vegetative propagation. For this reason they are also called the rejuvenescent cells or renewal spores.

The diatom unicells are of various forms. They are placed under the following two taxonomic groups :

1. Order **Centrales** : The unicells are radially symmetrical.
2. Order **Pannales** : The unicells exhibit bilateral symmetry.

8.4 Navicula

8.4.1 Classification

Order	-	Pennales
Sub-order	-	Biraphideae
Family	-	Naviculaceae

NOTES

Genus - *Navicula*

Navicula is one of the common examples of Pennales. A large number of species of this genus are found in fresh water.

NOTES

8.4.2 Cell Structure and Cell Wall

Frustules are symmetrical and are usually without intercalary bands. The valves are attenuated towards the pole and usually with capitate or rounded apices. The raphe is axial, distinct and straight with small but well defined polar and central nodules. The axial area where the raphe lies is narrow and either without or with a central nodule. Lateral to the axial field, parallel rows of straie or rows of punctuate are present. These are either strictly transverse or some what radiate in the region lateral to the central nodule. In girdle view, frustules appear to be small rectangular (Fig. 8.1).

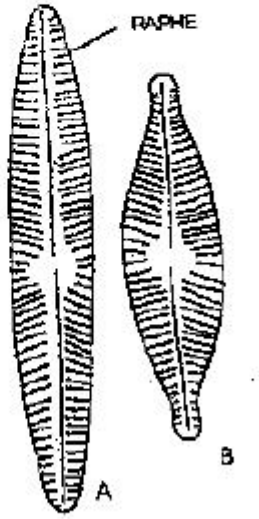


Fig. 8.1 : *Navicula* Spp.

8.4.3 Protoplast

Usually there are two large chromatophores in each frustules but in few forms there is only one or four or eight chromatophores. Generally frustules are solitary and free-floating but in some marine species they lie parallel along their axis within repeatedly branched tubes.

8.4.4 Reproduction

Sexual reproduction is initiated after cell divisions have reduced the cell to a certain critical size. Two cells then come together and invest themselves in a mucous envelope. The nucleus in each cell then undergoes two meiotic division followed by cytokinesis into two cells. Two gametes are formed in each mother cell which fuse in pairs to form two auxospores, one within each mother cell. These auxospores become greatly enlarged and ultimately new siliceous frustules of maximum size are produced within each auxospore.

8.5 Phaeophyta (Brown Algae)

NOTES

The brown algae are almost exclusively marine except few members. There are only three rare ones which are fresh water and usually grown in the streams that drain directly into the ocean. These are *Pleurocladia, Bodanella and Heribandiella*. The marines forms are found in the shallow waters along the coasts of all seas but they attain their greatest development both in number and larger size in the cold waters of oceans and seas of northern latitudes. The majority grow in shallow in the intertidal zones of rocky coastlines.

The members of this division are popularly called the red algae. They are perhaps the most slowly of all the seaweeds and are predominantly marine. Brown Algae about 1500 species of almost exclusively marine, brown coloured algae, known as seaweeds, that make up the brown algae phylum in the Protist kingdom.

8.5.1 Distinguishing Features

1. Brown algae or phaelophyta (Gk. Phaios = brown, phyton = plant) include about 2000 species.
2. Most of the brown algae are marine, except three- Pleurocladia, Heribaudiella and Bodanella, which are found in fresh water.
3. They grow in tidal and sub-tidal regions of colder seas. However, *Ectocarpales, Dictyotales* and sargassum species grow in warm waters.

   Branched filamentous heterotrichous forms of thallus is found in *Ectocarpus* and Multiaxial construction forms is present in *Myriactual pulvineta*.
4. Unixial pseudoparenchymatous forms (e.g. *Hecatonema sargassicola*) and parenchymatous form (e.g. *Laminaria, Fucus).* Besides, some forms appear like a miniature tree (e.g. *Lessonia flavicans*). The plants of *Postelsia palmaeformis* appear like palm trees, commonly called see palm.
5. The plant body of some highly advanced forms (eg. Fucales, Laminariales) is differentiated into basal more or less rook like hold fast, erect branched or unbranched, tubular or compressed stripe and leaf like blades.

NOTES

6. A large number of brown algae popularly as 'Sea weeds'. Some of them are the largest sea plants. The gaint brown algae are called kelps. The largest kelps are Nereocystis and (20-30 meters) and macrocystis (40-60 meters).
7. Most of the brown algae are lithophytes, found attached to rocks and stones by their hold fast. Few are epiphytes and endophytes. *Laminaria* is attached firmly to the rocks below by hold fast, which glues them down.
8. Some of the brown algae are free floating, e.g. species *of Sargassum (S. natans, S. fluitans). Sargassum* species grows in warm water and cover thousands of hectares in the parts of North Atlantic Ocean. This area is popularly known as Sargasso sea. Free floating sea weeds can be a big menace to shipping as they get entangled in the bottom of the ships thereby slowing down their speed.
9. Many species of brown algae possess air-bladders which keep them a float by providing buoyancy.
10. Higher forms (viz., Fucales, Laminariales) show internal differentiation of thallus usually in there zones – outermost photosynthetic meristoderm, middle cortex and central medulla. They possess food conducting tubes, similar to phloem in vascular plants, which carry organic food from the bladders the hold fast at the rate of 38-78 cm/hr. These conducting tubes are called trumpet hyphae. They possess sieve septa.
11. Phaeophycean cell wall is made up of inner layer of cellulose and outer mucilaginous layer of a mixture of polysaccharides collectively called as phycocolloids. The phycocolloids of brown algae are nonsulphated mucosaccharides-alginic acid, fucoidin and fucin. They protect thalli from drying during low tide, freezing under low temperature and mechanical injury when beaten against rocks.
12. Each cell contains more than one parietal chromotophores. They may be discoid, ribbon-shaped or plate like. Each chromatophores has three or four thylakoids per band and is surrounded by an envelope. It has single, stalked, projected naked pyrenoid.
13. The chromatophores contain chlorophyll a, chlorophyll c, β-carotenes and xanthophylls (eg. Lutein, flavoxanthin, violaxanthin). Besides, they contain

large amount of brown coloured xanthophylls fucoxanthin ($C_{40}H_{56}O_6$) which masks the green colour of chlorophylls and that is why these algae appear brown in colour.

14. The accumulation product of photosynthesis is D-mannitol (a sugar alcohol) and the reserve food material is laminarian.

NOTES

15. In most of the brown algae, the cytoplasm contains many small vacuoles and refractive bodies called fucosan vesicles. These vesicles contain fucosan (a phenolic substance), which is colourless inside the water but turns brown or black when exposed to air.
16. Vegetative reproduction takes place by fragmentation (eg. *Sargassum*), adventitious branches, stolons and specialized nests of cells called propagules.
17. Asexual reproduction takes place by the formation of motile and non-motile neutral spores, tetraspores and monospores. The zoospores are usually produced inside the zoosporangia. They are pyriform, biflagellate and have chromatophores, contractile vacuoles and eye spot. They have heterokont flagellation, i.e. possess two unequal flagella – one whiplash type ant the other tinsel shaped.
18. Sexual reproduction is isogamous (in Ectocarpales) or anisogamous (in Cutleriales) and oogamous (in Fucas, laminaria, Dictyota etc.) In the most of the brown algae, the gametes are flagellated. However, in some forms the female gamete is non-flagellated.
19. Fertilization is external, i.e., the gametes fuse outside the gametangia in water.
20. There is no zygotic meiosis in brown algae. The diploid zygote produces a diploid thallus.
21. In *Ectocarpus, Dictyota* the Alternation of generation is isomorphic and in the *Laminaria* it is heteromorphic..

Class : Phaeophyceae

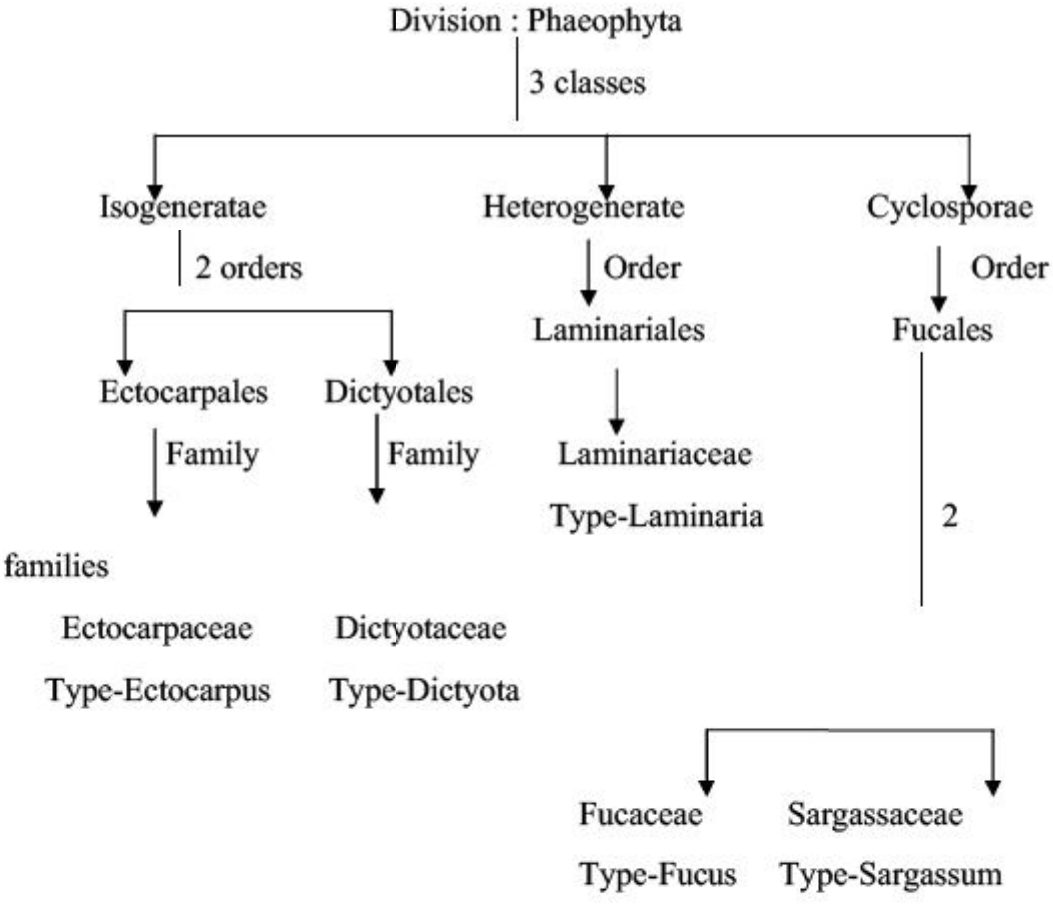
1. The members are mostly marine, brown in colour and have complicated and organized thalli.

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2. They are commonly known as 'Sea-weeds', great economic importance.
3. The cells have several chromatophores with excess of fucoxanthin along with other pigments.
4. Reserve food material is alcohol and polysaccharides.
5. Reproduction is vegetative and sexual both and the motile sex cells are biflagellate having two flagella laterally inserted and of unequal length.
6. Sexual reproduction ranges from isogamy to oogamy.

Classification

Scientific classification : Brown algae make up the phylum Phaeophyta in the kingdom Protista. Kelp are classified in the order Laminariales. Sargassum weed is classified in the genus Sargassum.



8.6 *Laminaria*

8.6.1 Classification

Class : *Phaeophyceae*

Order : *Laminariales*

Family : *Laminariaceae*

Genus : *Laminaria*



Fig. 8.2 : *Laminaria* Sporophyte

Laminaria is a *brown alga and* commonly known as *Kelp.Laminaria* is a *marine* alga and includes about 40 species.It is widely distributed in temperature and Article zones. The common species are *Laminaria flavicans*.

8.6.2 Structure.

A *diploid sporophyte plant is* consists of a *holdfast, stipe* and *blade.*It is attached with substratum by a *solid disc shaped holdfast.* It consists of *hapteron* which are root-like, branched or unbranched threads . From the holdfast *smooth, cylindrical* or *flat* stipeis are arises,which grows up to *30-40 feet.* The stipe bears a *single* or *many* leaf like structures called *blade* or *lamina.* The lamina is flat, long leaf-like and ribbon shaped. New lamina arises at the apex of the stipe. The lamina grows up to 2 meters.The margin of the blade contains fruit bodies called sori. The sori contain sporangia.*Laminaria* is ***heteromorphic.*** The sporophytes are very large and the gametophytes are ***microscopic.***

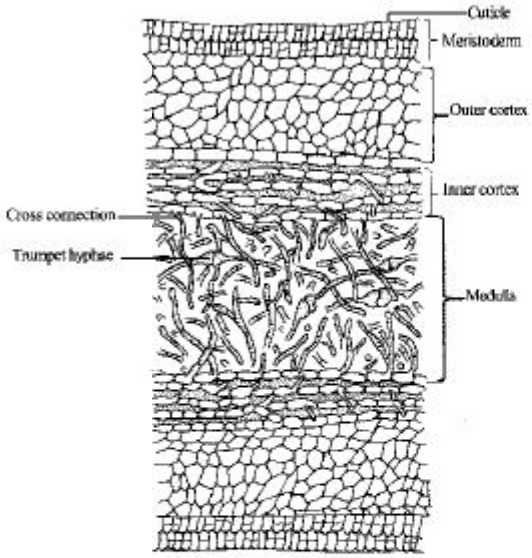


Fig. 8.3 : *Laminaria* Internal structure

8.6.3 Internal Structure of Thallus

The transverse section of the thallus shows *three regions* namely an outer *epidermis (meristoderm),* a middle *cortex* and inner *medu.*The epidermis consists of two layers of

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meristematic cells. The outer layer is formed of thickened *periclinal walls*. The thickening material forms a mucilaginous non-cellular layer called the *cuticle*. The meristematic cells are *small* and *cuboidal* in shape.

NOTES

Between the *meristoderm* and *medulla* , cortex is present,which is consists of *large cells*. The cortex consist of an outer **cortex *(elongated broad cells)* and inner cortex(*elongated cells).*** The elongated cells contain thread like outgrowths or ***cross connection*** and ***hyphae.*** The inner cortex contains ***mucilage canals*** filled with ***mucilage***.The inner layer is medulla and consists of loosely arranged cells, ***cross connections, hyphae*** and ***trumpet hyphae.***The cell consists of a ***cell wall, plasma membrane,*** **a *nucleus*** and ***chromatophores.*** The ***fucosan*** is the stored ***reserve food.***

8.6.4 Reproduction

Three methods of reproduction are found in *Laminaria*.

(1) *Vegetative reproduction (2) Asexual reproduction (3) Sexual reproduction*

Vegetative Reproduction

The vegetative reproduction takes place by means of ***stolans***The stolans arise from the holdfast region. and grow horizontally and turn up to grow into new ***plantlets.***

Asexual Reproduction

The asexual reproduction is carried out by the *diploid sporophyte.* The blade of the sporophyte contains fruit bodies called *sori* on both sides.

Dark *brown* and irregularly arranged sori are present,which are produced on mature plants.The sorus contains *club-shaped*, *unilocular*. *sporangia* and *paraphyses*. The sporangia intermingle with paraphyses.The paraphyses are *sterile protective hairs.* The sporangia contain haploid *spores.*

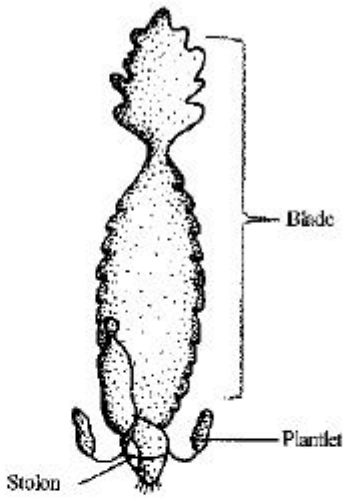


Fig. 8.4 : L*aminaria* Plant with

Development of Sporangia

The sporangia develop from the *meristoderm* cells of the blade. Some meristoderm cells of the blade *elongate* and *palisade* – like.Due to the

enlargement of these cells the *cuticle* is lifted up in that region.Each enlarged cell divides transversely into an *upper paraphysis* initial and a lower *basal cell*.The upper paraphysis initial develops into a *paraphysis.*The lower basal cell develops into a *sporangium.*

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Development of Meiozoospores

The protoplast of the sporangium undergoes *meiosis* and *mitosis* to form 32 daughter protoplasts, *zoospores are developed by protoplasts*. As the zoospores are formed after *meiosis*, they are called *meiozoospores*. One *nucleus*, a *chloroplast* and a pair of *flagella are present in each* zoospore.The flagella are unequal in length. The long flagellum is *tinsel* type and the other flagellum is *short* and it is *whiplash* type.Whan wall of the sporangium dehisces. The meiozoospores are released.From the 32 meiozoospores, 16 develop into *male gametophyte* and 16 develop into *female gametophyte.* The meiozoospores settle down with the flagellated end directing downwards.It withdraws its flagella and divides into a ***multicellular*** and ***smallgametophyte***. The gametophyte is ***microscopic***. The female gametophyte is smaller than the male gametophyte.

Sexual Reproduction

The sexual reproduction is *oogamous type* and *haploid gametophytes which is heterothallic* reproduce sexually.The male sex organ is called *antheridium*and and female sex organ is called *oogonium.*Antheridium is unicellular *which contains colourless.* antheridiaThe antheridium contains a single *nucleus* and two reduced *chromatophores.*Each antheridium produces a *single, biflagellate antherozoid.*

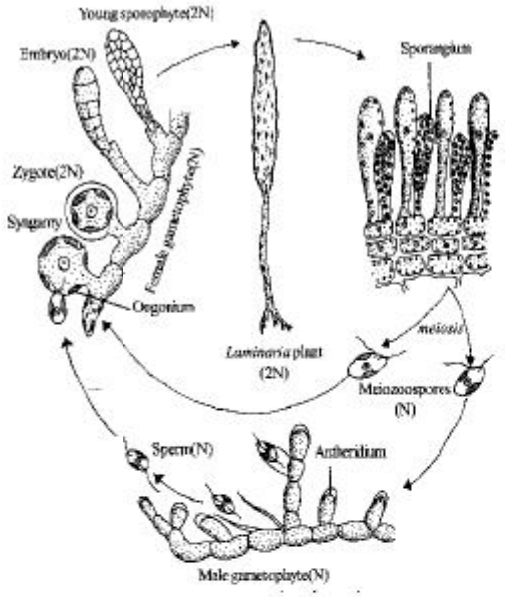


Fig. 8.5 : *Laminaria* – Sexual Reproduction

Oogonium

The female gametophyte produces oogonium.Any cell of the female gametophyte develops into oogomium. *Tubular* or *pyriform* oogonium produces a single *egg.* The mature egg is liberated by the rupture of *oogonial wall.*The egg remains attached with the oogonium by a *gelatinous cushion.*

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Fertilization

Antherozoids swim in the water and reach the egg. The fertilization takes place in the water. A *diploid zygote is formed by fusion of male and female gametes.*

Germination of Zygote

The zygote undergoes ***mitosis*** to produce a ***diploid sporophyte***. The young sporophyte remains attached to the tip of oogonium.The sporophyte develops rhizoids from the base. When the rhizoids develop the female gametophyte dies.After the death of the female gametophyte, the sporophyte develops into an independent plant.Laminaria is a diploid sporophyte (2N).

8.7 Rhodophyta (Red Algae)

Red algae are the members of the phylum Rhodophyta, a large group of aquatic algae with approximately 6000 species. The red algae are characterized by reddish phycobilin pigments – phycoerythrin – that mask the color of the chlorophylls. Most species grow near tropical and subtropical shores below the low-tide mark. A few are found in fresh water.

Most red algae are small to medium-sized multicellular organisms. The bodies of some are relatively complex, resembling those of kelp. Sexual structures and reproductive cells are highly specialized. Red algae vary greatly in shape; plate like, corraline, crustlike, leathery, and featherlike forms are known. Coralline species accumulate lime as they grow – appearing as flat pink coverings on stones, or fanlike growths resembling true coral – and contribute much of the lime in coral reef deposits. Fossil of red algae have been found in rocks 500 million years old.

8.7.1 Distinguishing Features.

1. Red algae or Rhodophyta (Gk. Rhodo = red; phyton = plants) include about 5,000 species growing mainly in marine habitats up to depth of 30-90

meters. Only a few genera inhabit fresh waters (e.g. Batrachospermum, Compsopogan, etc.). Unicellular Porphyridium grows in terrestrial habitats.

2. They generally grow attached to rocky stones (lithophytes). Some deep water red algae are calcareous (i.e. have incrustation of calcium carbonate) and build up hard stony thalli responsible for the production of lime stones and coral reefs (e.g. Corallina, Lithothamnion). Some grow as parasites or semiparasites on larger algae.

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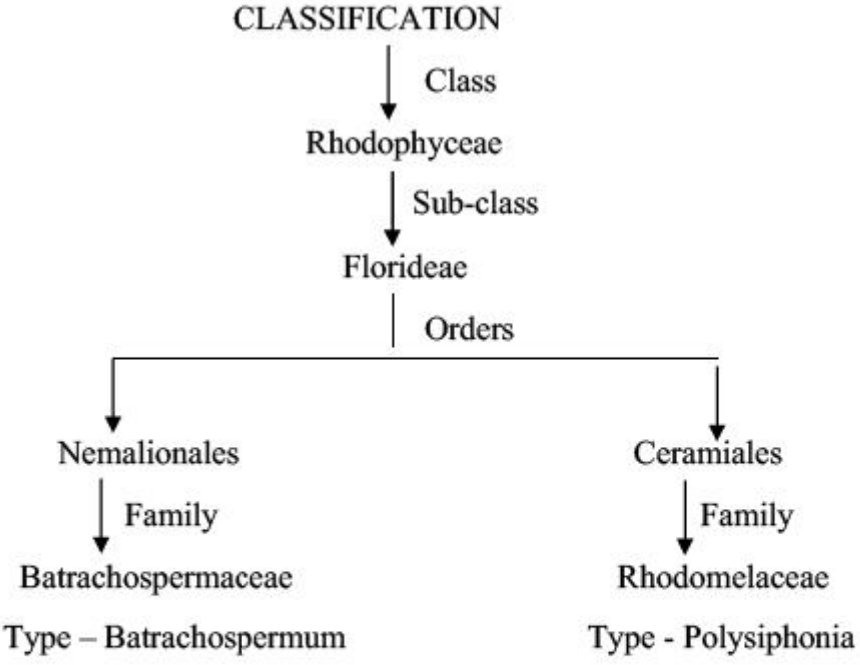
3. The organization of the thallus varies from microscopic unicellular (e.g. Porphyridium), Palemelloid (e.g. Asterocystis) unisexual filamentous branched forms (e.g. Grimelia), multiaxial filamentous branched forms e.g., Polysiphonia) to multicelluar psendoparenchymatous thallus (e.g. , Gellidium). Some large thalli reach up to a half meter in length.
4. The cells are eukaryotic i.e. possess true nuclei.
5. The cell wall is made up of cellulose, pectic compounds and certain mucopolysaccharides called phycocollooids. The important phycocolloids are agar, carrageenin and funori.
6. Internally the cytoplasm bears coloured plastids, called, chromatophores. They are double membrane bound structures, which comprise of a large number of photosynthetic lamellae, called thylakoids. The thylakoids are not stacked.
7. The photosynthetic pigments located in the chromatophores are – Chlorophyll a, Chlorophyll d, β-carotenes, xanthophylls and biloproeins, the biloproteins (or phycobilins) are water soluble pigments located in phycobilisomes associated with chromatophores. There are two types of biloproteins r-phycoerythrin (red in colour) and r-phycocynin (blue in colour).
8. Presence of excess amount of r-phycoerythrin (red in colour),gives the characteristic red colour to the algae which masks the colour of other pigments. Phycoerythrin absorbs the blue green part of the sunlight's spectrum. The blue green light short wave length and penetrated deep into the water. It is because of this reason the real algae reach the maximum depth in sea no other photosynthetic forms grows.
9. Due to the formation of more phycoerytherin than chlorophyll the red algae appear more red in deep water. However, they appear green violet or purple

when grow in shallow water due to presence of more chlorophyll as compared to phycoerythrin.

10. The reserve food material is in the form of floridean starch. It is very much similar to glycogen.

NOTES

11. The red algae constitute an ancient group with no flagellated or motile cells formed at any stage in their life cycle.
12. Vegetative reproduction occurs by fragmentation.
13. Asexual reproduction occurs by the production of different types of non motile spores-monospores, neutral spopres, carpospores, tetraspores, etc.
14. Oogamy is advanced type of sexual reproduction In which male sex organs are antheridia (spematangia) and female sex organs are carpogonia. Non motile male gametes are produce in antheridia and called spermatia. The carpogonium (the female sex organ) is a flask shaped structure differentiated into swollen base containing egg nucleus and an elongated trichogyne. The spermatia are carried to female sex organs by water current.
15. Post-fertilization changes result in the formation of a new structure, called carposporophyte.
16. Life cycle of many red algae exhibit an alternation of generations of gametophyte (habloid) and sporophytic (diploid) generations.



8.8 *Gelidium*

8.8.1 Classification

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Division	:	Rhodophyta
Class	:	Rhodophyceae
Sub-class	:	Florideae
Order	:	Gelidiales
Family	:	Geldiaceae
Genus	:	*Gelidium*

It is widely distributed small ; 1 *Gelidium is a* small and widely distributed seaweed growing attached to rocks in the littoral zone. *G. corneum* grown on rocks in pools in the upper littoral belt in the Indian Coast.

8.8.2 Structure

It forms an entangled mat of branched anastomosing polymorphic axes, which are sometimes quite leathery. From the dorsiventral, creeping stolon, clustes of erect fronds tend to arise on the upper side (Fig. 8.6 A) and peg-like hold fasts on the lower side.

The axes are pheudoparenclsymatous and uniaxial (Fig. 8.6 B). The apical cells is lenticular. Internal hypae are commonly present in many species and appear to serve some mechanical supporting function.

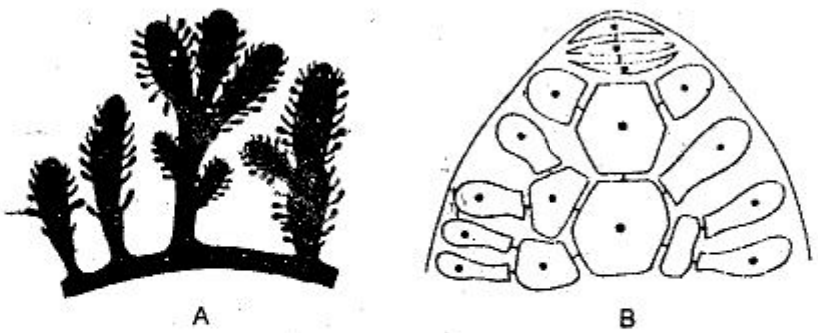


Fig. 8.6 : *Gelidium pulchellum*. A. art of thallus B. Section of apical region

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8.8.3 Reproduction

Vegetative Reproduction : Vegetative propogation occurs from detached parts of fronds or stolons.

Sexual Reproduction : The spermatangia (Fig. 8.7 A) and carpogonia (Fig. 8.7 B) are formed in the cortical cells of upright fronds. The cystocarps occur near the terminal portions of the thalli or in specialized club-shaped, lateral branches of limited growth. The cystocarp-bearing branches of *G.corneum* are swollen.

Cruciately dividing tetrasporangia (Fig. 8.7C) are located terminally in unmodified vegetative blades or in cleavate structures borne marginally on these blades.

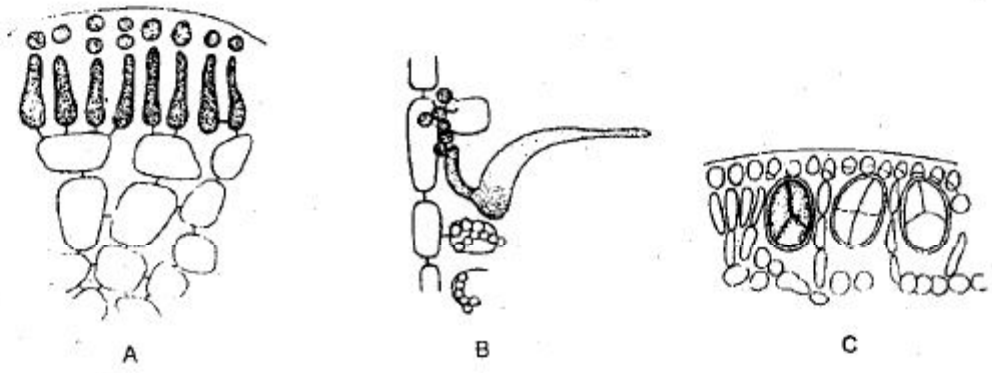


Fig. 8.7 : *Gelidium* spp. A. Spermatangia B. Carpogonium and its fusion with nurse cells C. Formation of tetrasporangium

In *G.robustum*, both tetrasporangial and carposporangial plants exhibit rhythmic activity in spore discharge. The carposporangial plants release more spores than the tetrasporangial plants, and they also remain active over a longer duration of time as compared to the tetrasporangial plants.

8.9 Summary

The Bacilliariophyta are called diatoms. They are unicellular or colonial the cell walls are silicified, composed of two halvs that fit together like the halves of a petridish or pill box box they are golden brown with reserved food oil and leucocin. Reproduction by cell division and auxospores. Its of great economic importance as it accumulates large deposits of domain walls known as diatomaceous earth (Kieselghr)

Due to their well-developed thallus constructuion, Phaeophyceae occupy a disting 'status' method of reproduction but the presence of multicellular reproductive organs and developed anatomical features do not justify such conclusion. The nature of swarmer suggests that the Phaeophyceae possible evolved from some unicellular flagellate organisms. Since the brown algae lack jacket layer around reproductive organs, xylem for conduction, a cuticle for protection against evaporation and mode of reproduction is simple. The Phaeophyceae did not receive any higher position.

NOTES

The red algae are probably one of the oldest groups of eukaryotie algae as evidenced by their characters. One of the striking features of most of the red algae is the presence of a pore like opening (pit-connection) in the cell wall through which cytoplasmic connection is maintained from cell to cell.

The members of the division Rhodophyta can be distinguished from other eukaryotic algae .

8.10 Glossary

- **Alternation of generations** : The occurrence in one life history of two or more different forms differently produced, usually as alternation of a sexual with an sexual form.
- **Anatomy:** The science which treats of the internal structure of plants.
- **Antheridia: Plural of antheridium.**
- **Antheridium:** Male gametangium in which male sexual cells are produced in many cryptogams.
- **Antherozoids:** Male sexual cells in antheridia
- **Archegonium:** A female gametophyte in which oosopheres are formed, and in which the young plant begins development.
- **Dehiscene:** The spontaneous opening of an organ releasing spores etc.
- Diatomology: The science of diatoms has developed dealing with the various aspects of the huge number of diatom species and their unique structure
- **Fertilization:** The union of male and female nuclei.
- **Gametophyte:** The gamete forming phase in alternation of plant generations : sexual generation of plants

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- **Oosphere:** An Egg before fertilization.
- **Oospore:** The zygote or fertilized egg cell.
- **Sori:** Plural of sorus.
- **Sporangia:** Plural of sporangium.
- **Sporogenesis:** Spore formation.
- **Thallus:** A combination of cells presenting no differentiation of leaf and stem.
- **Zygote:** Cell formation by union of two gametes or reproductive cells.

8.11 Self-Learning Exercise

Section-A (Long Answer Type Questions)

1 Write in detail the general characters of Bacilleriophyta ?
2 Describe the mode of reproduction in Diatoms ?
3 Write about *Navicula* ? .
4 Describe the mode of reproduction in *Laminaria*.
4 Describe the structure of *Laminaria* thallus and its stipe anatomy.
5 Write about *Gelidium*
6 Explain the division Bacillariophyta on the basis of the following points : (1) General characters (2) Cell structure (3) Reproduction
7 Explain the classification of Phaeophyta
8 Write short note on Germination of Zygote of *Laminaria.*

Section -B (Short Answer Type Questions)

1. Write the five diagnostic features of Rhodophyta .
2 Explain the Cell structure of *Navicula*
3 Explain the classification of *Gelidium*

Section-C (Very Short Answer Type Questions)

1 Which algae is commonly known as '***Kelp***'.
2 Write two example of Pheophyata

Fill in the blanks :

3 Bacillariophyta are popularly called _____.
4 _____ algae, known as seaweeds.

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Unit - 9

Fungi : An Introduction

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Structure of the Unit

9.0 Objectives

9.1 Introduction

9.2 General Characters of Fungi

9.3 Substrate relationship in Fungi

9.4 Ultrastructure of Fungal cell

9.5 Thallus Organization in Fungi

9.6 Cell wall Composition

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9.0 Objectives

After going through this unit you will be able to understand:

- General characters of fungi
- Substrate relationship in fungi
- Detaibled structure of fungal cell
- Thallus organization types found in fungi
- The characteristic features of fungal cell wall
- Different types of nutrition in fungi

9.1 Introduction

Fungi (L.*fungus,* mushroom) are achlorophyllous, heterotrophic (saprophytic, parasitic, symbiotic or hyperparasitic), eukaryotic and spore-bearing organisms

surrounded by *a* well defined cell wall made up of chitin, with or without fungal cellulose, along with many other complex organic molecules. Fungi usually obtain food by absorption, except a few lower groups where they take in food by ingestion.

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FUNGI is the plural of the word FUNGUS which is derived from the Latin word FUNGOUR which means to flourish. The word was primarily used with reference to mushrooms which develop overnight. In usage the meaning of the word has been expanded to include thallus like achlorophyllous plants such as the `Molds and other similar organisms related to mushrooms. The fungi, thus are a large group of simple thallus like plants which lack chlorophyll. The older botanists employed the term in a wider sense to include bacteria, slimemolds as well as true fungi. About 5100 genera and more than 50,000 species of fungi are known today. Familiar examples of the fungi are the yeasts, molds` toad stools mushrooms,Polypores, Puffballs, Rusts and Smuts.

The branch of botany that deals with fungi is called Mycology (Gr. *mykes* means mushroom and *logos* means study of). Mycology is the study of mushrooms. It deals with life histories, realationships and evolutionary tendencies of fungi. The scientist who is concerned with fungi is called a mycologist. He studies structure, reproduction, physiology and taxonomy of fungi.

In common language the fungi may be defined as nongreen nucleated thallophytes. According to Alexopoulos (1962) the fungi include nucleated spore bearing achlorophyllous organisms that generally reproduce sexually and whose filamentous branched somatic structures are typically surrounded by cell walls containing cellulose or chitin or both. A more technical defination of fungi was later given by Bessey (1968) which says that fungi are chlorophyll-less non-vascular plants whose reproductive or vegetative structures do not permit them to be assigned to positions among recognised groups of higher plants or algae.

According to Alexopoulos and Mims (1979), the Italian botanist Pier' Antonio Micheli (1729) deserves the honour of being called the `Founder of Mycology' because of his researches on fungi which he published in *Nova Plantarum Genera.* Elias Fries (1794-1874), for his deep mycological understanding in earlier times, has been named the 'Linnaeus of Mycology' by Professor Eriksson Gunnar (1978) of Sweden.

9.2 General Charactestics of Fungi

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The general characteristics of fungi are summarised as follows :

Habitat : Ubiquitous i.e found everywhere as saprophytes, parasites or hyper parasites or symbionts.

Thallus : On or in the substratum and plasmodial, amoeboid, unicellular or multicellular, filamentous, if filamentous septate or aseptate.

Cell wall : Well defined; made up of chitin or of cellulose.

Nuclear status : Eukaryotic; Uninucleate, binucleate or multinucleate; homo- or heterokaryotic in nature.

Nutrition: Heterotrophic

Reproduction : vegetative,asexual, sexual/or parasexual through spores.

Distribution : Cosmopolitan. The fungi grow in diverse habitats. They are found in almost every available habitat on earth where organic material (living or dead) is present. They are universal in their distribution. Many of them are terrestrial. They occur in soil which abounds in dead, decaying organic materials. The terrestrial fungi are considered more advanced. They produce non-motile reproductive cells which are dispersed by wind, water or animals. Some fungi attack living organisms. They live in tissues of plants and animals. Some fungi are aquatic and are considered primitive. They live on decaying organic matter and living organisms found in fresh water and produce flagellate (motile) reproductive cells which swim to new localities. Many fungi grow on our foodstuffs such as bread, jams, pickles, fruits and vegetables. Some fungi are found in drinking water. Thus, the fungi contaminate both our food and drinking water. They are present all the time in air that we breathe. Majority prefer to grow in darkness and dim light in moist habitats.

9.3 Substrate Relationship in Fungi

It is the process of procuring nourishment or nutrient and is the principal function of the vegetative phase (mycelium). The supply of nutrients is essential for every living organism because the nutrients serve as structural units and also as energy sources for the building up of protoplasm which is the basis of life.*Nutritional requirements.* The fungi utilise both organic compounds and inorganic materials as the source of their nutrient supply. In other words, organic and inorganic compounds constitute their food. No fungus is able to

make any increase in its dry weight in the absence of organic food materials, because of lacking chlorophyll, the fungi are unable to photosynthesize or use carbon dioxide to build up organic food materials. They are, thus heterotrophic for carbon (organic) food compounds which they in their natural habitats obtain by living as saprophytes or parasites from dead or living plants, animals or micro-organisms or their wastes.

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Essential Elements. The constituent elements of the organic and inorganic substances which fungi make use are C, **O,** H, N, P, K, Mg, S, P, Mn, Cu, Mo, Fe and Zn required by some fungi but not all. These elements which fungi require as food are termed as essential elements. Some of these elements, fungi needs in extremely small trace amounts and the others in comparatively larger amounts. The former are called the **trace** or micro elements and the latter macro elements. The fungal growth is adversely affected or the fungus fails to grow if any one of the essential elements is lacking in the culture medium. Examples of the macro elements are C. N, **O,** H, S, P, K and Mg. The macro elements are body builders and provide energy for metabolic processes.

Sources of Macroelements. The organic substances ususally utilized by fungi are very varied in nature. Yeasts, for example, can use acetates as sources of carbon but for most fungi the chief sources of cabon are the carbohydrates. The carbohydrates are needed for building up body and also as a source of energy. In a typical fungus, 50% of the dry weight is carbon. Of the carbohydrate source of carbon most fungi use simple sugars. Glucose, for instance, is suitable for almost all fungi. Next in preference are the fructose. Less commonly used are the hexose sugars and some pentoses. Xylose among the pentoses has been reported to be superior to glucose for some fungi. Mannitol is equivalent to glucose for many fungi. Maltose which occurs in nature as a byproduct of starch hydrolysis is utilized by many fungi. Sucrose is also a good source of carbon for some. From among the polysaccharides, starch and cellulose are utilised by a fewer fungi which can synthesize the appropriate hydrolytic enzymes. Some fungi are able to make good growth on fats as the only source of carbon. Organic acids are generally poorer sources of carbon for most fungi. Basidiomycetes include most of the lignin utilizing fungi

Proteins, lipids, some organic acids and higher alcohols are utilised by some

fungi as a sole energy source. Growth, however, is always better on a substance containing a suitable carbohydrate.

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Besides carbon fungi require nitrogen. To obtain nitrogen they utilise both organic and inorganic materials as the source. The chief organic sources of nitrogen are protein, peptide or an amino acid. Certain groups of fungi show specializations in respect of certain nitrogen sources. For example, the Saprolegniaceae and Blastocladiales include a number of species which grow only with organic nitrogen such as amino acid. In nature, fungi decompose proteins and other materials to obtain their supply of nitrogen. In pure cultures amino acids, peptides, or peptones, gelatin, casein and egg albumin can serve as sources of organic nitrogen for building up protoplasm. Urea is also considered as a utilisable nitrogen source for some fungi.

Many fungi, however, obtain nitrogen from inorganic sources.A number of fungi are known which use both nitrate and ammonium. Lindberg (1944) reported that *Mucor hiemalis,* and *Marasmius sps.* use ammonia but are incapable of utilizing nitrate salts. Fewer fungi are able to utilize nitrate salts. Nitrites can be toxic. Organic sources of nitrogen can also serve as sources of carbon. Metcalfe and Chayen (1954) reported that soil inhabiting *Rhodotortula* and yeast-like *Pullularia pullans* fix atmospheric nitrogen. However, nitrogen fixation is not widespread ability in fungi.

Hydrogen and oxygen are supplied in the form of water which is the major constituent of fungus mycelium forming about 85-90% of the entire weight.

The chief among the inorganic nutrients which the fungi require in fairly large amounts for their mineral nutrition are **sulphur, phosphorus, potassium** and magnesium. These **macronutrients** the_fungi obtain from simple inorganic salts or sources such as sulphates for sulphar and phosphates for phosphorus. These must be supplied in any culture medium. **Some** fungi are reported to require only minute traces of Iron, Zinc, copper, manganese, boron cobalt and molybdenum. These trace elements or micronutrients are considered essential for growth. The form in which the major and the minor metallic element requirements are utilised is the Anion.Fungi store excess food in the form of glycogen or lipids.

The fungi, require minute amounts of specific, relatively complex organic compounds for growth. These are the **vitamins** or **growth factors.** Many fungi synthesize their own supply of appropriate growth factors from a simple

nutrient solution of defined composition. Such fungi are thus autotrophic for vitamins and are called **auxo-autotrophic.** They need no exogenous supply. There are other fungal members which depend in whole or in part on an external source, because they are unable to synthesize one or more of the essential growth substances. The fungi heterotophic for their needs of growth factors are termed auxotrophic. There are marked difference between the vitamin demands of the different species of a genus or even the strains of a single species. The important fungal vitamins, which may function in enzyme systems include ,thiamine (B_1), biotin, pyredoxine (B_6) and riboflavin (B_{12}). A few fungi also need nicotinic acid and pantothenic acid.In majority fungi require thiamine (B_1) The growth factors are

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Catalytic in their actions. Thus basic nutritional needs of fungi are:suitable organic compound as a source of carbon and energy, suitable source of nitrogen,Inorganic ions of sulphur, phosphorus, potassium and magnesium in significant amount, inorganic ions of iron, zinc, copper, manganese and molybdenum only in minute trace and certain vitamins or organic growth factors in trace amounts.

Besides nutritional requirements listed above the growth of fungi is influenced by certain habitat factors such as temperature, oxygen supply, moisture, pH value and by-products of metabolism.

9.4 Ultrastructure of Fungal Cell

The vegetative fungal cell has almost the same general ultrastructure as that of other eukaryotes. These details are given below:

1. The cell remains surrounded by a *cell wall* made up of elongated micro-fibrillar units, which consist of chitin or fungal cellulose. Chitin, a cell-wall constituent of most fungi, was said to be absent in Oomycetes. But findings of Lin and Aronson (1970) and Lin et *al.* (1976) indicate its presence even in Oomycetes. According to Bracker et al. (1976) the chitin microfibrils are formed by the enzyme chitin synthetase.
2. The cell wall is followed by plasmalemma. It regulates the movement of soluble substances into and out a hypha. *Plasmalemma* is a delicate, extremely thin membrane which closely invests the protoplast. The plasma membrane is pressed against the cell or hyphal wall except for occasional invaginations in some regions. It is differentially permeable

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and shows a typical tripartite structure under the electron microscope. There is an electron dense layer on either side of the less dense central region.

3. In between the plasmalemma and cell wall, or at the surface of the plasmalemma, some membranous structures have been reported in some fungi. They have been named *lomasomes* and *Plasmalemmasomes.* According to Heath and Greenwood (1970) a lomasome is the `membranous vesicular material embedded in the wall external to the line of the plasmalemma. whereas a plasmalemmasome represents the 'various membranous configurations which are external to the plasmalemma, often in a pocket projecting into the cytoplasm, and less obviously embedded in the wall material.

4. *Cytoplasm:* Within the plasma membrane is the colourless cytoplasm in which sap-filled vacuoles may occur. In young hyphae and hyphal tips, the cytoplasm appears rather uniform and homogeneous. Immersed in the cytoplasm are structures known as the organelles and inclusions. The organelles are living structures, each with a specific function. The inclusions are dead, have no specific function and thus are not essential to cell survival. Amongst the cell organelles are included the endoplasmic reticulum, mitochondria, ribosomes, golgi apparatus and vacuoles.

5. The cells contain either many smaller *vacuoles* or a single large vacuole, each of which remains surrounded by a vacuolar membrane or *tonoplast. (v) Inclusions.* The cytoplasm contains various kinds of inclusions. Examples of stored foods are lipid globules, granules of glycogen, oils and the carbohydrate trehalose, proteinaceous material and volutin. The glycogen, may occur in vacuoles. There are no starch grains. The cytoplasm, in addition, secretes several kinds of ferments, enzymes and organic acids. Plastids or strach grains are absent.

6. *Mitochondria* and many food particles made up of glycogen and lipids are also present. Structurally the fungal mitochondria resemble those of green plants. The cytoplasm contains small, usually spherical bodies known as the mitochondria. Each mitochondrion is enveloped by a double membrane. The inner membrane is infolded to form the cristae which are in the form of parallel flat plates or irregular tubules. The cristae contain

the same fluid that fills the space between the two membranes. The mitochondria function as the power house of the cell. There is no fundamental difference between the mitochondria of fungi and those of green plants.

7. Other cell organelles and inclusions include ribosomes, vesicles, micro-tubules, microbodies and crystals. Golgi bodies are not reported in all fungal cells. Ribosomes are numerous, minute, almost of uniform size and distributed throughout the cytoplasm and also on endoplasmic reticulum. *Golgi Apparatus (Dictyosomes).* With the exception of oomycetes there is less certainty of the occurrence of structures similar to those of the golgi apparatus. Moore and Muhlethaler (1963) reported a golgi apparatus consisting of three flattened sacs surrounded by many bubble-like structures in *Saccharomyces* cells.

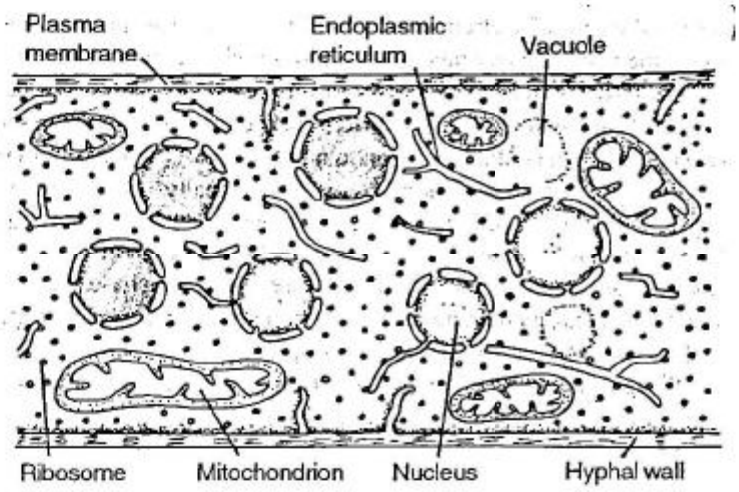


Fig. 9.1 : Fungal Cell

8. All fungi lack chlorophyll. However, some other pigments have been reported to be distributed either in the cell wall, or irregularly in the cytoplasm, or just near the oil grobules. Matsueda *et al.* (1978) isolated a novel fungal pigment, neocercosporin (C_{29} $H_{26}O_{10}$ m.p.237' C) from *Cercosporina kikuchii. It is* a reddish violet pigment.

9. The cells are uninucleate or multinucleate, and the *nuclei* are either globose or ellipsoid. The nuclear membrane is porous and consists of an outer and an inner layer of electron-dense material and a middle layer of electron-transparent substance. The cytoplasm in the individual cells contains one, two or more globose or ellipsoid nuclei which in the

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somatic portion are small and usually range from 1-2 or 3μ in diameter. They cannot be seen without special techniques. Structurally the nucleus consists of: (i) a central, dense body with a clear area around it. (ii) Chromatin strands, and (iii) the whole structure surrounded by a definite nuclear membrane. The central body takes heavy iron haematoxylin stain and is usually Feulgen-negative. In electron micrographs it appears as an amorphous or granular mass. Mycologists usually designate it as the nucleolus.it contains RNA. During nuclear division the chromatin strands become organised into chromosomes which are extremely small and difficult to count. Under the electron microscope the nuclear membrane is seen to consist of inner and outer layers of electron dense material and the middle one of eletron transparent substance. The nuclear membrane has pores. At certain points the nuclear membrane is continuous with the endoplasmic reticulum.

Somatic Nuclear Division. The older mycologists believed that the somatic nuclear division in most fungi (except yeasts) differs markedly from normal mitosis. Moore (1964) termed it Karyochorisis in contradistinction to normal mitosis or karyokinesis . Lu (1974), however, stated that in fungi mitosis occurs more or less normally and the fungal nucleus passes through the stages characteristic of mitosis namely, interphase, prophase, metaphase, anaphase and telophase. The cell division is closed and thus termed intranuclear,It means the nuclear membrane remains more or less intact and does not disorganize during prophase. Centrioles appear in close association with the nuclear membrane. They appear in a pair and each migrates to the opposite poles of the nucleus to control the formation of the spindle.

10. The unit membrane of all the membrane bound structures (like mitochondria, nucleus etc.) consists of phospholipids along with proteins. The membranes are of uniform thickness, of about 0.02μ.

9.5 Thallus Organization in Fungi

1. Thallus. The vegetative phase of a fungus is a thallus. It may be unicellular or filamentous.

a) Unicellular Thallus : In some of the lower fungi such as the Chytrids, the thallus is more or less a spherical, single-celled structure .At

the time of reproduction it becomes a reproductive unit. The latter produces the asexual or sexual cells. Such fungi are called holocarpic.

b) Filamentous Thallus: The vast majority of the fungi have a filamentous thallus. It originates through the germination of a spore. The spore on germination produces short tubular structure of limited growth . it constitutes the thallus and technically called a hyphae. these fluffy thallus consisting of a cottany mass of fine branched filaments are called hyphae . These hyphae at certain stage of maturity extend into air and produce reproductive units and the rest thallus spread over the substratum and continue normal activities,such fungi are called Eucarpic. The hyphae comprise the vegetative body of the thallus of a fungus which is called the mycelium. Mycelium is afood procuring structure and carry out the general activities of the plant cell like digestion respiration and Excretion.The medium upon which the mycelium grows is known as substratum. The aerial hyphae in some fungi become coloured. Black orange, yellow, red, blue and brownetc. The colour is usually confined to the hyphal wall. The pigments play no role in the physiology of the fungus. The growth in length takes place at the tips of the phyhae and is thus termed apical.

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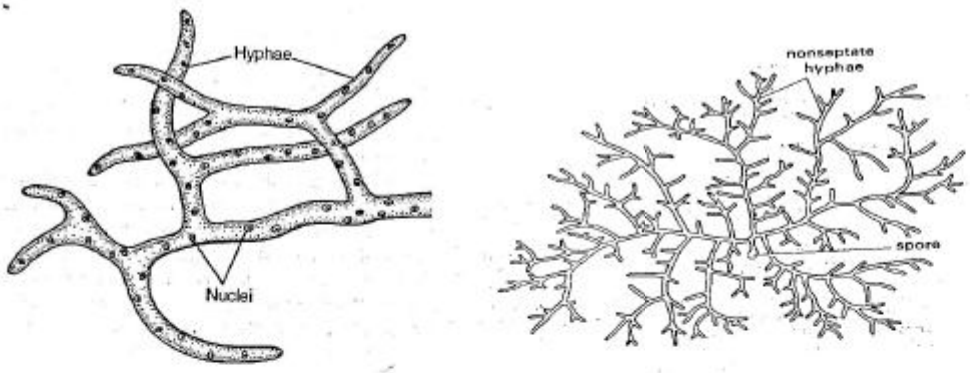


Fig 9.2 : Fungi Vegetative structure showing aseptate hyphae and mycelium

2. Kinds of Mycelia. The fungus mycelium is a multinucleate structure lacking complete internal cell boundaries.

I) Aseptate Mycelium: In the algal fungi phycomycetes the mycelium in the vegetative phase usually lacks internal partitions of any kind The hyphae are thus multinucleate and aseptate. The mycelium is a continuous mass. It grows terminally by the apical elongation of the

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hyphae accompained by increase in the number of nuclei by nuclear divisions: The aseptate, multinucleate mycelium is called coenocytic The septa in the aseptate, coenocytic mycelium, are formed only to cut off reproductive structures, or to seal off a damaged portion. Such septa are solid plates. They lack pores.

II) Septate Mycelium: The members of other classes of fungi (Ascomycetes and Basidiomycetes) develop internal cross walls called the septa which divide the hyphae into segments. The septa appear at regular intervals behind the hyphal tip. The segments may be uninucleate or multinucleate. In a septate mycelium the septa between the cells are transverse longitudinal or oblique septa are rare.The formation of septum is always preceded by the division of nucleus. If the cell has more than one nuclei there is simultaneous division of all the nuclei before wall formation. The septa in the septate mycelium of fungi are incomplete. Each has a central pore and rarely more than one pore. Through these the cytoplasm and other organelles even nuclei can regularly pass from one cell to another.

The septa in all the fungi (septate Phycomycetes, Ascomycetes, Basidiomycetes and Imperfect Fungi) have a similar origin. They arise at regular intervals behind the hyphal tip. The septum originates at the periphery on the inside of tubular hyphal wall as a ring (annular) or rim of wall material. The annular growth grows slowly inwards towards the centre (centripetally) like an iris diaphragm increasing in width and decreasing the diameter of pore. A cross wall or septum is finally formed which is seldom complete. The centripetal growth of the setum in fungi is rapid.

Septal pore is a small hole or a pore remains in the centre of the septum. The perforated septum gives rigidity to the tubular hypha maintaining, at the same time, the protoplasmic continuity from cell to cell. In basidiomycetes septum produces more complex pore called dolipore (meaning a large jar).The rim of the central pore is swollen thickened and form a barrel shaped structure with open endswhich are guardedby cap like covers known as Parenthosome. Dolopore septum is the characteristic feature of class basidiomycetes.

3. Infection structures

Infection structures are specialised structures formed in parasitic fungi at the tips of germ tubes or hyphae on the outside of the host. The simplest pre-penetration structure are terminal swelling on germ tubes called appressoria(sing. Appressorium, L. Apprimere = to press against) and if they are found on short lateral branches of hyphae they are known as hyphopodia (sing. Hyphopodium, Gr. Hyphe = web, pous = foot). These pre penetration structures serve to anchor the fungus to the host surface, usually by secreation of mucilaginous matrix. It may secrete enzymes like cutinase , which help in the passage of penetration peg through the host cell wall coupled with mechanical forces. Then the apex swells to form an appressorium. A septum separates the appressorium from the germ tube. After about 2 hours of its contact with the stoma a penetration peg grows into the substomatal cavity, producing a substomatal vesicle and an infection hyphaa develops from this to produce a haustorium mother cell on the parenchyma of the leaf. Formation of haustorium a specialised nutrient absorbing structure completes the infection process.

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4. Translocating structures

All mycelia fungi translocate nutrients in their hyphae, but some fungi produce complex and characteristics multicellular structures for transport of nutrient across nutrient free environments. Two types of structures can be identified depending on their mode of development namely mycelia strands or mycelia cords and rhizomorphs.

(A) Mycelial strands and Mycelial Cords

Mycelia strands are aggregates of parallel, relatively undifferentiated hyphae commonly seen in Basidomycota and in some Ascomyota. The familiar spawn of the cultivated mushroom is an example.

In *Phallus impudicus* (stinkhorn) the mycelia strands are more tightly aggregated and are known as mycelial cords. Besides water mycelia cords have been shown to translocate carbohydrate and organic nitrogen over considerable distances between sources and sinks of these materials.

(B) Rhizomorphs (Gr. Rhiza = root, morphe = shape)

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Rhizomorphs are highly differentiated aggregations of hyphae and are found in relatively few species, in contrast to mycelia strands or cords, which are produced by more number of fungi and less complex. In these structures, hyphae lose their individually and form complex tissues that exhibit a division of labour. The well known examples of rhizomorphs are of *Armillaria* spp., which are serious parasities of trees and shrubs.

5. Surviving structures

The hyphae of many different species do routinely become organised to form larger structures that are easily visible to the naked eye. They are as follows:

A. Sclerotia (sing. Sclerotium, Gr. Skleros = hard)

Sclerotia are pseudoparenchymatous aggregations of hyphae embedded in an extracellular glucan matrix. These specialised masses of cells are resistant to unfavourable conditions and are formed in or on a host, may include host tissue or not but are not associated with spores production at any time. They can be dense with a clearly defined internal structure consisting of hard melanised outer rind (which may or may not be present), cortex, and medulla. They are produced by smaller number of Ascomycota and Basidomycota.

Sclerotia can be microscopic, very small consisting of only few cells (< 100 µm in diameter) and thus are known as microsclerotia. They are merely clusters of melanised chlamydospore like cells. Such microsclerotia can be observed in *Verticillium dahlia,* a plant pathogen.

B. Stromata (sing. Stroma, Gr. Stroma = mattress)

A stroma is similar to sclerotia as they also are compact, hard masses of vegetative cells, with or without tissue of the host or substrate, much like a miniature mattress or a cushion on which or in which fruiting bodies usually are formed. They are usually irregular in shape and not rounded. Examples is many Ascomycetes (eg. Xylariales).

C. Bulbils

These are compact, multicellular, thalloidic propagule initiated in several ways but are always homogeneous throughout development. All cells are

produced acropetally from colourless, thin walled hyphae, which later expand synchronously to about 4-10 times the diameter. Bulbils are masses of pseudoparenchymatous raspberry like structures undifferentiated internally and often are hyaline. Ex. Terrestrial Basidiomycetes *Minimedusa polyspora.*

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9.6 Cell Wall Composition

Like plant cells and bacteria, fungal cells and hyphae also posses a rigid cell wall giving a definite shape. The chemical composition of the fungal cell wall shows much variation, and the variations follow taxonomic lines. Hence, the cell wall composition is an important criterion in fungal taxonomy and in establishing the relationships between various groups. The composition of cell wall is variable among the different groups of fungi or between the different species of the same group. In the majority of Cells of fungi the wall lacks cellulose but contains a form of chitin like substance known as fungal cellulose which is not identical with insect chitin.

The suggested formula for fungus chitin is $(C_{22}\ H_{54}\ N_4\ 0_{21})_n$. Electron microscope studies reveal that chitin occur as elongated variously oriented microfibrillar units. These are laid down in layers and form the basis of the structural rigidity of fungal cell walls. The microfibril layers generally run parallel to the surface. Associated with the microfibrillar components is the nonfibril material. Under E.M they appear as multilamellate structure whose cytoskeleton is fibrillar substance made up of cellulose, chitin or glucose fibrils. The major component is a polymer of N-acetyl- beta glucoseamine with a chemical formula of $(C_{22}\ H_{54}\ N_4\ O_{21})_n$.

The major chemical constituents of cell wall are polysaccharides which constitute 8090% cell wall by weight and remainder consists of proteins, lipids and inorganic ions. Among the polysaccharides that occur in fungal cell walls, chitin and cellulose are important. Chitin, a strong but flexible nitrogen containing polysaccharide, is a polymer of N-acetyl glucosamine. The OH group of carbon atom 2 of D-glucose units is replaced by N-acetyl amino group (NHCOCH.) to form N-acetyl glucosamine, and chitin is formed by polymerization of these units by β-1,4 linkages. Cellulose is a polymer of D-glucose units formed by β-1,4

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glycosidic linkages. The structural formulae for the repeating units that make up cellulose and chitin are shown in Fig. 9.

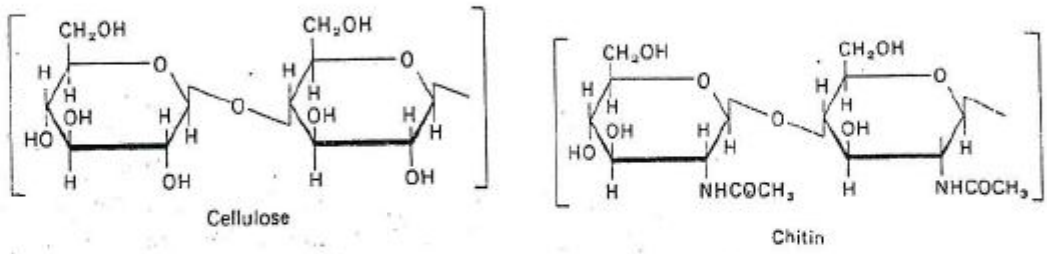


Fig. 9.3 : Structural formulae of main fibrous components of fungal cell walls

The chief chemical constituents are various polysaccharides, proteins, lipids besides other substances have also been reported.In the lower fungi, the biflagellate oomycetes are said to be distinct from all other fungi in the cellulose nature of the cell. The basic structural constituent of the cell wall in the Zygomycetes and higher fungi (Ascomycetes and Basidiomycetes) is chitin, It is a polysacharide based on the nitrogen containing sugar (glucosamine). It is probable that more or less closely associated with chitin in the cell wall are pectic materials, protein, lipids, cellulose, callose and minerals. Insoluble Beta Glucan forms the chief constituent of wall material in Ascomycetes and Basidiomycetes. In yeast chitin is absent and wall is mainly composed of microfibrils of mannan and *B* glucan (Hawker, 1966). Mannan is a polymer of hexose sugar mannose whereas glucan is polymer of glucose. Some investigators have reported the occurrence of lignin in several fungi. It is doubtful whether this substance is chemically the same as the lignin of higher plants. It is obvious that our present knowledge of the chemical composition of the cell wall of fungi is incomplete. Like the cellulose wall, the chitin wall of most fungi is permeable both to water and substances in true solution.

The other polysaccharides present in the cell wall of fungi include glucan (also a homopolymer of glucose), mannan (homopolymer of mannose), glycogen (also a homopolymer of glucose), chitosan (a polymer of D-glucosamine), polyuronides and some heteropolysaccharides.

An elaborate review of the cell wall composition of fungal groups was made by Bartnick Garcia (1970), and he identified eight categories in cell wall of fungi basing on chemical composition mainly of polysaccharides. The categories are given in the table 9.1.

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Table 9.1 Chemical composition of cell wall in different Fungal members

S.No	Chemical Category	Taxonomic Group	Example
1.	Cellulose-Glycogen	Acrasiales	***Dictyosteleum***
2.	Cellulose-Glucon	Oomycetes	***Phytopthora***
3	Cellulose-Chitin	Hyphochitridiomycetes	***Rhizidiomyces***
4.	Chitosomes-Chitin	Zygomycetes	***Mucor***
5.	Chitin-Glucon	Chytridiomycetes	***Neurospora***
6.	Mannan-Glucan	Basidiomycetes	***Polyporus***
7.	Mannan-Chitin	Ascomycetes	***Saccharomyces***
8.	Polygalactoseamine-Galactan	Tricomycetes	***Amoebidium***

9.7 Nutrition in Fungi

Fungi are heterotrophic i.e like animals. But unlike animals which ingest and digest their food. Fungi first digest and then ingest their food by producing enzymes outside their bod.These enzyme break down large and relatively insoluble molecules like carbohydrates, proteins and lipids into smaller and more soluble molecules, that can be absorbed through cell wall and cell membrane and can be used by the organism. The presence of free water is essential for the process of diffusion of soluble nutrients into the cell.

On the basis of their mode of nutrition, they have been broadly divided into three categories:

1. Saprophytes/Saprotrophs
2. Parasites
3. Symbionts/Mutualist

NOTES

9.7. 1 Saprophytes:

The fungi are plants of varied habits. They lack chlorophyll and like animals are unable to manufacture their own food from carbondioxide and water. In their mode of nutrition, the fungi thus differ from all green plants. They obtain food readymade from an external source thus All fungi are, heterotrophs. Like all other plants, they cannot ingest solid food but absorb it directly through cell membranes either by living as saprophytes (saprobes*)* or parasites. The saprophytes grow where dead organic matter abounds in the substratum. This mode of life is called saprophytic (saprobic). Such decomposers fungi which bring about spoilage of useful products are known as biodegraders . Along with some bacteria, saprophytes are the great recyclers of organic matter in natural and agricultural environment. Of course recycling is important because it involves the breakdown of complex material, like cellulose,(the most abundant polymer on earth) and lignin (by some wood-rotting fungi) into simple molecules.

9.7.2. Parasites:

A parasites (Gr. Parasites = table mate) can be defines as an organism that obtains some or all of its nutrients from the living tissues of another organism, while being in intimate association with it.

A parasite that cause disease is termed a pathogen. The notable fungal pathogens of crop plants worldwide are powdery mildews, rusts, smuts and vascular wilt disease. Fungi cause about 100,000 disease of plants, of this more than 70 percent disease afflict major crop plants, resulting in an economic loss of billions of dollars each year.

A diversity of fungi obtains part or all of their nutrition by attacking and consuming living microscopic invertebrates such as nematodes and rotifiers. More than 300 species of nematodes and rotifier destroying fungi have been identified, belonging to Chytridiomycota , Zygomycota, Ascomycota. Basidomycota, as well as from fungus like organism belonging to Oomycota.

The fungus colonies the host and digest it with the help of digestive hyphae. Examples are *Arthrobotrys oligospora, Lagenidium* spp., *Olpidium vermicola*, *Verticillium* spp., etc.

NOTES

Parasites are of two types based on the way they obtain their nutrients. In one of the lifestyle, as part of its feeding process, the parasite kills the living host cells in advance of its entry, by producing toxins or degradative enzymes and then absorbing released nutrients and growing between and into dead and dying cells. These are known as necrotrophic parasites (Gr. Neckros= death, trophein = to nourish) necritrophs/ perthotrophs. The other lifestyle is where the parasites obtains some or all of its nutrients from the living cells or tissues of another host, often by means of special nutrients absorbing structures- haustoria(sing. Haustorium, L. Haustor= drinker). These parasites are biotrophic parasites. The organism on which the parasite feeds is called the host. The presence of the parasite may cause an abnormal condition of the host which is called disease. The thallus of a parasitic fungus may grow on the external surface of the host but usually it is hidden from view the former are called the ectoparasites (Vine molds) and the latter endoparasites.

Parasites are of two types based on the way they obtain their nutrients. In one of the lifestyle, as part of its feeding process, the parasite kills the living host cells in advance of its entry, by producing toxins or degradative enzymes and then absorbing released nutrients and growing between and into dead and dying cells.These are known as necrotrophic parasites (Gr. Neckros= death, trophein = to nourish) necritrophs/ perthotrophs. The other lifestyle is where the parasites obtains some or all of its nutrients from the living cells or tissues of another host, often by means of special nutrients absorbing structures- haustoria(sing. Haustorium, L. Haustor= drinker). These parasites are biotrophic parasites.

Necrotrophs: these can be classified on the basis of the kind of host they parasites. **(a)Nacrotrophs of plants**: these are pathogen of mature tissue and are characterised by tissue invasion of plants in non stressed conditions leading to death host cells. They are host specialized because they must tolerate or overcome the specific resistance factors of a particular host.

NOTES

(b)Nacrotrophs of insects: Initially this parasites kills cells of the insects, but ultimately kills the insect(host). Most of these fungi are terrestrial and filamentous, although the arthropod-parasite *Chytrids* and Oomycetes are aquatic. Most species sporulate when the host is nearly dead. Some of genera occurring as necrotrophs on arthropods.

(c)Necrotrophs of fungi (mycoparasites): Necrotrophic mycoparasites kill the host cells and then feed on them. About six species of *Phythium* are non pathogenic to plant, but parasitise other fungi (majority of *Pythium* spp. are plant pathogens).

(ii)Biotrophs: like necrotrophs, biotrophic parasitic fungi can attack plants, insects, arthropods as well as other fungi (biotrophic mycoparasites). Majority of the biotrophs belong to division Oomycota, Ascomycota, Basidomycota, and Trichomycetes. The balanced parasites are so adapted in their demands upon the host that the latter is able to supply the needs of the parasite and continues to live itself. According to the damage done to the host plant, the parasitic fungi may be divided into two sorts, destructive parasites and balanced parasites. The destructive parasites cause the worst diseases of our field crops, garden crops and forest trees. They kill the host cells or tissues or produce substances toxic to the host.s

(a) **Biotrophs of plants:** These fungi have an extended nutritional relationship with living host cells, the ability to keep the cells living for a long time and a mechanism for securing a nutrient supply from the living host tissues. The hyphal of most biotrophs grow primarily between host cells and give rise to soecialised hyphal branches that penetrate the host cells wall and then invaginate the host plasma membrane without killing the cell. These branches, known as haustoria, are thought to be involved in the uptake of nutrients from the host cell.

(b) **Biotrophs of insects:** Laboulbeniales is one of the largest orders in the class Ascomycetes. All species of these fungi are obligate biotrophic exoparasites of the Anthropoda, especially insects, except a small number of species found on mites and millipedes.

(c) **Biotrophs of fungi (mycoparasities):** There are several types of biotrophic mycoparasities with different feeding mechanism. The most common and distinctive group is the haustorial biotrophs. In this the host remains alive and the parasite feed and proliferate on the host surface. This form of parasitism is shown by species of *Piptocephalis* and *Dispira*. These genera commonly parasities other members of zygomycota, such as *Mucor*, and *Pilaira* growing on dung or in soil.

NOTES

(i) **Fungal parasites of humans:** most of the fungi infecting humans are opportunistic parasites. These grow more commonly as saprotrophs in soil, composts, bird excreta, etc. But can infect through wounds or through lungs. Most of the spores of such parasites are air borne eg. *Aspergillus fumigates, Blastomyces dermatitidis* and *Histoplasma capsulatum.* All these pathogen pose a threat to deblilitated individuals suffering from life threatening disease, immunosupressed or to transplant patients.

1. Obligate parasites: They can grow only upon suitable living host tissues.The best examples of obligate parasites are the downy and powdery mildews. So far all attempts to grow them on dead artificial media have failed.
2. Facultative saprophytes : They live as parasites and attain their best development as such. However, they are able to grow apparently indefinitely as saprophytes under emergent circumstances. *Phytophthora infestans* is a parasite on potato causes *potato blight diseases.*
3. Facultative parasites. Normally they are saprophytes in their habit but may now and then become parasites. Some *Fusarium* species are good examples of this type. They live as saprophytes in the soil when suitable host plants are sown in such a soil, they attack them and start living as parasites. example Botrytis *cinerea* is another good example of a facultative parasite.

9.7. 3 Symbionts or Mutualists

The fungi absorb nutrients from other organism but are not detrimental to them. Such fungi are known as mutualistic fungi. One another type of association in which the fungus enters into a partnership with another organism. In this case the advantages are not all on one side. Both the partners are mutually benefited and this type of association is known as symbiosis.

NOTES

(a) **Lichens:** this is an association of fungi (mycobiont) with algae and cyanobacteria. Although lichens may seem infrequent in polluted cities, they can form the dominant vegetation in unfavourable environments.

(b) **Mycorrhizae:** In this case a fungus establishes a relationship with the roots of certain higher plants particularly the forest trees. In *Pinus* the fungal hyphae form a weft around the pine roots. The root hairs are absent in this region of the root. It is suggested that the fungal hyphae do the work of the root hairs, they absorb water and minerals in solution from the soil and transmit to the roots of the tree. The tree provides food to the fungus. This type of mutually beneficial association between a fungus and the roots of a higher plant is called mycorrhiza.This is an association of fungi with roots of higher plants. The fungal symbiont in a mycorrhiza gets carbohydrates from plant host, and the plants gets minerals from the fungus.

(c) **Plant endophytes or ectophytes:** These fungi are present in or on the leaves and stem of healthy plants. Leaf and stem endophytes are a more recent discovery, and some of these fungi can protect both conifers and grasses against insect herbivory and influence flowering . Many of these fungi produce secondary metabolites they may be antibacterial or antifungal eg. *Pezicula* sp. On several deciduous and coniferous trees.

(d) **Animal endophytes or ectophytes:** These are fungi which are present within or on host animal with or without causing any damage to the animals. Many fungi belonging to Ascomycota and Basidiomycota are associated symbiotically with arthropods, wood wasps, ambrosia and bark beetles, leaf cutting ants and termites. Ants have grown crops of fungi for about their 50 million years. *Ambrosia* beetles are found in the tunnels of ambrosia trees in association with yeasts, *Ascoidea* and *Dipodascus,* known as Ambrosia fungi. Besides providing nutrients, the ergosterol provided by the fungus is essential for larvae to develop into adults. The fungi are transported in specialised pouches that ranges from small depressions in the insect cuticle to larger glandular structures that produce secretions probably nourishing the fungal cells. These fungus filled pouches are known as *Mycangia.*

9.8 Summary

Fungi are unique group of organisms which differ from all other organisms in their behavior and cellular organization. Generally two major growth forms are found in fungi the unicellular and the multicellular filamentous. The

multicellular filamentous forms are made of hyphae.Hypha of most of the species are interrupted by cross walls called septa. These septate hypha are observed in Ascomycetes , Deuteromycetes and basidiomycetes.

Fungi are achlrophyllous, heterotrophic, eukaryotic, spore bearing organisms surrounded by a well defined cell wall made up of fungal chitin with many other complex organic molecules. The cell wall composition is an important criteria in fungal taxonomy and fungi is classified on the basis of chemical structure of cell wall .

NOTES

On the basis of nutritional requirement fungi are heterotrophic, feeding by absorption than ingestion. On the basis of mode of nutrition fungal members are divided broadly in three major groups i.e. Saprophytes, Parasites and Symbionts.

Fungi digest their food by producing enzymes outside their body.These enzymes breakdown large insoluble molecules like carbohydrates, protiens and lipids into smaller and soluble molecules, which later on absorbed through cell wall and cell membrane and can be used by the organisms.

9.9 Glossary

- **Fungus (fungi, plural):** A eukaryotic, non photosynthetic, spore forming organism. They range from single celled organisms to very complex multicellular organisms.
- **Hypha (hyphae, plural):** A very fine thread that is the basic structure of filamentous fungi.
- **Mycelium:** A branched network of fungal hyphae.
- **Chitin:** A tough, resistant, nitrogen-containing polysaccharide forming the walls of certain fungi, the exoskeleton of arthropods, and the epidermal cuticle of other surface structures of certain protists and animals.
- **AppresAscogonium:** the female gametangia in Ascomycota.
- **Basidium :** A structure bearing on its surface a definite number of basidiosporesthat usually are formed following karyogamy and meiosis.
- **Dikaryon:** A pair of closely associated sexually compatible nuclei derived from different parent hypha or cell.

- **Haustorium:** An absorbing organ originating on a hypha of a obligate parasitic fungi that penetrates the host cell wall and invaginates the host plasma membrane.
- **Holocarpic:** An organism with the thallus that is converted entirely into one or more reproductive ststructure.
- **Imperfect Fungi:** Fungi that reproduce asexually i.e. Deuteromycetes.

NOTES

9.10 Self-Learning Exercise

Section A (Very Short Answer Type Questions)

1. The word fungus is derived from the latinword.....
2. The science of study of Fungi is known as .....
3. The fungi which grows on dead and decaying organic matter is known as
4. The nutrition in fungi is.....
5. The cellwall of fungi is made up of .....
6. The common food stored in fungi is

a. Starch b. Glycogen c. Oil d. Fat

7. Sclerotium refers to a modified mycelium which is

a. An underground structure b. a hard resting body

c. mainly food storing organ d. easily carried off by wind

Section B (Short Answer Type Questions)

1. Define Fungi?
2. What is meant by facultative saprophyte?
3. Give three modifications of fungal mycelium and mention their uses ?
4. Differentiate between green plants and fungi?
5. Give salient features of fungal parasites.
6. Define Ambrosia Fungi?

Section C (Long Answer Type Questions)

1. Describe in detail, giving examples the various modes of nutrition found in fungi?
2. Define Fungi? Discuss an ultrastructure of Fungal cell in detail with the help of Suitable diagram?

3. Describe the chemical composition and ultra structure of Fungal cell wall in detail?

4. Discuss substrate relationship in fungi?

5. Describe the structure , reproduction types found in fungi with the help of suitable diagram?

6. Mention the various types of spores found fungal members?

NOTES

9.11 References and further readings

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NOTES

Unit - 10

Reproduction in Fungi

Structure of the unit

10.0 Objectives

10.1 Introduction

10.2 Modes of Reproduction in Fungi

10.2.1 Vegetative Reproduction

10.2.2 Asexual Reproduction

10.2.3 Sexual Reproduction

10.3 Heterothallism

10.4 Heterokaryosis

10.5 Parasexual Cycle

10.6 Recent Trends in Classification of Fungi

10.7 Summary

10.8 Glossary

10.9 Self -Learning xercises

10.10 References and further readings

10.0 Objectives

After going through this unit you will be able to understand

- about reproduction and its importance
- Methods of reproduction found in fungi.
- The meaning of heterothallism and homothallism
- about parasexuality and its importance in fungi

- Various criteria and the systems of classifications proposed by mycologists.

10.1 Introduction

NOTES

Reproduction is the formation of new individuals having all the characteristics of the species from which it has arisen. Typically, fungi reproduce both asexually and sexually although not necessarily at the same time. In general, asexual reproduction, sometimes called somatic reproduction, does not involve the formation of specialised sex cells or sex organs, fusion of nuclei, i.e. karyogamy (Gr. karyon = nut; gamos = marriage), followed by meiosis. In other words, it is the nonsexual production of specialised reproductive cells such as spores. A broader definition, however, also includes any method of propogation of new individuals, such as simple division of a unicellular organism into daughter cells or of a multicellular thallus into a number of fragments each of which grows into a new individual.

10.2 Modes of Reproduction in Fungi

The fungi reproduces vegetatively, Asexually and sexually.

10.2.1 Vegetative Reproduction

There are several modes of vegetative propagation in fungi, such as:

(i) **Fragmentation:** Some fungi employ fragmentation of hyphae as a normal means of propagation. Under favourable conditions, each fragment of mycelium will grow into new Individuals. Fragmentation in nature may occur accidentally by the tearing off of parts of the mycelium through external forces. Often in the laboratory, the same method of, mycelial fragmentation is employed to keep fungal cultures growing on artificial medium by transferring a bit of mycelium to fresh medium and thus starting a new colony.

(ii) **Fission:** Another simple method employed by unicellular fungi is fission of somatic cells. Fission is the simple splitting of a cell into two daughter cells by simple constriction, division of a nucleus by mitosis, and the subsequent formation of a transverse cell wall. This method is typically

observed in a number of forms including some yeasts such as *Schizosaccharomyces octosporus,* commonly known as fission yeast.

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(iii) Budding : This method involves the production of a small outgrowth (bud) from a parent cell. As the bud is formed, the nucleus of the parent cell divides mitotically and one daughter nucleus migrates into the bud. The bud increases in size while still attached to the parent cell and eventually breaks off and forms a new individual. Budding takes place in the majority of yeasts, eg. *Saccharomyces cerevisiae.*

(iv) Sclerotia : This is a modification of mycelium. It is hard, resting storage object. It also serves as a means of perennation and vegetative propagation. With the return of favourable condition it germinates.

10.2.2 Asexual reproduction : The asexual cycle is usually repeated several times during the season and produces exact of the parent. It takes place by means of several types of spores some of which are as follows :

10.2.2.1 Zoospore: (Gr. zoon = animal; spora = seed, spore) These are motile spores, self-propelled by means of flagella and are produced in the fungal groups which are mostly aquatic or, if terrestrial, rely on water for dispersal or infection. Propulsion is often coupled with chemotactic movements, as the zoospores have the ability to sense chemicals diffusing from suitable substrata thus moving towards them.

Zoospores are of following kinds:

1. Posteriorly unifigellate zoospores with flagella of whiplash type:

This is characteristics of the Chytridiomycota. Each whiplash flagellum has 11 microtubules arranged in the 9 + 2 pattern typical of eukaryotes.

Such spores are driven forward by sinusoidal rhythmic pushing of the flagellum. This type of zoospore flagellation is termed opisthokont (Gr. opisthen = behind, at the back; kontos = a pole)

2. Posteriorly multiflagellate zoospores:

They are produced in a small group of true fungi. For example, in *Neocallimastrix,* a rumen-inhabiting Chytrid (order Neocallimastigales), there may be up to 16 flagella.

3. Biflagellate zoospores with two whiplash flagella:

They are the type of zoospore with unequal length flagella are called anisokont and are found in some Myxomycota and the Plasmodiophoromycota.

4. Anteriorly uniflagellate zoospores with a flagellum of the tinsel type:

NOTES

They are characteristic of the Hyphochytriomycota. The axoneme sheath of the tinsel or straminipilous flagellum (L. stramen = straw; pilus = hair) is adorned by two rows of fine hairs. These are called flimmer hairs or tripartite tubular hairs or mastigonemes (Gr. mastigion = a small whip; nema = a thread).

5. Biflagellate zoospores with anteriorly or laterally attached flaglella:

There are two type of flagella, one of which is of the whiplash type and the other of the tinsel type, are characterstic of the Oomycota. Zoospores with the two different kinds of flagellum are heterokont.The motile zoospores may be uniflagellate or biflagellate pear shaped structures produced by the lower fungi in spherical pearshaped, sporangium e.g. *Synchytrium, Albugo.*

(ii) **Sporangiospore (Gr. Spora=seed;angion=vessel)**

A sporangium is a sac-like structure whose entire contents are converted through cleavage into one or more, usually many, spores known as sporangiospores. The sporangiospores of nearly all the true fungi are non-motile and are called aplanospores (Gr. a = not, pianos = roaming). In the Zygomycota, and especially in the Mucorales, the asexual spores are contained in globose sporangia or cylindrical sacs termed merosporangia. The spores may be uninucleate or multi-nucleate, and are unicellular, generally smooth walled , globose or ellipsoid in shape, and vary in colour from hyaline to yellow due to carotenoids in the cytoplasm. When mature, they may be surrounded by mucilage, and be usually dispersed by rain-splash or insects.

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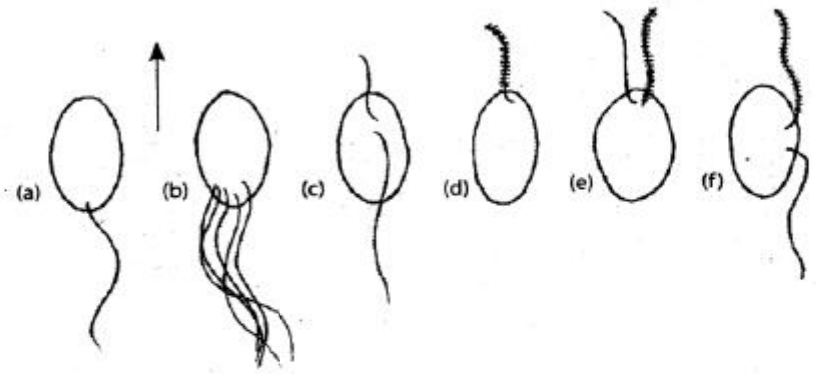


Fig.10.1 : Various type of Zoospore a. Posteriorly uniflagellate b. posteriorly multiflagellate c.

With unequal flagella d. anteriorly uniflagellate e. biflagellate heterokont

(iii) Conidiospores(Gr.Konis= dust)

Conidiospores, commonly known as conidia, are asexual reproductive structures. They are found in many different groups of fungi, but especially in Ascomycota, Basidiomycota and Anamorphic fungi. In Anamorphic fungi, conidia are the only means of reproduction and no sexually reproduced spores are known. The cells which produce conidia are known as conidiogenous cells. If the conidium arises directly from the segment of the fungal thallus without enlargement, the development is known as thallic.

In most conidia, the development is blastic, i.e. there is enlargement of the conidium initial, before it is delimited by a septum. They may be holoblastic (both the inner and outer wall layers of the conidiogenous cell contribute to conidium formation). eg. *Cladosporium herbarum* or enteroblastic (only the inner wall, or a completely new wall layer is involved in conidium formation) e.g. *Aspergillus, Penicillium* etc.These are non-motile spores produced exogenously by constriction at the ends of special hyphaI branches called conidiophores. They may be produced single (e.g. *Pythium, Phytopthora)* or in chains (e.g. *Aspergillus, Penicillium)*

(iv) Oidia

Some fungi like *Mucor*, the hyphae forming mycelium often become divided by transverse walls into a large number of short segments, each of which is capable of germinating and developing into a new plant. These segments which may remain united in chains or become free from other are known as oidia.

(v) Chlamydospores

The chlamydospores also produced like that of oidia but they differ from the latter in being thick walled and coloured black or brown. They may terminal or produced at irregular intervals along the hyphae.

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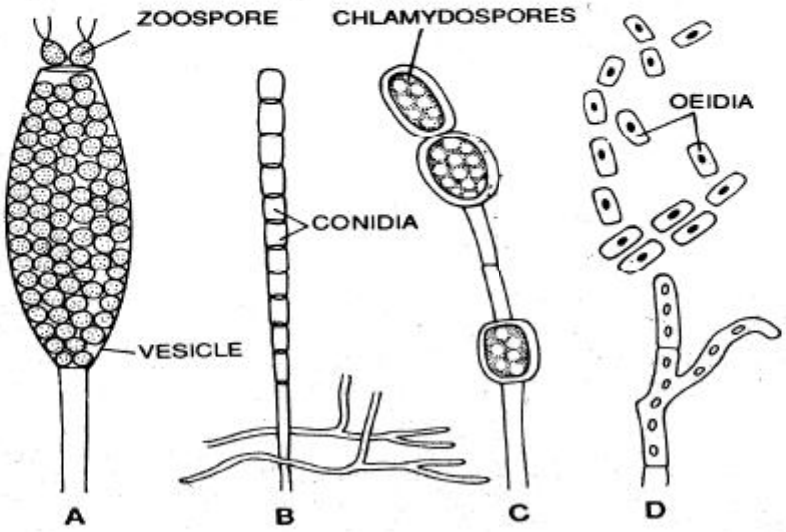


Fig 10.2 : Asexual spores in fungi A. Zoospore B.Conidia C. Chlamydospore D. Oidia

10.2.3 Sexual Reproduction

The sexual reproduction is a subsidiary process in the fungi. In case of fungi like other organisms the sexual reproduction takes place by the union of two compatible nuclei and consists of three phase.

In the first phase, called plasmogamy, it is the union of two protoplasts, which brings the nuclei close together within the same cell. The fusion of the two nuclei (brought together by plasmogamy) is called karyogamy and constitutes the second phase of sexual reproduction. Karyogamy follows plasmogamy almost immediately in some species, while in others these two events are separated in time and space, with plasmogamy resulting in a binucleate cell containing one nucleus from each parent. Such a pair of nuclei is known as dikaryon.

Nuclear fusion, which eventually takes place in all sexually reproducing fungi, is sooner or later followed by meiosis, which again reduces the number of chromosomes to the haploid (reduction division) and constitutes the third phase of sexual reproduction.

NOTES

1. **Plasmogamy**—It involves the fusion of two protoplasts bringing two haploid nuclei close together in the same cell.
2. **Karyogamy**—It involves the fusion of two haploid nuclei brought together during plasmogamy. This results in the formation of a diploid structure the zygote.
3. **Meiosis**—It follows nuclear fusion which eventually takes place in all sexually reproducing fungi. It again reduces the number of chromosomes from diploid zygote nucleus to original haploid number in the daughter nuclei.

Most fungi, on the sexual basis, may be classified into three categories:

A. **Hermaphrodite or Monoecious**: Species producing distinguishable male and female sex organs on a single thallus. A hermaphroditic species can reproduce sexually by itself if it is self-compatible.

B. **Dioecious:** Species consisting of male and female thalli, with some thalli producing only male and others only female sex organs. A single thallus of a dioecious species cannot reproduce sexually by itself normally, since it is either male or female.

C. **Sexually undifferentiated:** species producing morphologically indistinguishable male and female organs.

The sex organs of fungi are generally called gametangia (sing. gametangium). These may form different sex cells called gametes or simply may contain nuclei that are the functional gametes. We use the terms isogametangia and isogametes; respectively, to designate gametangia and gametes that are morphologically indistinguishable, we use heterogametangia and heterogametes to designate male and female gametangia and gametes that are morphologically different. In the latter case, the male gametangium is called the antheridium and the female gametangium is called either an oogonium or ascogonium depending on the fungal group.

The sexual reproduction in fungi is varied. It may be of following types:

(a) Planogametic copulation: Planogametes are motile gametes. This involves the fusion of two naked gametes. The fusing gametes may be isogametes, anisogametes or heterogametes.

(b) **Gametangial contact**: In this case the gametes are transferred directly from on gametangium to the other. These gametes are undifferentiated protoplasts and represented by nucleus. Actually they never fuse.

(c) **Gametangial copulation:** It involves the fusion of the entire contents of the gametangia.

NOTES

(d) **Spermatization**—In certain cases e.g. ascomycetes and basidiomycetes there is the formation of certain non-motile, male cells the spermatia. These spermatia are brought in contact with female gametangia, receptive hyphae or somatic hyphae to which they are attached. The partition wall dissolve and contents of spermatia pass into female organ.

(e) **Somatogamy**—In most of the members of Ascomycetes and Basidiomycetes there are no sexual organs produced and the sexual act is accomplished by the fusion of two nuclei from somatic cells. This fusion result the formation of zygote, or zygospore. They produce spores which in their turn develop in mycelium.

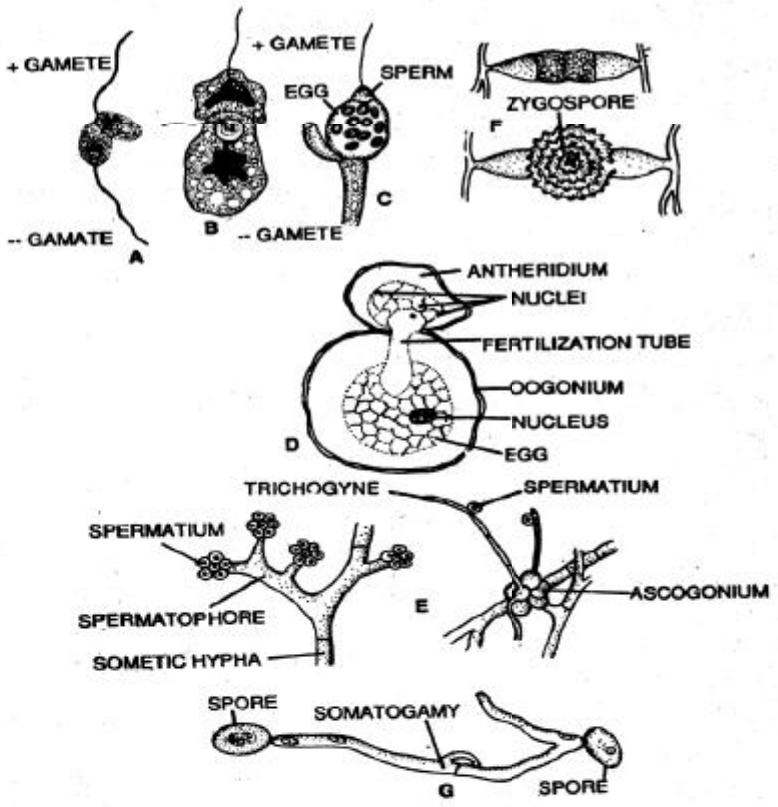


Fig. 10.3 : Types of Sexual reproduction found in Fungi; (A-C) Planogametic copulation(Iso, Aniso and heterogamete),D gametangial contact

NOTES

G Somatogamy Various type of sexual spores are produced in fungi viz. Oospores, Zygospores, Ascospores and Basidiospores.

(i) Oospore(Gr . Oos= Egg)

An oospore is a sexually produced spore which develops from unequal gametangial copulation or markedly unequal gametic fusion. It is the characteristic sexually produced spore of the Oomycetes.Oospores develop from fertilised oospheres, or sometimes parthenogenetically. One or more oospheres develop within oogonia, which are multinucleate, globose female gametangia. The number of oospores per oogonium may be important taxonomically. In the Saprolegniales, there are usually several oospores per oogonium, whilst in the Peronosporales, there is typically, only one.

The oospore or egg develops a thick outer wall, and lays down food reserves usually in the form of lipids.

(ii) Zygospores (Gr. zygos = yoke)

Zygospores are sexually produced spores formed as a result of plasmogamy between gametangia that are usually equal in size. They are resting structures. Zygospores are the typical sexually produced spores of Zygomycota, e.g. Mucorales and Entomopthorales. Zygospores are often large, thick-walled, warty structures with large food reserves and are unsuitable for long-distance dispersal. They usually remain in the position in which they are formed, awaiting suitable conditions for further development. The gametangia which fuse to form the zygospore may be uninucleate or multinucleate, and correspondingly the zygospore, within which nuclear fusion and meiosis eventually occur, may have one, two or many nuclei within it.

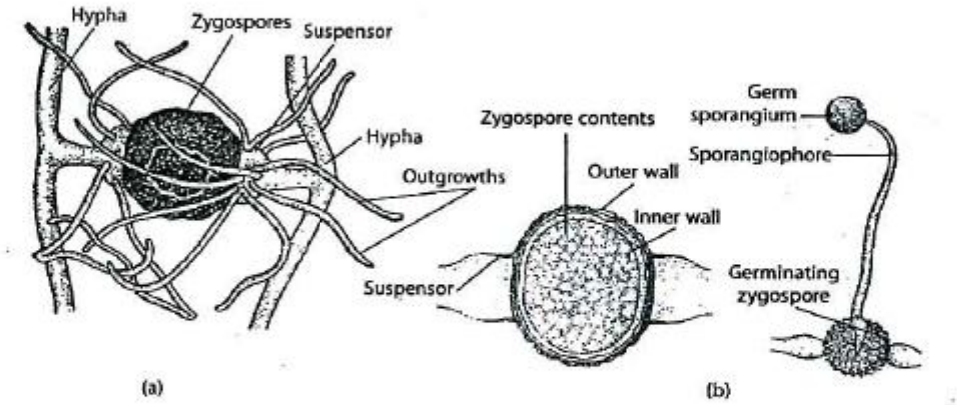


Fig 10.4 : Formation of Zygospore in the member of Zygomycetes

(iii) Ascospores (Gr. askos = sac)

Ascospores are the characteristic sexual spores of the largest group of fungi known as Ascomycetes. They are formed in the ascus as a result of nuclear fusion immediately followed by meiosis. The resulting four haploid daughter nuclei then divide mitotically to give rise to eight haploid nuclei around which the ascospores are cut out.In most Ascomycetes , the eight ascospores are contained within a cylindrical sac or ascus, from which they are forcibly ejected by a squirting mechanism, in which the ascus contents, consisting of ascospores and ascus sap, are ejected by explosive breakdown of the tip of the turgid ascus, whose elastic walls contract. Ascospores vary greatly in size, shape and colour. The size may range from about 4-5 x 1 µm in small-spored forms such as the minute cup-fungus *Dasyscyphus*, to 130 x 45 pm in the lichen, *Pertusaria pertusa* ascospore shape varies from globose to oval or elliptical, lemon-shaped, cylindrical, needle-shaped and even sausage-shaped. Ascospores may be uninucleate or multinucleate, unicellular or multicellular, divided by transverse or by transverse and longitudinal septa. The wall may be thin or thick, hyaline or coloured, smooth or rough, sometimes folded reticulately, and may have a mucilaginous outer layer which may be extended to form simple or branched appendages. The wall surrounding the protoplast is composed of several layers:

NOTES

- Endospore, the innermost layer
- Epispore, the layer outside endospore
- Perispore, the ribbed layer outside epispore
- Surface layer, the lighter intercostal veins between the ribs, containing a material which is chemically distinct from the ribs. This material is continuous over the whole surface of the spore, giving it a relatively smooth surface.

(iv) Basidiospores (Gr. basidion = small base)

These are sexual spores characteristics of large group of fungi, the Basidiomycetes.They are asymmetric in shape, vary from sub-globose, almond-shaped (i.e. flattened), sausage-sh aped, to fusoid. The wall may be smooth or ornamented with spines, ridges or folds. Their size ranges from 3-20 µm, possibly related to their unique method of discharge. The colour of basidiospores is an important criterion of classification. They may be colourless, white, cream, yellowish, brown, pink, purple or back.

NOTES

The spore is attached, usually in groups of four, at the tip of a curved horn-like prong projecting from the apex of the basidium, sterigma (pl. sterigmata, Gr. sterigma = support)

The point at which the spore is attached to the sterigma is the hilum, persisting as a scar at the base of the discharged spore. Close to the hilum is a short conical projection, the hilar appendix, which is involved in the unique mechanism of spore discharge. The term ballistospore (Gr. ballo = to throw) is used to describe basidiospores that are violently projected from their sterigma.

The cytoplasm of the spore usually contains a haploid nucleus, resulting from meiotic division in the basidium. Sometimes a post-meiotic division results into two nuclei, especially in species with two-spored basidia, and also in four-spored species. The reserve content of the spore may be lipid/glycogen. In addition to the usual organelles, the basidiospore also indcludes microbodies associated with mitochondria and lipid globules, possibly functioning as glyoxysomes in the oxidation of lipids. The wall of basidiospore consist of following layers.

- **Endospore,** thin electron transparent innermost layer.
- **Epispore,** thick, dark-pigmented, electron-dense layer outside endospore, determines the size and form of the spore.
- **Exospore,** lies above the epispore. It is a colourless layer, chemically distinct from adjacent layers. In many spores, this is the outermost layer because the perispore and ectospore disintegrate. The surface of the wall may be lobed or folded.
- **Perispore,** envelops the other spore layers, including ornamentation derived from the exospore. It may disappear as the spore develops, or may persist, filling the space between the ornaments.
- **Ectospore,** the outermost layer.

Diversity of Spores

Fungi produce large number of spores, variable in morphology and structure, asexually and sexually. They are unicellular or multicellular, thin or thick-walled, branched or unbranched, dry or sticky, smooth or ornamented by mucilaginous extensions, spines, folds or reticulations and vary in colour from hyaline through green, yellow, orange, red, and brown to black. They are self-

propelled by means of flagella, or are carried passively by animal vectors, water or wind. They vary greatly in shape from globose through oval, oblong, and needle-shaped to helical to even insect-like in appearance.

Single-celled spores are termed Amerospores (Gr. a = a part; i.e. not divided), two-celled spores are Didymospores (Gr. didymos = double), spores with more than one transverse septa are Phragmospores (Gr. phragmos = a hedge, barricade), and spores with transverse and longitudinal septa are Dictyospores (Gr. diction = a net).

NOTES

The size of the spores may range from minute to large (2 µm to over 150 µm in diameter). Special terms have also been used to refer to spore shape. Scolecospores (Gr. skolex = a worm) are worm shaped, staurospores (Gr. stauros = a cross) have arms radiating from a central point or axis, helicospores (Gr. helix = twisted).

Spore septation, shape,colour, along with other criteria have been used in classfication and identification of fungal families.

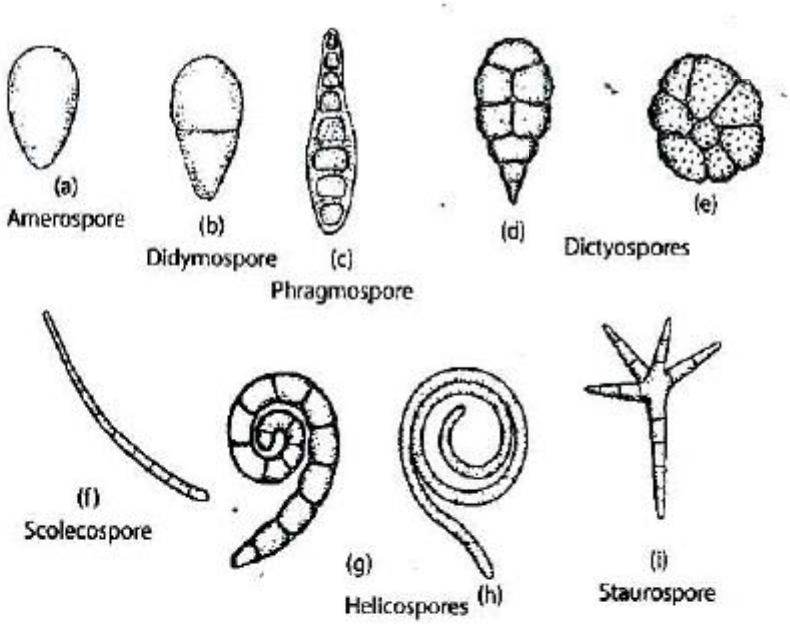


Fig.10.5 : Types of Asexual Spores Formed in Fungi

Dispersal of Spores

Most fungal spores are not self-propelled. They may be actively or passively released for dispersal by several effective methods.

NOTES

Active dispersal: In this method the energy for separation of the spore from the parent fungus is generated by the fungus itself.

Passive dispersal : This involves agents such as, gravity, wind currents, rain-splash, water currents, or animals. Dispersal may also occur by human traffic.

Spores of fungi in general differ from the somatic cells in the following ways:

- Thicker wall with additional layers which are pigmented.
- Cytoplasm dense and some of the organelles like ER and mitochondria are poorly developed.
- Relatively low water content, low respiration rate and low rates of protein and nucleic acid synthesis.
- Presence of high energy storage compounds such as lipids; glycogen and trehalose.

Sexual Compatibility

Compatibility in a way governs sexual reproduction; it should not be confused with sex, although closely related to it. There are many fungi that produce clearly distinguishable male and female sex organs on the same thallus. But individuals in these are sexually 'self-sterile' because their male organs are incompatible with their female organs and no plasmogamy can take place. On the other hand, there are many fungi which do not produce differentiated sex organs at all. Since we cannot distinguish their sex, we refer to them as mating type, Based on compatibility, fungi belong to one or another of the following three groups:

(i) Homothallic Fungi: Those in which every thallus is sexually self-fertile and can, therefore, reproduce sexually by itself without the aid of another thallus. (ii) Heterothallic Fungi: Those in which every thallus is sexually self-sterile, regardless of whether or not it is hermaphroditic, and requires the aid of another compatible thallus of a different mating type for sexual reproduction. Heterothallic fungi belong to one or the other of two general groups: unifactorial or bipolar heterothallism, in which, mating is controlled by one pair of loci and bifactorial or tetrapolar heterothallism, in which mating is controlled by more than one pair of loci located on different chromosomes (iii)

Secondarily Homothallic Fungi: In some heterothallic fungi, an interesting mechanism operates during spore formation whereby, two nuclei of opposite mating type are incorporated regularly into each spore or at least some spores. Germ tubes arising from these spores are therefore self-fertile and behave as if they are homothallic when in reality they are actually heterothallic. This condition has been referred to as either secondary homothallism or pseudohomothallism or amphithallism.

NOTES

10.3 Heterothallism

A.F. Blakeslee, an American geneticist in the year 1904 observed at while some species of *Rhizopus* formed zygospores freely, others e.g. *R. nigricans (=R. stolonifer)*, formed these only rarely. He examined zygospore formation in several Mucorales and discovered the phenomenon of heterothallism in fungi. When two isolates of *R. nigricans* or *Mucor hiemalis* were grown together in a Petri dish, zygospores appeared at the point of contact between hyphase of the two isolates. Blakeslee called these fungi which required the another isolate for zygospore formation, as heterothallic and the phenomenon as heterothallism. He designated the two isolates, or mating types, the (+) and (—) strains, as their gametangia were morphologically similar and indistinguishable into male and female individuals. The opposite condition in which an individual, originating from a single asexual spore, was capable of forming zygospore independently, was called **homothallism.**

In heterothallism the two mating partners are derived from two genetically unlike spores, designated as (+) and (-) spores. The heterothallic species always consisted of two types of individuals, the (+) and (-) mating types. Blackeslee assumed that the (+) strain represented the female and the (-) the male.

In mating experiments, the (+) mating type gametangia of heterothallic species fused with the male and (-) mating type gametangia with the female, suggesting that the (+) mating type was female and the (-) male.

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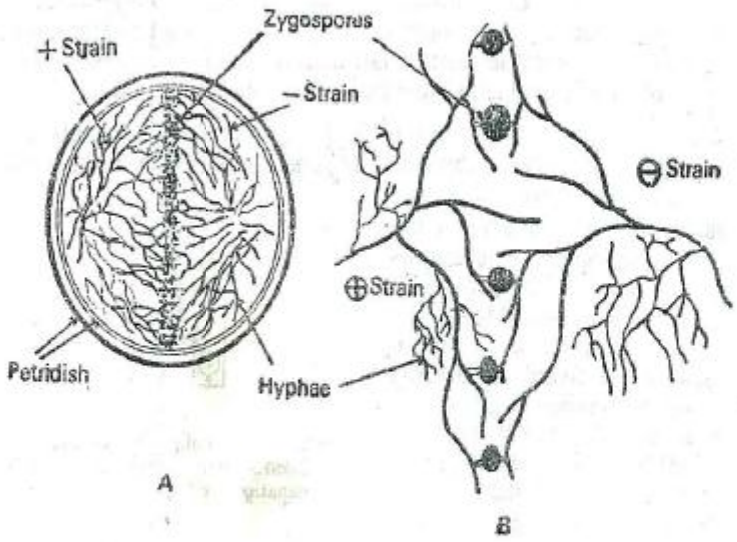


Fig 10.6 : Heterothallism in fungi

Morphological and Physiological Heterothallism

Whitehouse (1949) distinguished two major types of heterothallism: **morphological** and **physiological.** When the two interacting thalli produce morphologically distinct male and female sex organs (or gametes) the heterothallism is called morphological heterothallism. In physiological heterothallism, the interacting thalli differ in mating type or incompatibility, irrespective of the presence or absence of the sex organs or gametes.

Genetic Determinant of Heterothallism

The heterothallism may be due to: (I) lack of both male and female organs on the same thallus, or (2) in-compatibility between the sex organs formed on the same thallus with regard to karyogamy. The two conditions are genetically controlled by factors called, the sexual and incompatibility factors.

Sexual factors are responsible for the formation of sex organs and gametes. The maleness or femaleness is determined by the direction of nuclear migration during plasmogamy. The male serves as the donor of the nucleus and the female as the recipient. Incompatibility factors determine the mating capacity in addition to, or in absence of, sexual factors. In presence of sexual factors, and consequently of sex organs, the incompatibility factors determine the possibility of mating between the male and female sex organs or gametes. In absence of sex factors, when no sex organs or gametes are formed, as happens in most

higher Ascomycetes and Basidiomycetes, the incompatibility factors are the sole of sexual fusions.

The segregation of these factors during meiosis determines the sexual status (i.e. whether sex organs or gametes are formed) and the mating behaviour (i.e. whether homothallic or heterothallic). Three types of segregations may occur during meiosis: (1) segregation of sexual factors (2) segregation of incompatibility factors and (3) no segregation of either factors. The segregation pattern is exhibited by the thalli that develop from the spores containing the meiotic nuclei. The spores of type (1) and (2) give rise to thalli that are self-sterile i.e. heterothallic. spores of type (3), on the other hand give rise to homothallic thalli.

Raper (1966) distinguished six types of heterothallic fungi. The segregation of the sexual and incompatibility factors of these various heterohallic fungi fall into two categories: (A) two alleles at one locus, and (B) multiple alleles at one or two loci.

A.Two Allele – or Bipolar Heterothallism

Fungi in this category have two mating types; each containing genetically different nuclei. The sexual compatibility is controlled by a pair of genetic factors A and a (which may be sexual or incompatibility factors) located at a single locus on different chromosomes. The use of (+) and (-) designations seems preferable because A/a implies dominance of A over a.

This is, therefore, also called as "two-allele heterothallism". During meiosis, the two chromosomes, containing the (+) and (-) alleles are separated in the haploid spores (viz. germ spores, ascospores or basidiospores.) The spores give rise to two types of thalli which must fuse in order to bring the two compatible (+) and (-) nuclei together. The two mating types are designated as (+) and (-) strains.When the two alleles represent sex factors, the two types of thalli formed are unisexual, producing male or female sex organs or gametes.

The heterothallic hermaphrodite (= self sterile) individual also come under two allele heterothallism.

NOTES

B.Multiple Alleles at One Locus

This type of heterothallism is controlled by multiple alleles at a single locus, instead of a pair of alleles. If we name the locus as A, the multiple alleles can be designated as A1, A2, A3 .....An. The meiotic products give rise to thalli, which are of several mating types (equal to the number of the alleles). The thallus containing the allele A1 can mate with a thallus of any mating types except A1. Like the two-allele heterothallism, here also the genetic factors may involve sexual or incompatibility factors. Incompatibility factors are more commonly involved. It is a characteristic of the Basidiomycetes (excluding rusts and smuts).

When the alleles involve sexual factors, several types of strains are formed, each typically self sterile but capable of mating with the other types. This type of heterothallism has been found in all the studied members of Saprolegniales, Leptomitales and Peronosporales. The sexual strains constitute a linear series in which only those strains which lie at the two ends are strictly male or female; the rest have relative maleness or femaleness.

Multiple alleles At two Loci

This type of heterothallism is found in Basidiomycetes, excepting the rusts. It involves only incompatibility factors and therefore, sex organs are not formed.

In this type of heterothallism the out-breeding is complete, (100%) against 25% in bipolar. This is due to enormous increase in the number of the possible mating type of the thalli.

Flat and Barrage Reactions

When two thalli with a common A or B alleles are mated, though plasmogamy takes place and heterokaryons are formed, fruiting never occurs. If the heterokaryons have common A alleles (and dissimilar B alleles), the mating is termed flat reaction such heterokaryons show poor growth; hyphae are curly and irregularly branched.

The mating between thalli containing similar B alleles (but different A alleles) show what is called a barrage reaction The hyphae at the point of contact show cessation of growth, resulting in a "barrage" or zone of no growth between the

colonies of the two thalli. Common B factors, according to parag (Ioc. cit.) prevent karyogamy and meiosis.

10.4 Heterokaryosis

The term heterokaryosis (hetero =dissimilar, karyons=nuclei) has been defined as the coexistence of genetically different nuclei in cyto¬plasmic continuity with one another. The phenomenon, discovered by Hansen and Smith (1932) in Botrytis cinerea. It is a near-universal, feature in fungi. Heterokaryosis plays the major role in bringing about variability and sexuality in fungi. It is the pre-requisite for parasexual cycle, in the same way as heterozygosis is for sexual reproduction.

In the broader sense, a fungus population, consisting of genetically different individuals, is designated as heterokaryotic. According to Parmeter(1963) the dikaryotic cell containing dissimilar nuclei e.g. the spores of rusts, is clearly heterokaryotic. The heterokaryotic condition arises by (1) mutation, (1) anastomosis,and (3) inclusion of dissimilar nuclei in spores after meiosis, in heterothallic fungi.

1. Mutation

A high frequency of mutation, which is characteristic of fungi, is the main source of variability. It is difficult to handle species of *Penicillium, Aspergillus, Verticillium, Fusarium* etc in homokaryotic condition. Mutation frequently renders it heterokaryotic. It has been clearly demonstrated that new races of *Phytophthora* in USA, in absence of sexual reproduction, have arisen by mutation. Hansen (1938) observed, that the single spore of *Fusarium* by frequent mutations produced variants of the wild type in cultures.

2. Anastomosis (The Fusion of Hyphae)

This is a feature of common occurrence in fungi, and is certainly a big source of heterokaryosis. In general, fusion is mostly intraspecific, though inter-specific and intergeneric fusions have been reported.

Nuclear migration from the point of union to the remainder of the mycelia involving daughter nuclei of the parent nucleus takes place and give rise

to heterokaryotic mycelium. Alternatively, hyphal growth may initiate at the point of fusion, containing nuclei derived from both-the parent type. In nature, the most familiar example of anastomosis is the development of dikaryon in Basidiomycetes. Anastomosis is the method used for "making" heterokaryons in laboratory.

NOTES

3. Inclusion of Dissimilar Nuclei in Some Spores

Meiosis results in the production of genetically different nuclei sharing common cytoplasm. *Neurospora tetrasperma* and other secondary homothallic fungi, dissimilar nuclei are contained in the same spore which on germination given rise to a heterokaryotic thallus.

4. Significance of Heterokaryosis

1. Substitute for Heterozygocity and Variability: Heterokaryosis provides a substitute for heterozygocity rather than for sex. It is important for maintaining variability (by virtue of the presence of geneticially dissimilar nuclei. Heterokaryosis is a substitute for heterozygocity rather than for sex.
2. Heterokaryosis and Pathogenicity: Heterokaryosis plays an important role in the pathogenic activities of rusts and smuts. It is essential for pathogenicity in smuts.
3. Origin of New Races: Nelson et al (1955) inoculated a resistant wheat variety with different races of rust, which individually failed to cause infection. Lesions appeared after some time. It was made possible by anastomosis between the inoculated races, which resulted in the origin of a new pathogenic race.
4. An Initial Step in Parasexual Cycle: Heterokaryosis is an integral, first step of parasexual cycle.

10.5 Parasexual Cycle

For a long time sexual reproduction was thought to be the only mechanism of achieving genetic recombination. Novel alternative to sexual reproduction was discovered in fungi (*Aspergillus nidulans*) by Pontecorvo

and Roper (1952) of the University of Glasgow. This they named as the parasexual cycle. In this process the genetic recombination is achieved through "mitotic crossing over" and "haplodization". It is also called as somatic recombination. The events of sexual reproduction are extremely uniform, having a fine coordination between recombination, segregation and reduction, there is no such coordination in the parasexual cycle. The karyogamy and haplodization are accidental events not mind by space and time. The parasexual phenomenon was next reported in *Aspergillus niger,* which, unlike *A. nidulans,* lacks a sexual cycle. The phenomenon is now reported in several fungi belonging to Asco and Basidiomycetes.

NOTES

Steps of Parasexual Cycle:

The various steps of the parasexual cycle have been worked out in detail for *Aspergillus nidulans, A. niger* and *Pencillium chrysogenum*. In *A. nidulans,* which serves as the typical example, the parasexual cycle occurs in the following four steps:

1. Establishment of heterokaryosis.
2. Formation of heterozygous diploids
3. Occasional mitotic crossing-over during multiplication to the diploid nuclei, and
4. Occasional haplodization through aneuploidy.

1 **Establishment of Heterokaryosis:** The presence of haploid nuclei of dissimilar genotypes in the same cytoplasm is a pre-requisite for recombination. This is achieved by heterokaryosis, which is brought about by : (1) mutations, and (2)Anastomosis between hyphae of different origin.This step is equal to plasmogamy of sexual reproduction.

2 **Formation of Heterozygous Diploids:** Nuclear fusion in heterokaryotic vegetative cells was first noted by Roper (1952) in *Aspergillus nidulans.* The nuclear fusions between dissimilar nuclei result in the formation of heterozygous diploid nuclei or "zygotes" a rare event, occurring at the rate of one in a million.

NOTES

The heterozygous diploid nuclei, which are fairly stable, by multiplication and sorting out through conidia give rise to diploid thalli. The diploid colonies are recognized by : (1) higher DNA content of their nuclei, (2) the bigger size (1.3 times.) of their conidia, and (3) certain phenotypic characteristic of the colony. This is typical of parasexual phenomenon and the prolonged diploid phase involving repeated nuclear divisions enhance the chances of "mitotic crossing-over.

3 **Occasional Mitotic Crossing-over during Multiplication of Diploid Nuclei:** This is is the most important or 'key event' in parasexual cycle. It is during this step that genetic recombination takes place. Crossing-over during mitosis is a rare phenomenon first noticed in 'fruit fly' (*Drosophila melanogaster)* by Stern in 1936. In *Aspergillus nidulans,* mitotic crossing-over occurs only rarely, with a frequency' of 10^{-2} per nuclear division. Interestingly enough, in some fungi, like *Penicillium chrysogenuem* and *Aspergillus niger,* it is as frequent as during meiosis. Pontecorvo and Roper (1952) invoked mitotic crossing-over to explain the development of new heterozygous, recombinant haploid nuclei, which was subsequently also proved Cytologically. It is a characteristic feature of mitotic crossing-over that the exchange, or chiasmata formation, is confined to a single chromosome pair out of the whole complement of chromosomes. In meiosis, the crossing-over occurs simultaneously in all the chromosomes. The subsequent splitting of chromosomes and segregation of strands is as, it occurs in mitosis.

Crossing over followed by segregation of strands, gives homozygosis for all markers distal to the point of chiasma. Markers proximal to the point of exchange and markers on other chromosomes remain heterozygous.

4 **Occasional Haplodization through Aneuploidy:** The diploid nuclei give rise to haploid nuclei by gradual loss of chromosomes during successive mitotic divisions i.e.aneuploidy This is called haplodization.Haplodization occurs at a constant frequency of 10^{-3} per

nuclear division, is the result of aneuploidy.The aneuploids are genetically unstable and once loss of chromosome started the selection favours the development of fully balanced haploid nuclei.

Parasexual cycle closely simulates the events of the sexual cycle. It Involves everything : plasmogamy, karyogamy and haplodization but in a modified from and without any fixed plan with regard to time and space.

Role of Parasexual Cycle in Nature

Parasexuality has been known only as a laboratory phenomenon. However, the results of Ingram (1968) strongly suggest that it may be widespread in nature. Though it has been demonstrated only in Asco, Basidio-, and Deuteromycetes, there are strong evidences of its occurrence in some coenocytic fungi, like *Phytophthora cactorum* (Buddenhagen, 1958).

10.6 Recent Trends in Classification of Fungi

The word 'classification' may be defined as the scientific categorization of the organisms in a heirarchical series of groups. In spite of the existence of many varieties, biological strains and physiological or cultural races, the species is generally considered as the smallest group. More similar species are grouped together into a genus, similar genera are grouped into a family, families into an order, orders into a class, similar classes into a division, and divisions into a kingdom. The latter is supposed to be the highest taxonomic rank.

Linnaeus (1753), the famous botanist and classifier of organisms, proposed that if a thing simply existed then it was a mineral, if it lived then it was a vegetable, and if it also had some senses then it was an animal. If such an assumption is applied to fungi, they are neither minerals nor have any discernable senses, and hence they are naturally vegetables. This idea actually gave rise to the notion that all living things belong to one of the two great kingdoms i.e. Plants and Animals and the fungi belong to plant Kingdom.

G. C. Ainsworth (1973), while discussing the status of fungi, put forward a promising aspect of all living organisms before the future biologists about existence of only two kingdoms, i.e. plant and animals kingdoms.

NOTES

Cytochrome-C^2 studies of different organisms, made by Nolan and Margoliash (1968), also suggest that fungi form phylogenetic line distinct from animal and plant kingdoms.

The 'five-kingdom system' based on the level of organization and mode of nutrition of the living things, provides fungi a status of an independent kingdom. There exist three fundamental modes of nutrition among the living organisms, i.e. photosynthesis (in which the organic matter is manufactured); absorption (in which the soluble organic compounds are absorbed or taken into the cell), and ingestion (in which the solid food particles are taken in). From the, organization point of view there exist unicellular forms where there is no well defined internal structures, and multicellular forms which show clear division of labour in their body. It was probably Bauhin who for the first time tried to classify fungi in his book *Pinax theatric botanici* (1623) wherein he described 100 species of fungi.

Carolus Linnaeus, (1753) placed all fungi in his 24th class Cryptogamia in his famous book *Species Plantaruam*. The first detailed classification of fungi, however, was proposed by Elias Magnus Fries in his three volume book *Systema Mycologicum* published during 1821-1832. He divided fungi into four classes: (i) Coniomycetes (ii) Hyphomycetes (iii) Gastromycetes and (iv) Hymenomycetes. Saccardo (1882) included Bacteria and slime molds in fungi in his famous book *Sylloge Fungorum* and divided fungi into six classes : (i) Schizomycetes (ii) Myxomycetes (iii)Phycomycetes (iv) Ascomycetes (v) Basidiomycetes and (vi) Deuteromycetes.

Bessey (1950) agreed with De Bary (1887) and placed the slime molds under the name Mycetozoa. His system of classification was largely based on the reproductive characters. True fungi were divided as follows :

1. Lower Fungi. Fruit bodies not formed. Only one class Phycomyceteae.

2. Higher Fungi. Fruit bodies are formed, divided into three classes :

(i) Ascomyceteae Fruit body asci; ascospores endogenously formed.

(ii) Basidiomyceteae Fruit body basidia; basidiospores formed exogenously.

(iii) Deuteromycetae. Sexual stage absent.

Sparrow (1958) created nine classes emphasising the importance of

flagellation of the oospores in the classification. He considered that flagellation should be treated as a good taxonomic and phylogenetic criterion.In 1961 Martin proposed a system of classification based on the septation of mycelium and spore characters.Modern mycologists are unanimous on the exclusion of bacteria from the fungi on the basis of lack of a true nucleus in the bacterial cell.

NOTES

The Committee on the International Rules of Botanical Nomenclature has made the following recommendations:-

(a) The names of divisions of fungi should end in—mycota.

(b) The sub-divisions should end in—mycotina.

(c) The names of classes should have a suffix—mycetes.

(d) The sub-classes should end with a suffix—mycetideae.

(e) The names of orders should end in—ales.

(*f*) The families should end with a suffix—aceae.

Division Mycota. The mycologists place division Mycota in the kingdom Plantae. This division includes non-green (achlorophyllous) nucleated thallophytes (fungi) which are characterised by the following features:-

(a) Obtain nutrition either by living as saprophytes or as parasites. Lacking chlorophyll, the mode of nutrition is thus heterotrophic and absorptive except slime molds in which it is phagotrophic.

(b) Somatic phase may be filamentous, unicellular or a plasmodium.

(c) Presence of a true nucleus with a nuclear membrane and nucleoli in the cell.

(d) Typically the cell wall is chitinised but some Oomycetes have a cellulose cell wall.

(e) Reserve food accumulates in the form of glycogen and not starch. In addition there are oil drops.

(f) Reproduce both by asexual and sexual methods.

NOTES

The division Mycota includes two sub-divisions, Myxomycotina and Eumycotina.

I. Subdivision Myxomycotina. This subdivision includes the slime molds which possess the following distinctive features:

(i) The thallus is a non-green, multinucleate mass of protoplasm called the plasmodium.

(ii) The plasmodium lacks a definite cell wall, and thus is amoeboid in shape.

(iii) It is free living,diploid and holocarpic.

All free living slime molds are placed in class Myxomycetes.

II. Subdivision Eumycotina: All other fungi except slime molds are included in this division.it is heterogenous group with following features:

(i) The somatic phase with exception of few unicellular forms are filamentous thallus called mycelium.

(ii) The unit of thallus/Mycelia is not a cell but hypha.

(iii) The hyphal cellwall is composed of fungus cellulose called chitin.

(iv) Except few members all are Eucarpic.

(v) The septa between the cell wall have central pore.

(vi) The growth of filament is apical.

(vii) Reproduction by asexual and sexual methods.

(viii) There is gradual and progressive simplification and ultimate elimination of sexual apparatus from lower to higher fungal members.

The older mycologists divide the subdivision Eumycotina, which includes the true fungi, into four classes, namely, Phycomycetes, Ascomycetes, Basidiomycetes and Deuteromycetes.

The modern mycologists, consider that the class Phycomycetes, which includes all the lower fungi, is not a natural group of closely related forms. Alexopolous (1962) split the lower fungi included in the class Phycomycetes into six classes.

It is customary to divide the true fungi Eumycotina into two main groups, the lower and the higher Fungi.

A. The lower fungi (Phycomycetes) They have comparatively a simple thallus which in some is unicellular and in other filamentous (Mycelium) The septa usually remain suppressed in the actively growing vegetative mycelium. They reproduce asexually by sporangiospores (generally motile, rarely non-motile), rarely by conidia. The early mycologists placed the lower fungi in a single class Phycomycetes which is split into the following classes on the basis of presence or absence of motile cells in the life cycle and the number, form and position of flagella on motile cells.

NOTES

Motile Cells Produced

1. Class Chytridiomycetes. Includes the lower fungi in which motile cells have a single flagellum of whiplash type inserted at the posterior end (opisthocont) The members of this class are called the chytrids.
2. Class Hyphochytridiomycetes. The motile cells (zoospores) possess a single flagellum of tinsel type which is inserted at the anterior end.
3. Class Plasmodiophoromycetes. The motile cells (zoospores) are biflagellate. Both the flagella are of whiplash type but one of these is longer than the other. The longer one has a sharply pointed end and the shorter one has a blunt end.e.g Club root organisms.
4. Class Oomycetes. The motile cells are biflagellate. The two flagella are generally of equal length.with two types the tinsel and the whiplash type.e.g downy mildews and blights.
5. Class Zygomycetes. Motile cells are absent. Asexual reproduction takes place by sporangiospores which are encapsulated and wind disseminated. The common examples are the pin molds and the bread molds.
6. Class Trichomycetes. The motile cells are lacking. The asexual spores are produced exogenously at the tips of special hyphae (conidiophores) and are called the conidia.

Motile Cells Lacking

The higher fungi. The somatic phase consists mostly of a mycelium which is usually septate. The septa have each a central pore and thus are

incomplete. No motile cells are produced in the life cycle. The higher fungi comprise the following three classes :

NOTES

1. Class Ascomycetes. The characteristic spores of the sexual or perfect stage are endogenous in origin and are called the ascospores. They are produced within special, sac-like structures called the asci. Plasmogamy takes place by the fusion of gametangia or somatic hyphae. Somatic phase is usually a septate mycelium which multiplies asexually by **conidia,** rarely it is unicellular (as in the yeasts) and is propagated by budding or rarely by fission.

8. Class Basidiomycetes. The characteristic spores of the sexual or perfect stage are exogenous in origin and are called the basidiospores. They are borne externally usually on club-shaped structures called basidia. The somatic phase consists of a simple or complex mycelium with or without clamp connections. Sexual organs are lacking. Plasmogamy, however, takes place by hyphal fusion.

3. Form-class Deuteromycetes or Fungi Imperfecti. Included in this class are the higher fungi in which the sexual or perfect stage is unknown. The somatic phase consists of a septate mycelium which multiplies asexually by conidia. The conidia are produced on conidiophores which may occur isolated or may be aggregated to form complex structures such as synnema, pycnidia and acervuli.

Classification Proposed by G.C. Ainsworth (1973)

The well-known general purpose classification for fungi was proposed by Ainsworth (1966), and followed by himself in *Dictionary of fungi* (1971) and also in *The Fungi, An Advanced Treatise.* (Ainsworth, 1973), may be considered as an ideal scheme of classification that reflects natural relationship. In this system the fungi with plasmodia or pseudoplasmodia are classified in the division Myxomycota, whereas most of the remaining usually filamentous fungi under division Eumycota.

Classification Proposed by Contantine J. Alexpoulos and Charles W. Mims (1979)

NOTES

Alexopolous and Mims (1979) place all fungi, including the slime molds, in kingdom Myceteae of superkingdom Eukaryota. Kingdom Myceteae proposed by Alexopoulos and Mims (1979) includes 3 divisions, 8 subdivisions, 11 classes, 1 form class 3 subclasses and, 3 form subclasses. Their proposed classification of fungi is given in tabulated form. They divided the kingdom Mycetae in three divisions namely 1. Gymnomycota 2. Mastigomycota 3. Amastigomycota which are further subdivided into subdivision,classes, subclasses and orders.

Division I Gymnomycota : includes phagotrophic organism devoid of cellwall. It comprises of two subdivision namely Acrasiogymnomycotina andPlasmodiogymnomycotina.

Subdivision I Acrasiogymnomycotina ; it includes a single class Acrasiomycetes.

Class: Acrasiomycetes : Lack flagellated cell except one species.it comprises of two subclass Acrasiomycetidae and Dictyosteliomycetidae.

Subdivision II Plasmodiogymnomycotina. It split into two classes:

Class I Protosteliomycetes

Class II Myxomycetes ; It includes true slime molds and comprise of three subclasses namely

Subclass I.Ceratiomyxomycetidae: having one order Ceratiomyxales.

Subclass II Myxogasteomycetidae: It comprises four orders namely ,Liceales, Echinosteleales, Trichlales and Physarales.

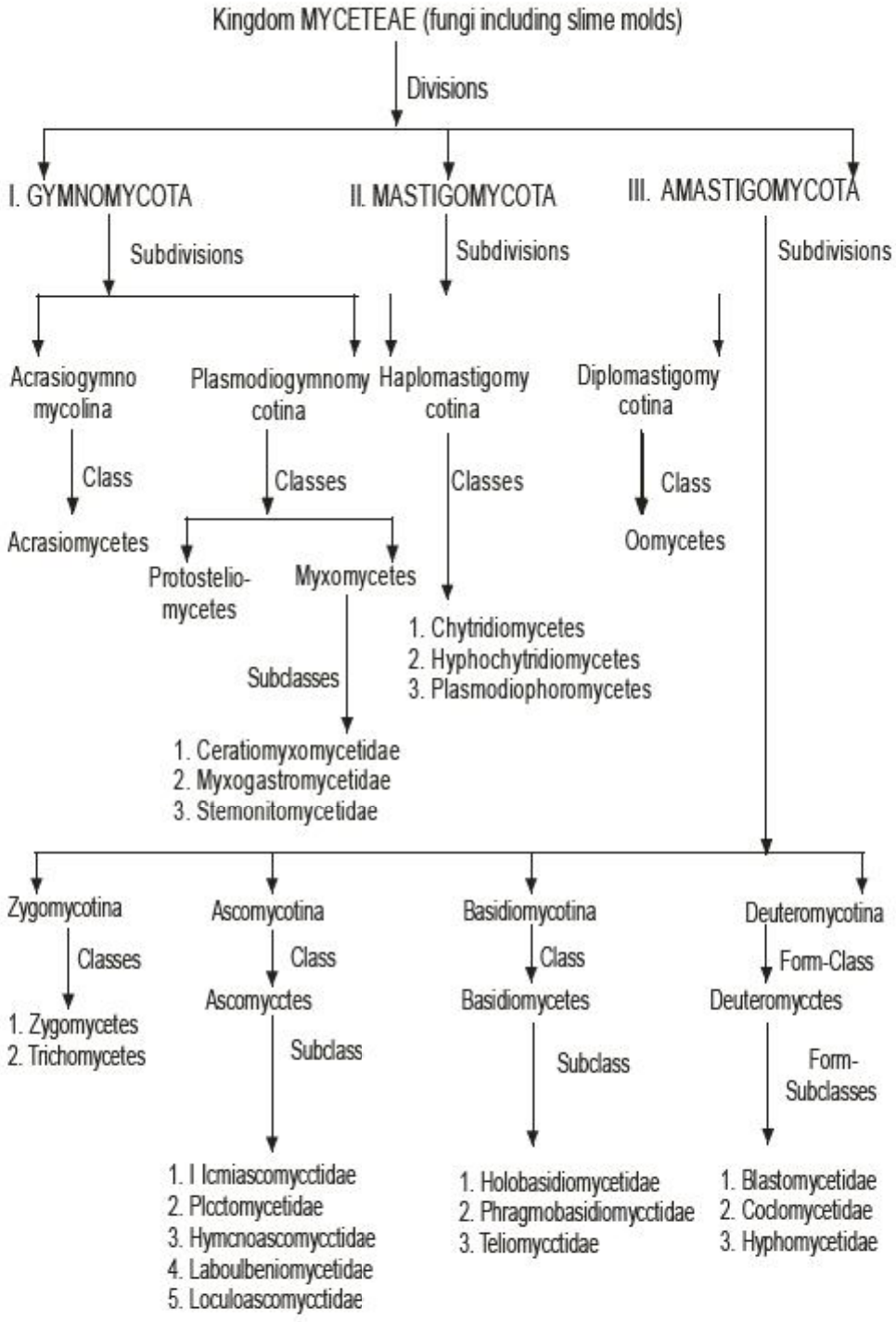


Table 10.2. Classification proposed by Alexopolous and Mims (1979)

Subclass 3.	Stemonitomycetidae with one order Stemonitales.
Division II.	Mastigomycota. Includes fungi with absorptive nutrition, unicellular or filamentous, mycelium coenocytic. It comprises two subdivisions :
Subdivision 1.	Haplomastigomycotina. Includes fungi with uni-or bi-flagellate zoospores. It comprises 3 classes :
Class 1.	Chytridiomycetes. Fungi producing zoospores furnished with a single whiplash flagellum inserted at the posterior end.
Class 2.	Hyphochytridiomycetes. Motile cells with a single tinsel flagellum inserted at the anterior end.
Class 3.	Plasmodiophoromycetes. Parasitic fungi producing biflagellate motile cells with both the flagella of whiplash type inserted at the anterior end.
Subdivision 2.	Diplomastigomycotina. Sexual reproduction oogamous, zoospores biflagellate, meiosis gametangial. This subdivision includes a single class :–
Class I.	Oomycetes. It comprises four orders namely, Lagenidiales, Saprolegniales, Leptomitales and Peronosporales.
Division III.	Amastigomycota. Fungi with absorptive nutrition, motile cells lacking, mycelium aseptate or septate. This division includes four subdivisions, namely Zygomycotina, Ascomycotina, Basidiomycotina and Deuteromycotina.
Subdivision 1.	Zygomycotina with two classes :
Class 1.	Zygomycetes. It includes six Orders.
Class 2.	Trichomycetes. It comprises five orders.

NOTES

Subdivision 2.	Ascomycotina. Fungi usually with a septate mycelium producing haploid ascospores in sac-like cells called Asci. This subdivision is represented by a single class :–
Class Ascomycetes.	It is subdivided into five subclasses as follows :–
Subclass 1.	Hemiascomycetidae comprising three orders
Subclass 2.	Plectomycetidae with five orders.
Subclass 3.	Hymenoascomycetidae with ten orders.
Subclass 4.	Laboulbeniomycetidae including two orders
Subclass 5.	Loculoascomycetidae with five orders.
Subdivision 3.	Basidiomycotina. Septate mycelium, produces basidiopores (meiospores) exogenously on various types of basidia. The subdivision includes a single class.
Class 1.	Basidiomycetes. It is split into three subclasses :
Subclass I.	Holobasidiomycetidae.
Subclass 2.	Phragmobasidiomycetidae
Subclass 3.	Teliomycetidae.
Subdivision 4.	Deuteromycotina. It includes imperfect fungi in which sexual stage is unknown. It comprises a single form class.
FormClass 1.	Deuteromycetes with three form subclasses namely Blastomycetidae, Coelomycetidae, and Hyphomycetidae.
Lichens.	Ascomycetous, Basidiomycetous and Deuteromycetous mycobionts, symbiotically associated with green or blue -green phycobionts) form various types of thalli.

10.7 Summary

NOTES

Fungi are among the most important organisms in the world. Reproduction is the method of formation of new individual having all the characteristics similar to that of parent from which it has arisen. Fungi generally reproduce by vegetative, asexual and sexual means.vegetative reproduction takes place by fragmentation, budding, Fission etc.The asexual reproduction is repeated several times during the season. Various types of asexual spores are produced by different fungal members like Zoospores, Aplanospores, Sporangiospore, Conidiospore and Arthospore etc. Sexual reproduction generally occurs only once ayear in the life cycle of any fungal member. The process of sexual reproduction consist of three phases i.e. plasmogamy Karyogamy and meiosis. Most of the fungi on sexual basis are classified in three main categories the hermaphroditic, Dioecious and the sexually undifferentiated group. Four specialized sexual spores are formed in fungi named, Oospore,Zygospore, Ascospore and basidiospore.

Based on sexual compatibility the fungal members belong to different groups like Homothallic, Heterothallic and secondary homothallic respectively. There are some fungi reported where true sexual cycle is absent and they derive the benefits of sexual recombination through a process known as parasexuality which is most common mode of sexual recombination in the members of Ascomycetes and Basidiomycetes.

Any act of grouping objects into categories is called classification.Initially fungi in their cellular organization being truly eukaryotic were kept in the plant kingdom.Earlier classification system were based on classic morphologic studies of past centuries.Major criteria used in the classification and phylogeny of fungi includes their morphology, anatomical characters, nutrition and physiology,cell wall composition,antigenic properties and molecular characters etc.Two important works have influenced fungal taxonomy the Ainsworth system and the Alexopolous and Mims system of classification.

One of the most important on line general classification of fungi is that of Genbank (www.ncbi.nlm.nih.gov/ Taxonomy)and tree of life web project (tolweb.org/tree).

NOTES

10.8 Glossary

- **Conidium:** A nonmotile asexual spore usually formed at the tip or side of sporogenous cell.
- **Dictyospore:** A spore with both transverse and longitudinal septa.
- **Flagellum:** A hair like structure with internal microtubules that serve to propel motile cell.
- **Gametangium :** The specialized cell types that becomes a fertile gamete producing cell during the sexual cycle.
- **Helicospore:** A coiled or helical conidium often found in aquatic fungi.
- **Heterokaryosis:** A condition in which genetically different nuclei are associated in same cytoplasm.
- Imperfect Fungi: Fungi that reproduce asexually only i.e Deuteromycetes
- **Perfect Stage:** The sexual state of a fungus.
- **Self Compatible :** Self Fertile thallus reproducing sexually without out crossing.
- **Zygospore:** A resting spore resulting from the fusion of two isogametangia in class Zygomycetes.

10.9 Self-Learning Exercise

Section A (Very Short Answer Type Questions)

1. Haustoria are produced

   a.by fungi parasitizing animal tissue b.by hyphae of obligate parasite c. in artificial culture d. hyphae of ectoparasitic fungi

2. Imperfect stage refers to the fungus of class

   a. Ascomycetes b. Basidiomycetes c. Deuteromycetes d. Zygomycetes

3. Clamp connection is the characteristic feature of class

   a. Basidiomycete b. Deuteromycetes c. Ascomycetes d. oomycetes

4. Isogametangial copulation is the feature of class

   a. Zygomycetes b. Oomycetes. C. Deuteromycetes d. none

5. The classification in fungi is based both on mycelia stages and.....

6. Parasexuality in fungi was reported by.....

7. Monoecious fungus is that which bears male and female sex organs on the .....thallus.

8. The group of fungi which lacks sexual reproduction are placed in the classs.....

9. The non motile asexual spores produced in fungi is called

NOTES

Section B (Short Answer Type Questions)

1. Who is credited with the discovery of Heterothallism and in whom?
2. Name the spore types produced through asexual reproduction in fungi?
3. Name the stages of sexual reproduction in fungi?
4. Define Heterokaryon?
5. What is dikaryon?
6. Name the types of sexual reproduction found in fungi?
7. Define parasexuality in fungi?
8. Give any two important characters of fungi used for their classification?

Section C (Long Answer Type Questions)

1. Give the scheme of classification of fungi proposed by Alexopolous and mention chief characteristic of each group?
2. Give a brief account of the general classification proposed by

Ainsworth?

3. Discuss main features of different classes of Fungi?
4. Write a detail note on sexual reproduction in fungi/
5. Discuss parasexual cycle and its importance in fungi?
6. Discuss the types of asexual spores found in fungi with suitable diagram?

NOTES

10.10 References and further readings

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Unit – 11

Phylogeny of Fungi and General Account of *Pilobolus, Chaetomium, Morchella, Melampsora, Polyporus, Drechslera & Phoma*

NOTES

Structure of the Unit

11.0 Objectives

11.1 Phylogeny of Fungi

11.1.1 Algal origin

11.1.2 Non-chlorophyllous unicellular origin

11.1.3 Protozoan origin

11.2 General Account of Fungi

11.2.1 Division Myxomycota

11.2.2 Division Eumycota

11.2.2.1 Subdivision Mastigomycotina

11.2.2.2 Subdivision Zygomycotina

11.2.2.2.a Class-Zygomycetes

Genus-***Pilobolus***

11.2.2.3 Subdivision Ascomycotina

11.2.2.3.a Class-Pyrenomycetes

Genus-***Chaetomium***

11.2.2.3.b Class- Discomycetes

Genus-***Morchella***

11.2.2.4 Subdivision Basidiomycotina

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11.2.2.4.a Classes-Teliomycetes

Genus- ***Melampsora***

11.2.2.4.b Class – Hymenomycetes

Genus- ***Polyporus***

11.2.2.5 Subdivision Deuteromycotina

11.2.2.5.a Class- Hyphomycetes

Form genus- ***Drechslera***

11.2.2.5.b Class: Coelomycetes

Form Genus- ***Phoma***

11.3 Summary

11.4 Glossary

11.5 Self-Learning Exercise

11.6 References and further readings

11.0 Objectives

After going through this unit you will be able to understand:

- the origin, evolution of fungi and their phylogenetic relationship with other organisms,
- general characteristic and broad classification of fungi,
- basis of classification of fungi and the major differences in different subdivisions or classes.
- detailed account and life cycle of the representative genus.

11.1 Phylogeny of Fungi

The early fossil record of the fungi is poor, as unlike other organisms, fungal structures do not fossilize well. Thus, theories on phylogeny of fungi are based on the morphological features of the extant fungi although other features are

also considered. It is considered that fungi have evolved from unicellular motile organism due to the fact that fungi possess flagellate condition.

Seward traced the existence of parasitic and saprophytic fungi from the Devonian period onwards. Phylogeny of fungi is studied on the basis of comparative morphology, cytology, serodiagnosis and fossil records. On the basis of these characters there are three different views regarding origin and evolution of fungi.

11.1.1 Algal origin: From the beginning of the 20th century fungi were proposed to be monophyletic. Alexander Braun (1847) declared that fungi were no more than collateral group of algae. It was assumed that all the fungi were derived from an algal ancestor after loosing its photosynthetic ability thus adapting to heterotrophic mode of nutrition. This gave rise to the flagellate fungi, from which rest of the fungi evolved. The loss of flagella and the evolution of zygospore gave rise to the Zygomycotina.

C.E. Bessey (1895), supported algal origin of fungi by the statement that the Phycomycetes are degenerate algae. He took into consideration only the superficial resemblance between algae and fungi completely overlooking their physiological processes.

There are many reasons to assume algae as nearest relative to fungi. For example, thread like filament, antheridial branch and oogonia of water moulds and the zoospores produced by some fungi. Pringshein (1858) supported this view. Others who supported this view were Cohn (1872), Sachs (1875), Brefeld (1885), C.E. Bessey (1895), E. A. Bessey (1835,45,55) and others.

Some mycologists proposed polyphyletic origin, with red algae as origin of Ascomycota. According to the supporters of this view Chytridiales have evolved from unicellular algae, the saprolegniales from Siphonales, the Zygomycetes from Conjugales and higher fungi from red algae. Sach (1875) suggested Floridean ancestry of the Ascomycetes on the basis of similarities between the Ascomycetes and the red algae in the reproductive structures in both the groups.

In late 1960s Oomycota was separated from the fungi. Slime molds were also separated into a different kingdom as well. Fungi were separated into two

kingdoms: All the flagellate fungi were placed in kingdom Protista (including Chytridiomycota and slime moulds) and the remainder in kingdom Myceteae.

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According to Brefeld (1885) higher fungi evolved in two lines each originating from distinct group of algae, one through Zygomycetes and other through Oomycetes.

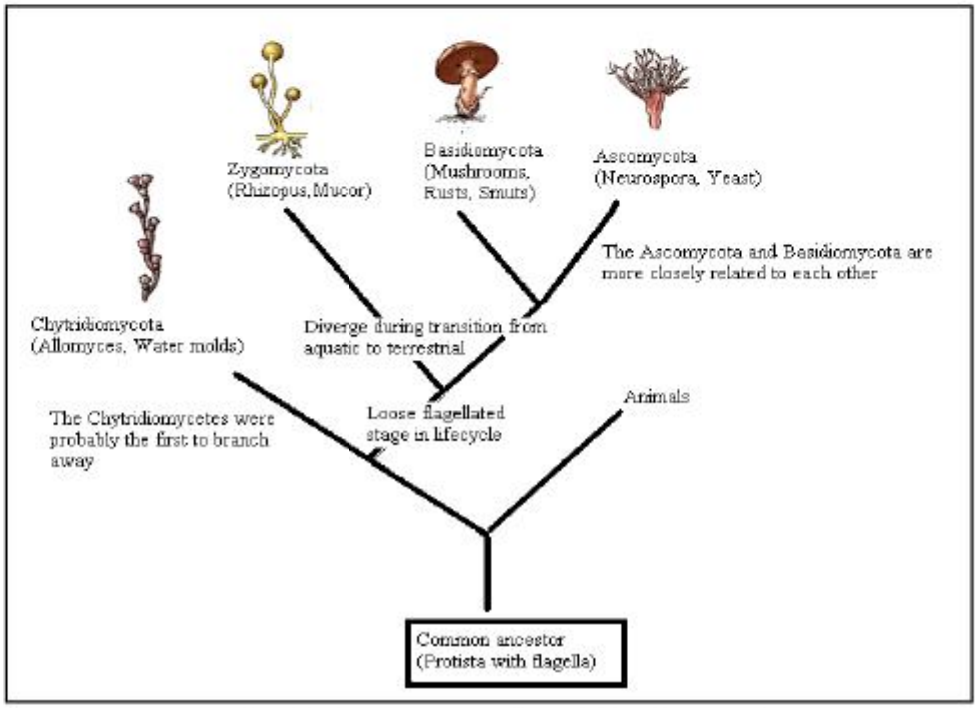


Fig. 11.1: Polyphyletic origin of Fungi

This idea was faded out in course of time because through physiological and cytological studies it has been established that the algae and fungi have parallel line of evolution having unicellular motile organism as their ancestor.

Algal ancestry of fungi was protested by De Barry (1881). He stated that the arrangement for classification of the Thallophyta by putting green organism (algae) and non green organism (fungi) is not a natural one due to the difference in their physiological processes. De Barry (1881) suggested that algae and fungi originated from unicellular green and nongreen ancestors independently in parallel lines of evolution. This view was supported by Atkinson (1909).

According to Dangeard (1886), J.H. Ashworth (1923) it is probable that fungi have evolved from lower forms along lines independent of those leading to plants and to animals.

11.1.2 Non chlorophyllous unicellular origin: Fischer (1892) and Atkinson (1909) suggested that the source of origin of fungi might possibly be sought in non chlorophyllous unicellular forms.

Copeland (1950) suggested three kingdom classification; Inophyta, Plantae and Animalia based on phylogeny. He placed most of the fungi, red and brown algae and all pigmented flagellates, nongreen algae and protozoa in the phylum Inophyta. He excluded the water moulds and the Myxomycetes from Inophyta. Pigmented forms (green algae, bryophytes and vascular plants) are kept under Kingdom Plantae.

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11.1.3. Protozoan Origin: Gobi (1884) was the first to propose an independent derivation of fungi from protozoa. It is based on similar metabolism and type of flagellation in both the Phycomycetes and Protozoans. On the basis of this theory the Phycomycetes have evolved from flagellates via Chytrids. These non-mycelial forms gave rise to the more advanced mycelial forms by progressive evolution. Many scientist who favoured this view include Dangeard (1886), Cavers (1915), Cook (1928), Martin (1935, 55) and Ingold (1959). They agreed that it is difficult to accept the derivation of fungi from algae.

Atkinson suggested that similarities in metabolic products and types of flagella are taken into consideration fungi should have originated from protozoa rather than from algae.

11.2 General Account of Fungi

E. A. Bessey (1950) classified fungi on the basis of reproductive characters. C. J. Alexopoulos (1962, 68) placed all fungi into division Mycota which was divided further into two subdivisions- Myxomycotina and Eumycotina on the basis of presence and absence of cell wall respectively. Whittakar (1969) proposed 5 kingdom classification under which Fungi was treated as a kingdom. Fungi are treated by Anisworth *et al.*, (1973) as a separate kingdom with two divisions one with plasmodial forms under division Myxomycota and the other with non plasmodial, unicellular or mycelial forms under division Eumycota with five subdivisions; Mastigomycotina, Zygomycotina, Ascomycotina, Basidiomycotina and Deuteromycotina.

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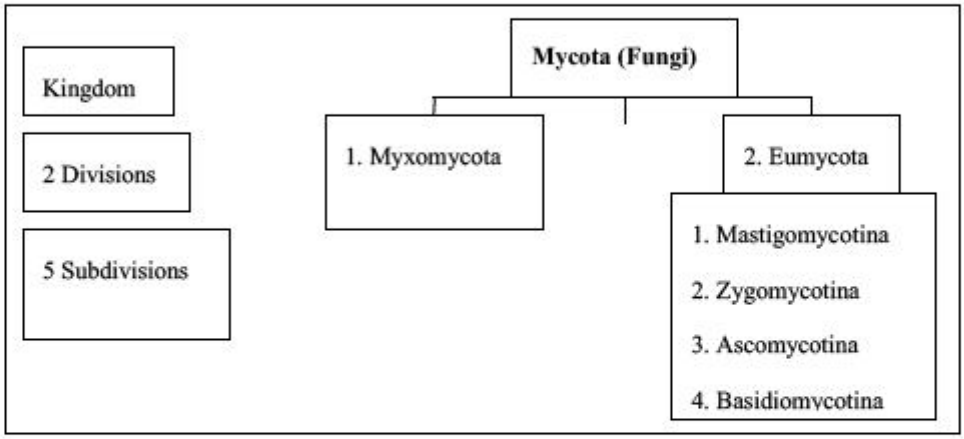


Fig. 11.2: Classification given by Anisworth *et al.*, (1973)

Kingdom – Mycota

Habitat : Saprophytic, parasitic, hyper-parasitic or symbiotic

Nutrition : Heterotrophic or absorptive organism,

Thallus : On or in the substratum, plasmodial, amoeboid or pseudo-plasmodial, unicellular or filamentous, achlorophyllous

Hyphae : Nonseptate/ septate, non-motile, with ptotoplasmic streaming

Motile stage : Zoospores/ gametes

Reserve food : Glycogen

Cell wall : Well defined composed of chitin but cellulosic in Oomycetes

Nucleus : Homo or heterokaryotic, haploid, very short diploid phase

Reproduction : Homo or heterothallic

Life cycle : Simple or complex, asexual and /or sexual

11.2.1 Division 1- Myxomycota

Vegetative thallus consists of net like or cellular structure; a plasmodium or pseudoplasmodium. They are naked (lacking a cell wall) during stages of development and culminates in the formation of spores which are walled structures. During entire or part of their life cycle they are more or less amoeboid, ingest solid food particles and reject the undigested food (Phagotrophic). When the spores germinate, it gives rise to either a simple uninucleate amoeboid cell or myxamoeba or planocyte provided with one or two anterior flagella. These flagella are retracted, forming myxamoebae. Both myxamoebae and planocyte multiply by fission. Myxamoebae by repeated

division of the protoplast give rise to a plasmodium which is multinucleate. In some, myxamoebae / planocyte fuse (sexual reproduction) and just before spore formation meiosis occurs. Thus spores are haploid.

11.2.2 Division 2-Eumycota (true fungi)

The fungi included in this division possess a definite cell wall. They are composed of chitin or hemicellulose. True cellulose is present in Oomycetes. The vegetative thallus of Eumycota vary from single-celled short lived organism whose entire cell is transformed into reproductive structures (Holocarpic eg. *Synchytrium*) to massive mycelia, which are perennial, giving rise to large spore bearing fruiting bodies as in mushrooms, puff balls or pore fungi.

Sexual reproduction involves a process of nuclear fusion and meiosis. This results in the formation of fructification or fruit body. Nature of the fructification is used from the beginning to divide true fungi into four major sub-divisions; Mastigomycotina, Zygomycotina, Ascomycotina, Basidiomycotina. Sub-divisions Deuteromycotina lack telomorphs (sexual or perfect stage) and most of the members of the subdivision are anamorphs (asexual stage).

11.2.2.1 Subdivision I- Mastigomycotina

Members of Mastigomycotina possess flagellate zoospores. In the biflagellate zoospores, flagella may be apically or laterally attached. The whiplash type is directed backwards while the tinsel type is directed forward. In anteriorly uniflagellate forms have tinsel type and posteriorly uniflagellate ones have whiplash type of flagella. Subdivision Mastigomycotina is classified further into 3 classes;

Class 1- Chytridiomycetes; Zoospores posteriorly uniflagellate, flagella of whiplash type. Thallus holocarpic, eucarpic, monocentric or polycentric. They lack true mycelium. 4 orders

Class 2- Hyphochytridiomycetes; Zoospores anteriorly uniflagellate with tinsel type flagellum. Thallus similar to Chytridiomycetes with vegetative system rhizoidal or hypha-like with intercalary swelling. Sexual reproduction by isogamous fusion.

Class 3- Oomycetes; Terminally or laterally biflagellate zoospores. Sexual reproduction oogamous. Thallus holocarpic, endobiotic and monocentric. 4 orders

NOTES

11.2.2.2 Subdivision II- Zygomycotina

Members of this subdivision produce highly branched coenocytic mycelium. Septa are laid down only to differentiate reproductive structures like sporangia or gametangia. Older hyphae also develop septa. Asexual reproduction is by aplanospores (non motile spores) and sexual reproduction is by gametangial fusion to give rise to zygospores. This subdivision has two classes:

Class 1-Zygomycetes and **Trichomycetes**

Class- Zygomycetes

These are terrestrial fungi that thrive and sporulate in damp places. Zygomycetes produce extensively branched, coenocytic, wide, thin walled mycelium. They can access and assimilate only substances like starch and sugars. The asexual spores are nonmotile sporangiospores, or true conidia. Sporangiospores are formed by modified sporangial units functioning as conidia. Sexual state is represented by zygospore or resting spore developed by the fusion of two gametangia (entirely zygogamous)

Four orders: Mucorales, Glomales, Enteromophthoales and Zoopagales

Order- Mucorales

Mycelium consist of well developed coenocytic hyphae; septa develop during formation of reproductive structure; Asexual reproduction is by sporangiospores which are nonmotile produced in terminal sporangia or rarely by conidia. The zygospore germinate by producing a germ sporangiophore which terminally bears a sporangium

Family- Pilobolaceae

Sporangiospores are developed in discoid or lenticular sporangium. Sporangial wall is black and heavily cutinized in the upper portion. In most species, sporangium is provided with sub-sporangial vesicle. At maturity, sub-sporangial vesicle is shot away under the influence of light. Zygospore is usually lifted up from the substratum by tong like hyphal growth during its growth.

Genus- *Pilobolus*

Systematic position:

Division	Eumycota
Subdivision	Zygomycotina
Class	Zygomycetes
Order	Mucorales
Family	Pilobolaceae
Genus	*Pilobolus*

NOTES

Pilobolus grows on the fresh dung of herbivorous animals, especially on horse-dung. It exhibits phototropic reactions. The mycelium of *Pilobolus* is composed of repeatedly branched coenocytic hyphae which spread in all directions through the substratum. The part of the fungus which rises above the surface of the substratum consists of the stalk bearing the sporangium: Water drops remain adhering on the stalk glitter in the early morning sun. The stalk swells up near the tip into a little globule, surmounted by a black cap, which is the sporangium itself.

Asexual Reproduction: The fungus reproduces asexually by the development of sporangia and sporangiospores. Spherical sporangiophore primordium or primary bulb develops as a minute orange protuberance slightly above the substratum. This bulb is cut off from the greatly enlarged end of the hypha by a transverse septum. Sporangiophore and sporangium are developed from this primary bulb or the primordium. The spherical primordium is packed with minute globules of yellow oil. Then an intensely yellow branch grows up from the bulb into the air assuming upright position.

Tip of the young sporangiophore is markedly phototropic. The tip of growing sporangiophore then swells up into a minute spherical bulb which is destined to become the sporangium. The swollen tip enlarges more and more to form a nearly spherical sac like structure which ultimately develops into a sporangium. Sporangium is filled with protoplasm containing oil drops giving yellow colour and the sporangiophore region becomes more or less colourless. The contents of the sporangium divide to form a large number of protoplasmic fragments, each of which surround itself with a cell wall and become a spore. At the same time the upper part of the sporangial wall begins to blacken and the subsporangial region starts to swell into a bladder-like structure which is much larger than the sporangium itself, and is known as a **subsporangial vesicle**.

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Often a second bladder is formed in the lower part of the sporangiophore which is anchored to the substratum by rhizoids. The entire portion of the sporangiophore between the two transverse septa constitutes a water-reservoir, in which a high hydrostatic pressure is set up, so that drops of liquid often exude through the lateral wall of the sporangiophore. Owing to this pressure, the septum lying at the base of the sporangium bulges into it forming what is known as **columella**.

The sporangium is solitary, discoid to lenticular and many spored. The wall of the sporangium itself is not uniform throughout; the upper part is thickened dark and cutinized bearing bristles with crystals of calcium oxalate, while the lower part adjoining the columella remains thin and is light coloured.

The sporangiophores are positively phototropic. The sporangiophore including the subsporangial vesicle contains clear watery liquid except at the base of the subsporangial vesicle where a conspicuous zone is invariably found due to accumulation of carotinoid orange pigment. This zone appears to the naked eye as a minute orange spot at the base of the subsporangial vesicle and has been interpreted by Buller (1921) as a eye-spot, the subsporangial vesicle being regarded as a lens focussing the light on the sensitive spot.

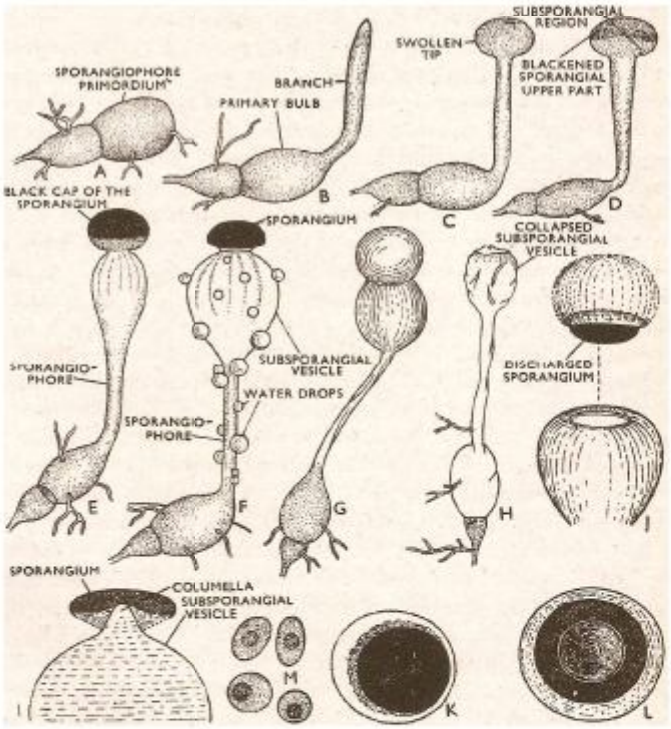


Fig. 11.3: ***Pilobolus*** **sp.** A-F Stages in the development of sporangium,

sporangiophore and subsporangial vesicle; G, H and J Stages in the discharge of sporangium; 1 Details of sporangium, columella and subsporangial vesicle; K-L Closer view of sporangia; M Sporangiospores.

The sporangium of *Pilobolus* is discharged in response to light. Due to phototropic movement of the sporangiophore, the sporangium tends to be directed towards open space. Inside the lower part of the sporangium there is a mucilaginous layer which coming in contact with water swells bursting the delicate wall so that the sporangium becomes free from the columella. The balanced hydrostatic pressure of the columella is no longer maintained as soon as the sporangium is set free from the columella, consequently the columella bursts which results in the squirting out of a jet of fluid from the sporangiophore which has been behaving as a reservoir, and ultimately projecting the sporangium violently to a great distance. The sporangium so hurled sticks to any object which it happens to hit, owing to the mucilage which still clings to it and also due to adhesive sporangial wall. The spores are eaten along with grass by herbivorous animals and become disseminated with the dung. Passage of the spores through the alimentary canal of the animals facilitates germination producing new individuals.

Sexual Reproduction: Sexual reproduction takes place by the process of isogametangial copulation. The development of gametangia takes place only when there is some hindrance in the formation of sporangia. During sexual reproduction two neighboring hyphae of the mycelium enlarge, and become club-shaped. The swollen portions grow upright placing themselves together side by side. At the same time a large quantity of protoplasm accumulates in them. The tips of the conjugating hyphae lie in such a position as to give the appearance of a pair of tongs. They are then cut off by transverse septa, one in each. The tips so delimited are the gametangia and the rest are the suspensors.

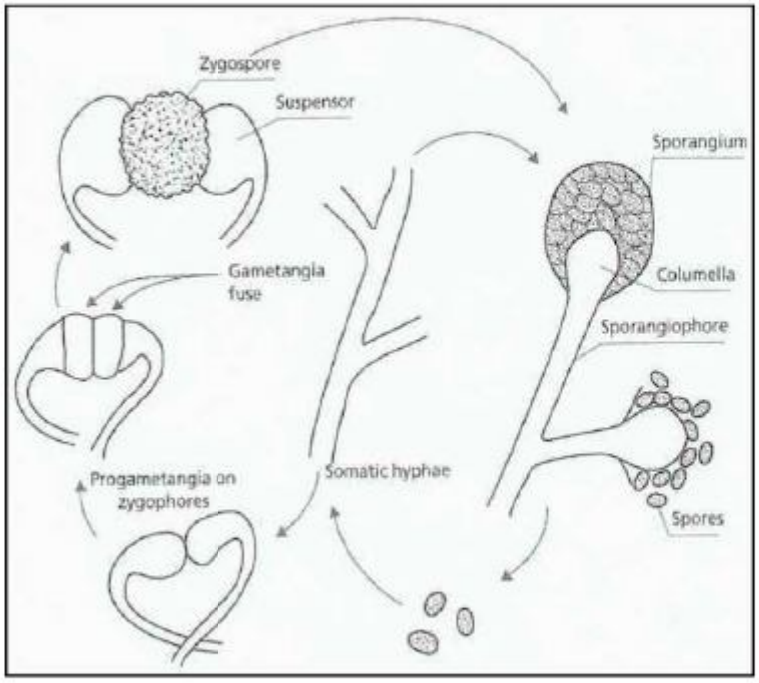


Fig. 11.4: Stages in Sexual Reproduction in *Pilobolus* species

The gametangia contain thick multinucleate protoplasm. Their common walls are dissolved. Plasmogamy, formation of a mass of protoplasm and pairing of nuclei follow in stage. The gametangia completely fuse into a single zygospore which rests upon the two suspensors. The suspensors give the appearance of a pair of tongs. The zygospore grows in size with a very tough and thick wall. After a long period of rest the zygospore germinates by the production of a germ tube which grows into a new mycelium. But more frequently the germ tube produces a germ sporangium at its tip. The spores of germ sporangium are dispersed after maturity and germinate to produce new individuals. Meiosis occurs during zygospore germination.

It has been experimentally demonstrated that in *P. crystallinus crystallinus* is heterothallic. It defines sexual strains which will alone conjugate with one another and produce zygospore whereas the hyphae of the same strain will not fuse sexually among themselves and fail to form zygospores.

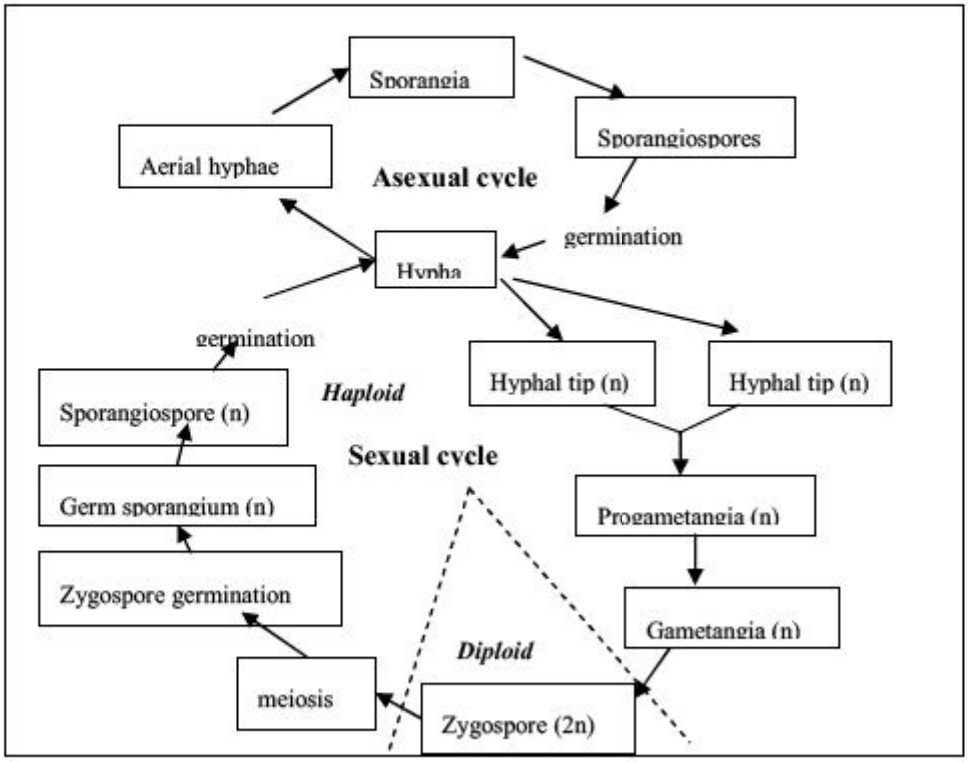


Fig. 11.5: Diagramatic life cycle of *Pilobolus*

11.2.2.3 Subdivision III– Ascomycotina

The primary character that distinguishes member of Ascomycotina is the formation of an ascus; a sac like structure which contains meiospores known as ascospores. Ascospores are haploid. They germinate to give rise to haploid uni or plurinucleate hyphae. The hyphal septum has a pore in the centre. The end around this pore is inflated and has on either side a hemispherical perforated cap. Such pore bearing septum is called dolipore septum. In sexual reproduction there is an interval between plasmogamy and karyogamy. After sexual fusion (plasmogamy) there is a prolonged dikaryophase which is dependent on monokaryotic mycelium for nutrition. Thus three phases clearly encountered in the sexual cycle of Ascomycotina are; Haplophase, dikryophase and Diplophase. Compatible nuclei in dikaryophase multiply and a system of ascogenous hyphae develops within the monokaryotic (haploid) vegetative tissue.

Diplophase in Ascomycotina is very brief. Sexual fusion occurs at the stage of formation of ascospores. The process of fusion of nuclei and formation of

ascospores is elaborate (*Fig. : 6*). Meiosis follows immediately after karyogamy producing haploid nuclei and reinstating haploid condition. The haploid tissue forms the framework of the ascoma. The ultimate branches of the ascogenous hyphae arrange themselves in hymenium.

NOTES

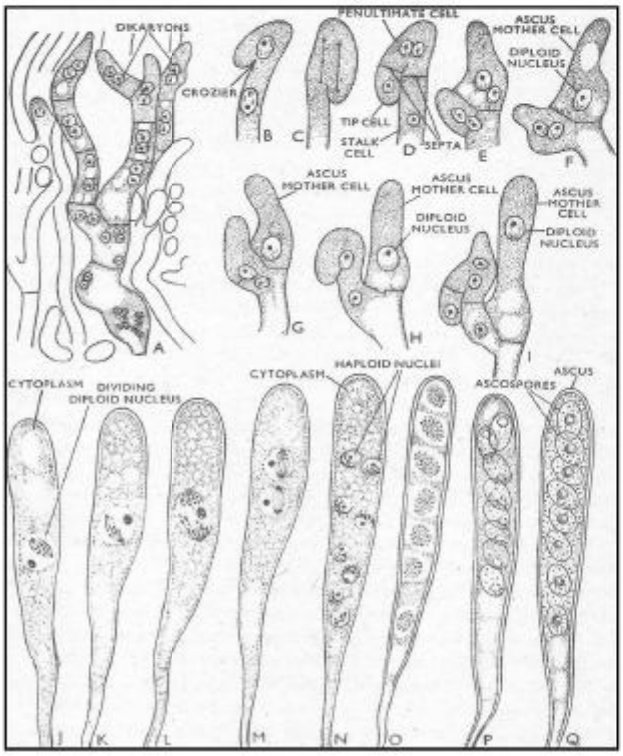


Fig. 11.6 : Development of Ascus and Ascospores from Ascogenous hypha (in *Pyronema confluence).* A; Forking of ascogenous hyphae with dikaryotic cells. B; Bending of tip of ascogenous hypha and crozier formation. C; Nuclei of crozier diving by conjugate division. D; Binucleate penultimate cell and uninucleate stalk and tip cells. E; Elongated binucleate penultimate cell, wall between stalk and tip cells dissolve to get dikaryotic cell below the penultimate cell. F; Ascus mother cell with a diploid nucleus and a dikaryotic cell below. G-I. Subsequent stages of growth of the ascus mother cell. J-Q; Successive stages in the development of ascus and ascospores from diploid nucleus.

Sexual reproduction, the resulting fruit bodies and the asci are the basis for the further classification of Ascomycotina into **six classes; Hemiascomycetes** (3 orders), **Plectomycetes** (1 order), **Pyrenomycetes** (4 orders), **Loculoascomycetes** (5 orders), **Laboulbeniomycetes** (1 order) and **Discomycetes** (6 orders)

11.2.2.3.a Class - Pyrenomycetes

Pyrenomycetes are characterized by the formation of perithecia. Asci are arranged regularly and are intermingled with paraphysis. Perithecia of pyrenomycetes have a distinct apical rarely lateral ostiole guarded by periphysis. Pyrenomycetes are divided into four orders; Erysiphales, Meliolales, Coronophorales and Sphaeriales.

NOTES

Order -Sphaeriales

Most of the members of the order are saprophytes, but a few are parasites or coprophilous. Asexual reproduction usually takes place by means of conidia which are formed on conidiophores. Sexual reproduction takes place by spermatia which fuse with the trichogyne of ascogonia. The fruiting body is usually flask-shaped or spherical perithecium and have bright fleshy or dark membranous or carbonaceous wall. Ostiole is provided with paraphysis in some species. This order contains 14 families.

Family - Melanosporaceae

The fruiting bodies or perithecia are with an ostiole at the tip. The asci are globose or oval; each ascus has eight dark coloured asci each of them having one or no germ pore; the wall of the ascus gets dissolved and the ascospores fill the cavity of the perithecium. Ascospores are released from the perithecium in a mucilagenous tooth paste like matrix.

Genus- *Chaetomium*

Systematic position:

Kingdom	Mycota
Division	Eumycota
Subdivision	Ascomycotina
Class	Pyrenomycetes
Order	Sphaeriales
Family	Melanosporaceae
Genus	*Chaetomium*

NOTES

Chaetomium (described by Kunze in 1817) is a dematiaceous filamentous fungus found in soil, air, and plant debris. It is an important cellulose-degrading fungus which destroys paper, fibers and other cellulose rich materials. The genus has about 80 species and all of them produce long beaked perithecia with hairs on their surface. On the basis of this characteristic shape and structure of perithecia, the genus can be easily identified. Presence of thin and long hairs on the outer surface of the perithecium is a characteristic feature of *Chaetomium.* The genus is named on this character (Gr. *Chaete* = long hair).

The most common ones are *Chaetomium atrobrunneum*, *Chaetomium funicola*, *Chaetomium globosum*, and *Chaetomium strumarium*. *Chaetomium thermophile* is a thermophilic and coprophilous fungus.

As well as being a contaminant, *Chaetomium* spp. are also encountered as causative agents of infections in humans. They are among the fungi causing infections wholly referred to as phaeohyphomycosis. Fatal deep mycoses due to *Chaetomium atrobrunneum* have been reported in an immuno-compromised host. Brain abscess, peritonitis and cutaneous lesions may also develop due to *Chaetomium* spp.

Mycelium of *Chaetomium* usually grows on the surface of the substratum and is profusely branched, septate and multicellular. The cells of the mycelium are multinucleate. *Chaetomium* colonies are rapidly growing, cottony and white in colour initially. Mature colonies become grey to olive in colour. From the reverse, the colour is tan to red or brown to black.

Only a few species of *Chaetomium* reproduce asexually through conidia. Conidia are produced at the tip of the aerial branches of the mycelium.

Chaetomium has both homothallic and heterothallic species. Female sex organs or ascogonia develop as lateral outgrowths of the vegetative mycelium. In early stages of the development, the ascogonia are coiled, aseptate and multinucleate but towards maturity they develop septa. At this stage terminal cell of each ascogonium develops into a long trichogyne which functions as the receptive organ.

Male reproductive structures or antheridia are absent in *Chaetomium.* In some species plasmogamy is brought about by somatogamous copulation.

Immediately after plasmogamy, one or more ascogenous hyphae develop from the ascogonium. Each cell of the ascogenous hypha has a dikaryon. The terminal cell of the hypha bends to form a hook-like structure which is known

as crozier. Both the nuclei present in the crozier undergo simultaneous divisions (conjugate division) as a result of which four daughter nuclei are formed. After these divisions two septa are laid down in the crozier in such a way that it gets divided into three cells. Of these the penultimate cell has two daughter nuclei and the apical and basal cells have one nucleus each. Both the nuclei present in the penultimate cell fuse to form a diploid nucleus and this cell now functions as ascus mother cell. It develops into an oval or cylindrical ascus. The diploid nucleus present in the ascus undergoes a meiotic and a mitotic division as a result of which eight haploid nuclei are formed. A wall is secreted around each nucleus and eight nuclei eventually develop into eight ascospores.

NOTES

The fruiting bodies occur on the surface of the substratum. Many sterile hyphae develop around sex organs during development of ascogonium and ascogenous hyphae. They develop a multilayered wall called peridium. It eventually assumes the shape of a flask. Such a fruiting body is known as perithecium. Perithecia are large, dark brown to black in colour, fragile, globose to flask shaped and have filamentous, hair-like brown to black appendages (setae) on their surface. The neck of the perithecium elongates into a beak like structure and has ostioles (small rounded openings). Perithecia contain asci and ascospores inside. The inner wall of perithecium is lined with hairs called paraphyses. The setae in the apical part of perithecium are either curly (e.g., C. *globosum)* or forked at the tip (e.g., C. *thermophile).*

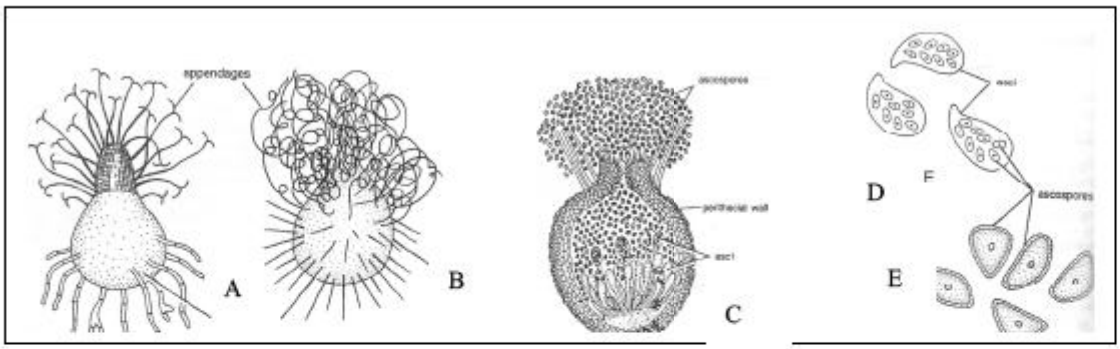


Fig. 11. 7: A-B. *Chaetomium:* Perithecium; A. *Chaetomium thermophile,* B. *Chaetomium globosum,* C. L.S. perithecium, D & E. Ascus, Ascospores.

Asci are clavate to cylindrical in shape. They are borne in groups at the base of the perithecium. The wall of the asci is mucilagenous. It disintegrates before the

maturity of the fruiting body and consequently the ascospores get embedded in the mucilagenous jelly present in the perithecium. The ascospores are released from perithecium along with mucilagenous matrix in the form of paste. Asci rapidly dissolve to release their ascospores (4 to 8 in number). Ascospores are one-celled, olive brown in colour, and lemon shaped. Each ascospore on germination gives rise to a mycelium.

NOTES

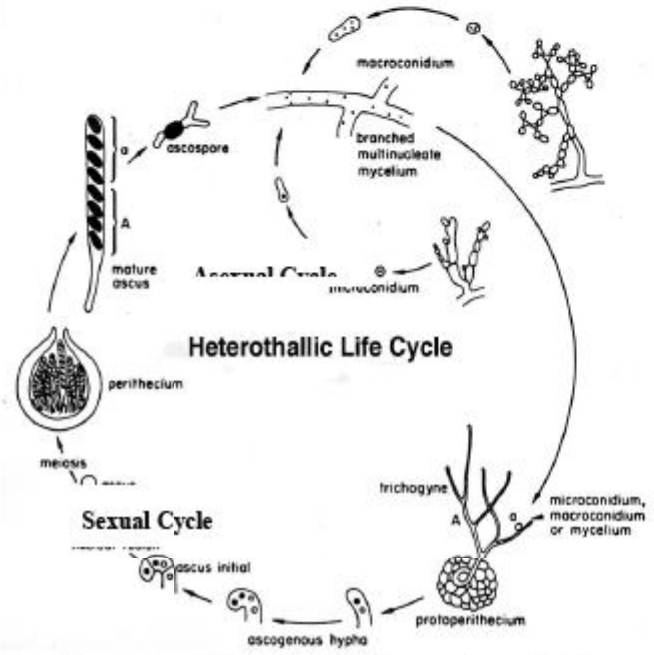


Fig. 11.8: Life cycle of Heterothallic species of *Chaetomium*

11.2.2.3.b Class- Discomycetes

The most distinguishing feature of this group is the formation of an apothecium. The apothecium may be sessile or stalked. It has an open hymenium consisting of both asci and paraphysis arranged in palisade like layer. The hymenium may be concave (*Peziza*), convex (*Pyronema*) or thrown into several folds (*Morchella*). The hymenial layer is bordered by the apothecial margin which may be at the same level as the hymenium or may extend beyond its level or, in rare case, a little below its level. The tissue which comprises the margin is known as the *ectal excipulum*, which extend downwards to form the flanks of the apothecium. The tips of the paraphysis which extend beyond the level of asci are glued together in a matrix to form a pseudoepithecium or they may branch apically to form epithecium.

Order- Pezizales

Members of the order are mostly saprophytes but a few parasites causing serious diseases of cultivated plants. Fungi reproduce both asexually and sexually. Asexual reproduction is by conidia but not so widely encountered. Sexual reproduction results in the formation of an ascocarp in which asci and ascospores are produced. The ascocarp may be from cup shaped or discoid being sessile or stipitate, to subglobose or columnar, pileate (pilus being saddle or bell or ridged sponge like). Asci are unitunicate and operculate; usually large symmetrical ellipsoidal or spherical ascospores. Ascus dehisces by an operculum or by pore.

NOTES

Family- Morchellaceae

Family is characterized by its large, stalked, honeycombed, companulate, pileate fruit body. Fertile region is cup shaped when young later become convex. The hymenium may be smooth or become grossy folded by unequal growth of the hymenial surface which is thrown into folds. The asci dehisce by the separation of a lid from the top. Copulation occur somatogamously or even autogamously as sex organs are completely lacking. Asexual reproduction is absent. This family is characterized by its smooth elliptical ascospores, without prominent internal oil drops.

Genus-*Morchella* (Guchhi)

Systematic position:

Kingdom	Mycota
Division	Eumycota
Subdivision	Ascomycotina
Class	Discomycetes
Order	Pezizales
Family	Morchellaceae
Genus	*Morchella*

NOTES

Morchella is a saprophytic genus occurs mainly on humus-rich soil and commonly grows on dead leaves and branches of deciduous trees. They are known as true morel, sponge mushroom or guchhi. It is most highly prized edible genus used as a delicacy. The genus is represented by eight species in India. *M. deliciosa* and *M. esculenta* are grown in Kashmir, Uttar Pradesh, Himachal Pradesh and Punjab.

Vegetative structure, mycelium is inconspicuous and subterranean, growing a few centimeters deep in the substratum. Mycelium is profusely branched, loosely interwoven and septate. The hyphal cells are multinucleate.

After rainy season aerial fruiting body (ascocarp) develops on the surface of the substratum. When sufficient food material is available the mycelium grows rapidly and hyphal mass aggregates under the soil surface and forms a compact structure, known as hyphal knot. The hyphal knot develops into a stalked fruiting body under favourable growth conditions. The young fruiting body is cup-shaped and asci are arranged in it vertically. Later growth of the hymenial surface is irregular. Thus the fruiting body develops many ridges and depressions and becomes folded. The folds in the hymenial layer increase the fertile surface of the fruiting body. The hymenium appears like a sponge at this state.

The mature ascocarp is 3-13 cm in length and it is differentiated into two parts; stipe and pileus. The stipe is a stalk-like structure, thick, fleshy and hollow structure of light yellow colour, measuring 1-2 cm in diameter. It is made up of pesudoparenchymatous tissue.

The pileus is a brown or black, hollow cap like conical structure and constitutes the fertile part of the ascocarp. The pileus is differentiated into the following three regions; (a) the innermost region (Trama) of the pileus is pseudoparenchymatous and is composed of sterile hyphae and (b) Sub-hymenium region (Hypothecium) is present outside the trama and is composed of many closely packed interwoven hyphae. (c) The fertile region of the pileus (Hymenium) is confined only to the grooves.

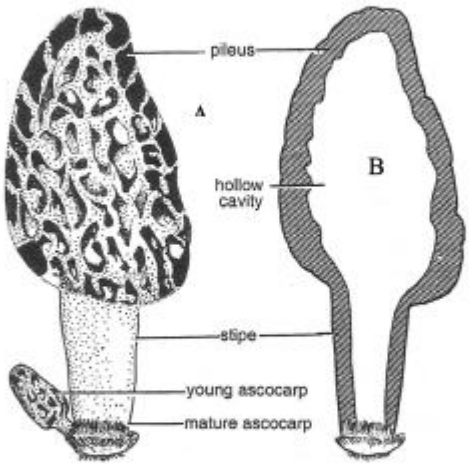


Fig.11.9: *Morchella*: Apothecium A; entire B; Longitudinal section

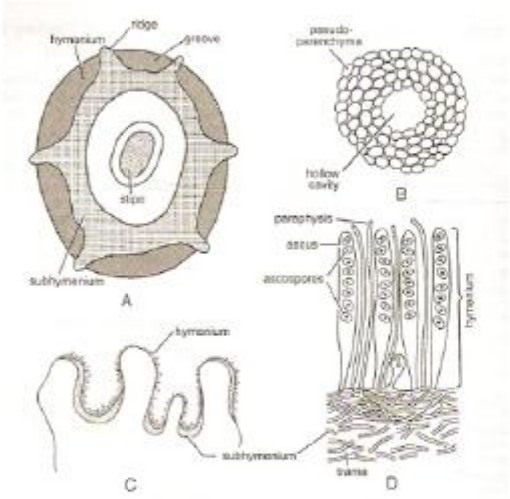


Fig.11.10: Internal structure of ascocarp; A; Diagrammatic representation of T.S. Pileus, B; T.S. Stipe, C; V.S. Pileus, D; A part of hymenium

In the hymenium, cylindrical, elongated and club-shaped hyphae are arranged perpendicular the surface of the pileus and they form a palisade like layer of asci and paraphysis. Each ascus bears eight ascospores placed obliquely in a single row. Ascospores are oval, hyaline and uninucleate. The paraphysis helps in the dispersal of ascospores. As the asci absorb water, the turgor pressure increase and ascospores are released through the apical pores.

Asexual reproduction is not known in *Marchella* and it reproduces only by the sexual method. Apparent sex organs are not formed in *Morchella* and the fruiting body (ascocarp) develops after the establishment of dikaryophase. Dikaryophase can be established in *Morchella* by two ways.

1. Somatogamous copulation or fusion of two somatic cells (somatogamy) where two somatic hyphae of the subhymenium region come in contact with each other and the intervening walls between these cells dissolved. The protoplasts of both the cells mix freely and two nuclei, one from each cell, pair to form a dikaryon. The remaining nuclei degenerate.

2. Autogamous pairing where dikaryon is formed by pairing of the two nuclei of the same somatic cell (autogamy). The remaining nuclei of the cell degenerate.

In both, somatogamy and autogamy, the fusion of nuclei takes place along the two steps; plasmogamy and karyogamy. In plasmogamy, the protoplasts of the

two fusing cells mix with each other and all nuclei are transferred to one cell. These nuclei do not fuse and establish dikaryophase. The dikaryotic cell formed after somatogamous copulation or autogamous pairing gives rise to many ascogenous hyphae. Each ascogenous hypha contains a pair of nuclei, formed by the division of the dikaryon. The terminal dikaryotic cell of the ascogenous hypha functions as ascus mother cell. During karyogamy the two nuclei of the dikaryon present in the ascus mother cell fuse to form a diploid nucleus, the synkaryon.

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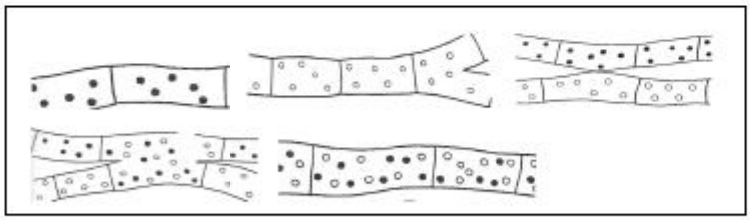


Fig. 11.11 : Karyogamy

After the fusion of the nuclei, the ascus mother cell elongates to form a cylindrical structure known as ascus. The diploid nucleus of the ascus divides by a meiotic division, followed by a mitotic division forming eight haploid nuclei. Each nucleus secretes a thin wall around itself and develops into an ascospore.

Ascospores are released from the ascus by the removal of the apical lid and are disseminated by wind. They germinate on a suitable substratum to produce new mycelia.

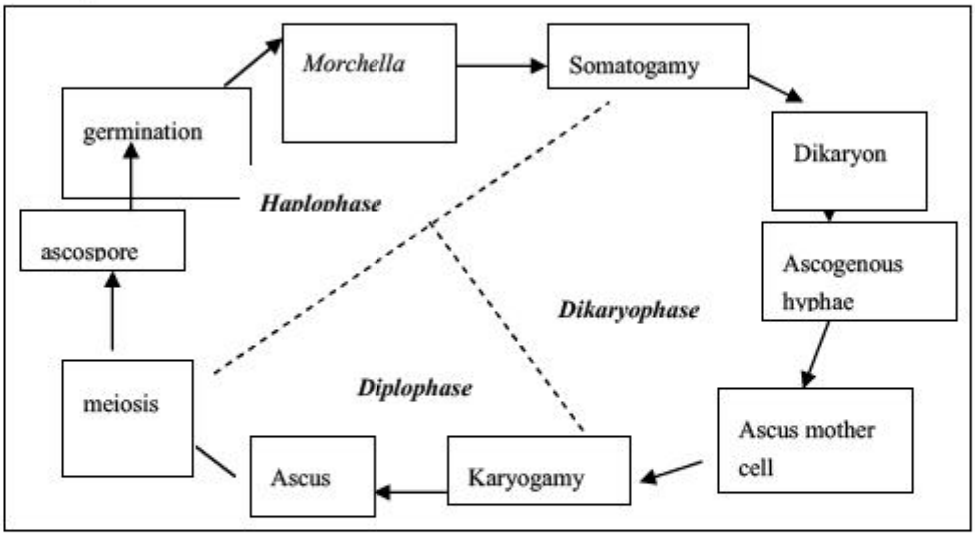


Fig. 11.12: Life cycle of *Morchella*

11.2.2.4 Subdivision IV - Basidiomycotina

The sexual spores are basidiospores. The spore bearing structure is a basidium on which basidiospores are born. The basidiospores are produced externally on sterigmata which are projections on basidia. The basidia are external and are terminal cell of the dikaryotic hyphae. Karyogamy and meiosis occur in basidia. The number of basidiospores per basidium is usually four but two spored basidia (*Agaricus bisporus*) and nine spore basidia (*Phallus impudicus*) also occur.

NOTES

The somatic mycelium in a course of development passes through three stages; monokaryotic primary mycelium, dikaryotic secondary mycelium and a portion of dikaryotic mycelium producing sterile tissue, tertiary mycelium. Secondary mycelium is characterized by the presence of bridge like hyphal connections known as **clamp connections.** Clamp connection is the bridge like hyphal connections characteristic of Basidiomycotina.

Members of the Basidiomycotina is further divided into **three classes; Teliomycetes, Hymenomycetes and Gastromycetes.**

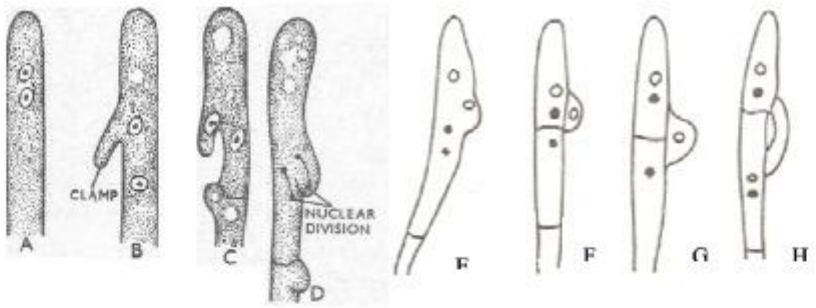


Fig. 11.13: Successive stages in the development of clamp connection. A; Binucleate terminal dikaryotic cell is ready to divide. B; Clamp is formed on the lateral wall in the middle of the cell and between the two nuclei. C; The clamp grows backward, one nucleus move into the clamp and other remains behind its base. D & E; Two nuclei divide simultaneously (conjugate division). F; One of the four daughter nuclei is imprisoned in the clamp until the growing clamp come in contact with the lateral wall. Two septa appears, one at the base of the clamp along the main axis and other directly under the clamp. G & H; wall

between clamp and lateral wall dissolves and the nucleus in the clamp moves to the basal cell.

NOTES

11.2.2.4.a Classes-Teliomycetes

Members of Teliomycetes do not produce basidiocarp but produce teliospores which on germination produce basidiospores. These teliospores are produced in sori or scattered within the host tissue and are parasitic on vascular plants. This class is divided into two orders; Uredinales (rusts) and Ustilaginales (smuts).

Order- Uredinales

Members have pleomorphic lifecycle, usually heteroecious, sometimes autoecious. The lifecycle of a macrocyclic rust produce five types of spores (a) Pycnospores in pycnidia (haploid stage) (b) Aeciospores in aecial cups (dikaryotic phase) (c) Uredia in uredosori (dikaryotic) (d) Telia in teliosori (dikaryotic) and (e) Basidiospores or sporidia produced after karyogamy and meiosis (haploid or monokaryotic). Some rusts are microcyclic where some spore stages are eliminated.

Family- Melampsoraceae

Characteristic features include Uredia without a peridium with capitate parphyses; and uredospores multicellular stalked. Telia crust like, long, covered by host tissue. Teleutospores sessile, single-celled forming a flat palisade like layer below the epidermis of the host.

Genus- *Melampsora*

Systematic position:

Division	Eumycota
Subdivision	Basidiomycotina
Class	Teliomycetes
Order	Uridinales
Family	Melampsoraceae
Genus	*Melampsora*

The fungus is heterothalic (require two compatible partners to produce sexual spores), obligate biotrophic fungus. *Melampsora* is causal agent of flax rust with wide host range in the genus *Linum* (~200species). *Melampsora lini* is an obligate parasite, infects linseed and causes 'rust of linseed' of cultivated flax and linseed (*Linum usitatissimum*).

The mycelium is intercellular, branched, septate, dikaryotic and sub-epidermal,

and usually found within the parenchymatous tissue of the host.

Melampsora lini is an autoecious (all the stages occurring on the same host), unlike *Puccinia.* It has no alternate host and all the stages in the life-cycle are found on the same host. It is a macrocyclic rust i.e. all the following five possible spore stages occur in the life cycle of *Melampsora*; (a) Asexual propagation through uredinial stage where uredia and Urediniospores (n+n) are produced, (b) Telia is the persistent stage (undergoing karyogamy) where teliospores (2n) are produced, (c) Basidia where sexual recombination takes place and Basidiospores (n) are produced. (d) Plasmogamy during Pycnial stage where pycniospores (n) are produced and (e) Completion of sexual cycle through aecial stage where aecium and Aeciospores (n+n) are produced which germinate to produce Uredia and uredospores. In the life-cycle of *Melampsora lini,* only four stages are visible on the host plant; pycnial, aecial, uredial and telial stage. Stage producing basidia nd basidiospores are not visible.

NOTES

The symptom of the disease is easily visible in the field due to the bright orange colour pustules. Early infections may completely defoliate flax plants and reduce the seed yield and fibre quality. The leaves, stems and capsules of the affected plants become covered with bright orange pustules, uredia or uredosori containing the uredospores occurring on both surfaces of the leaves. The crust-like telia or teleutosori containing teleutospores are seen on the stem and very rarely on leaves or capsules.

The uredosori (uredia) are small, scattered or in groups; rounded on leaves and elongated or oblong on stems but mostly on the underside of the leaves. The uredospores are globose, echinulate (with spiny exospores), dikaryotic and stalked. Each stalk consists of two or more cells. Several capitate paraphyses remain intermingled with stalked uredospores. Each paraphysis is single-celled, hyaline and longer than the stalked spore. The host epidermis bursts and the uredospores are released out. They are dispersed by wind and insects. Each uredospore geminates to produce new dikaryotic mycelium.

At the end of season the crust-like reddish brown or black telia are formed on the stem and branches. The telia are elongate, subepidermal forming a solid crust or even continuous layer in stem. Telia contain numerous teliospores which are sessile, cylindrical, one celled and reddish brown in colour. The fungus overwinters by means of teliospores on flax debris. The germinating teliospores undergo meiosis and produce basidium and haploid basidiospores.

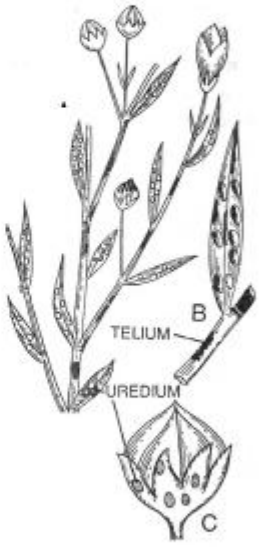


Fig.11.14: ***Melampsora lini;*** **Rust of Linseed: A; An infected twig showing uredia and Telia. B; Uredia and Telia on leaf and stem. C; Uredia on capsule**

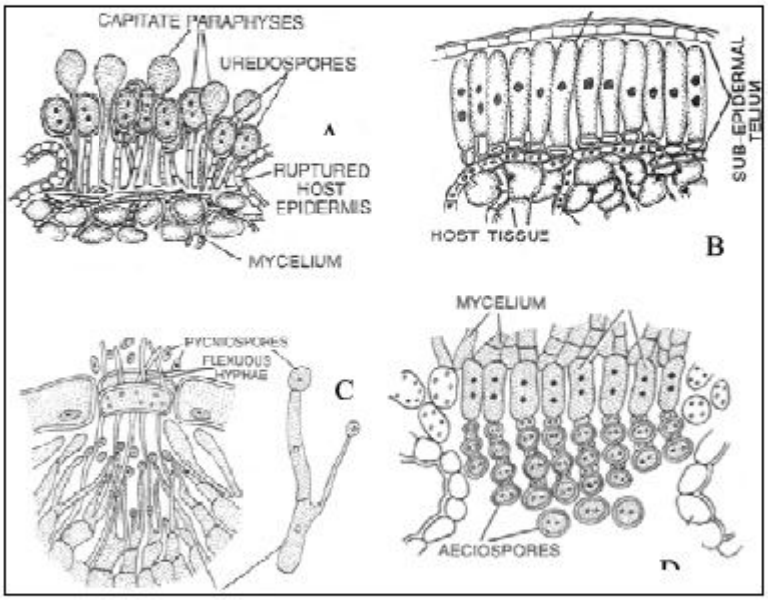


Fig.11.15: ***Melampsora lini;*** **Rust of linseed: A; v.s. through uredium, B; v.s. through subepidermal telium showing single celled, sessile teleutospores, C; flask-like pycnium with pycniosporophores, pycniospores flexuous hyphae D; aecium containing chain of aeciospores**

Basidiospores on germination give rise to pycnial stge on the same plant. The small, rounded, oval or flask shaped inconspicuous yellow, subepidermal pycnia are found on both the surfaces of the leaf. They may also be diffused. Pycnia produce minute and oval to globose haploid pycnospores and liquid exudates 'nectar'. The mature pycnia are composed of pycniosporophores and paraphyses. The pycniosporophores bear pycniospores at their apical ends.

After the formation of pycnia, near about a fortnight later small, orange coloured, scattered aecia are formed on the lower surface of the leaf. An aecium is derived from a pycnium fertilized with pycniospores from a pycnium of different mating type. They lack the peridium and they do no bear paraphyses. The aeciospores are polygonal and binucleate (dikaryotic). On germination each aeciospore gives rise to a dikaryotic mycelium.

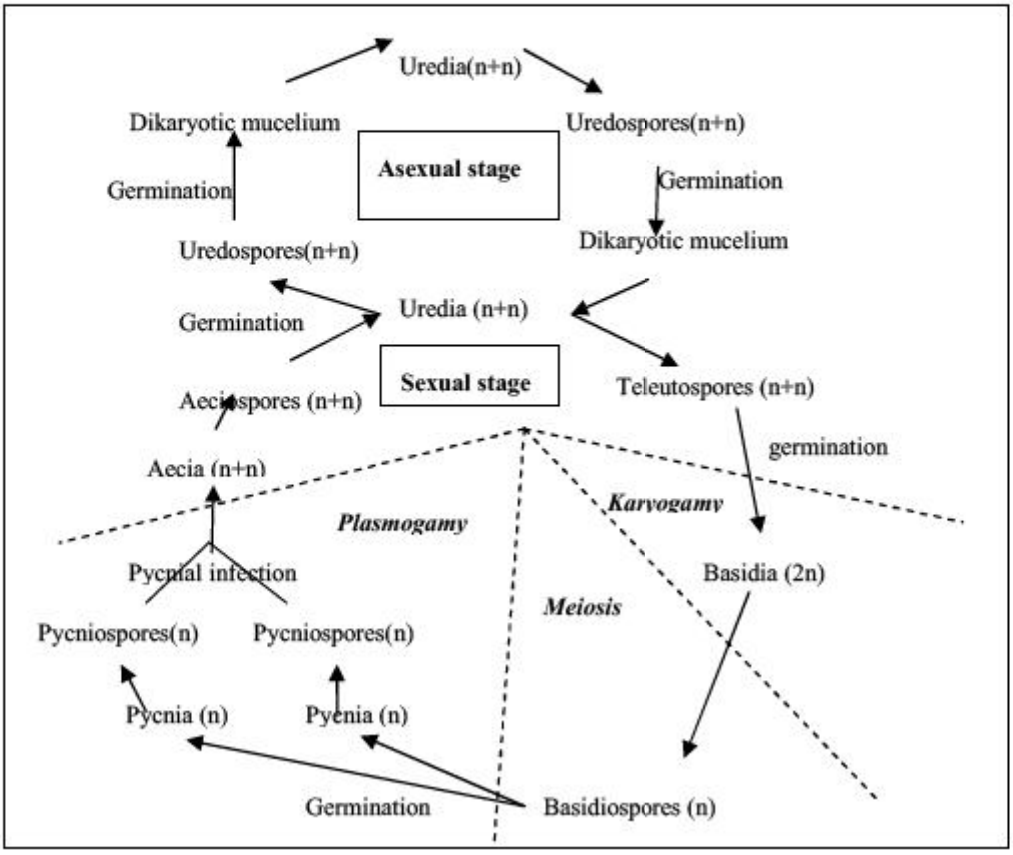


Fig.11.16: Life cycle of *Melampsora*

11.2.2.4.b Class – Hymenomycetes

Members of this class produce well developed basidiocarps. The basidia are typically organized as a hymenium on various types of fruit bodies. The basidia may be single celled (holobasidium) or septate with epi and hypobasidia (heterobasidium). The fruit bodies are formed from the dikaryotic hyphae which result from sexual reproduction by the fusion of two monokaryotes. Dikaryotization (formation of dikaryotic mycelium) or diplodization occur through the formation of clamp connection. This class is divided into two subclasses; Phragmobasidiomycetidae and Holobasidiomycetidae.

Subclass- Holobasidiomycetidae

Holobasidiomycetidae is characterized by an undivided or one celled, cylindrical to clavate basidium (i.e. holobasidum), which usually extends into four sterigmata each bearing a basidiospores. The basidiospores produced in this group are non-repetitive. It contains mushrooms, pore fungi, tooth fungi, coral fungi, chantarelles, boletes and bracket fungi.

NOTES

Order- Aphyllophorales (polyporales)

Members mostly saprophytic in soil, if parasitic produce distinct basidiocarps which have hymenophores and suppoting tissue. Hymenium exposed throughout its development (gymnocarpic) or at least sometime before maturity (hemiangiocarpic). Basidiocarps may be papery, leathery, corky, woody, or fleshy in texture. They are appressed, effused, sessile or stipitate, pileate and have various shapes.

The hymenium may be unilateral being developed on one side or amphigenous making growth all-round or on two sides of the basidiocarp. The fertile layer or hymenium may line the inside of tubes or surface of gills. The hymenial layers may be protected in gills or exposed. The hymenophore is unilateral or amphigenous, smooth, dentate, plicate (folded) or tubular.

Basidia holobasidiate with small sterigmata that are typically curved, slender and tapering, basidiospores are ballistospores (forcibly dischargd). The basidia remain intermingled with paraphyses

Family- Polyporaceae

The members of this family are called the pore fungi. They the wood inhabiting fungi and are commonly grow on both living and dead trees **(lignicolous)**. The polypores are the common wood rotters and notorious destroyers of timber. They are a common sight on the stumps and dead or dying, standing or fallen trees, sometimes covering the entire trunk as saprophytes. Some pore fungi grow in soil.

The visible portion of the fungus is the fruiting body (basidiocarp). The vegetative hyphae develop extensively in the substrate before a basidiocarp is produced. The basidiocarps are usually large bearing pores. In texture they may be fleshy, corky, woody, or gelatinous to cartilaginous. Shapes of the basidiocarps are extremely variable. The mature basidiocarp may be hard and woody, or tough and leathery, and are either sessile or stipitate. When young the basidiocarp is soft and pliable.

The main bulk of the basidiocarp - **hymenophore** is composed of vertically arranged tubes the ends of which usually appear as pores on the lower surface. The hymenial layer lines the inner surface of the tubes which open on the under surface of the pileus giving it a porous appearance. Hymenium is composed of basidia bearing basidiospores. Setae or cystidia are also sometimes present in

the hymenium. Mature basidiospores escape through the pores. The pore tubes develop from an interwoven mass of hyphae forming a fibrous tissue which is known as the **context**. The shape of the pores may be (i) circular called **pereid**; (ii) angular known as **hexagonal**; (iii) intermediate between rudimentary lamellae (gills) and pores termed **daedaloid** and (iv) almost resembling gills called **lamellate**.

NOTES

Bessey (1950) reported 48 genera whereas Overholts (1953) recognised only 13 genera. The common ones which have been recorded from India are *Polyporus, Fomes, Merulieus, Stereum* and *Polystictus. Polyporus* is considered here as a type of the pore fungi.

Genus- *Polyporus*

Systematic position

Division	Eumycota
Subdivision	Basidiomycotina
Class	Hymenomycetes
Subclass	Holobasidiomycetidae
Order	Aphyllophorales (polyporales)
Family	Polyporaceae
Genus	*Polyporus (Phellinus)*

Overholts (1953) recognised 162 species in genus *Polyporus* but some mycologists make as many as 250 species. The genus *Polyporus* includes both saprophytic as well as parasitic species. They are common on dead or dying, standing or fallen tree trunks. Some attack and destroy timber. They cause *brown wood rot* of various forest and shade trees and are known as the wood rotters. Dalbergia, Albizzia, Mulberry, birch, Oak and other timber trees are the common hosts. The most common species of this genus are *Polyporus versicolor* and *P. paragamenus. P. sulphureus* occurs at the base of deciduous trees, especially *Quercus sp* causing white rot of Oak. The specie, *Polyporus gilvus* (Schw.) Fr. is a parasite on *Shorea robusta* (sal), *Acacia arabica* (babul), *Dalbergia sissoo* (shisham), and many other hardwood trees. Some Indian species are *Polyporus agariceus* Berk.; *P. betulinus* Fr.; *P. circinatus* Fr.; *P. cubensis* Mont. and *P. gilvus* (Sehw.) Fr.

NOTES

Mycelium is inconspicuous and subterranean. The primary mycelium is formed by the germination of basidiospores. It consists of numerous white, slender, branched and septate hyphae. At first, it grows in the soil near the host roots. Eventually it attacks the roots and grows beneath the bark. The cells of the primary mycelium are uninucleate. Soon the cells become dikaryotic (binucleate) by hyphal fusions. This process is called dikaryotization. The dikaryotic cells by elongation and division by clamp connections form the dikaryotic secondary mycelium. The secondary dikaryotic mycelium is long-lived. As the parasitism becomes more severe the mycelium forms a complete, thick layer of hyphae around the central woody cylinder. The hyphae secrete enzymes which digest the lignified walls of the wood cells.

The fructification (fruit Body) is basidiocarp which develops from the secondary dikaryotic mycelium. Basidiocarp of *Polyporus* is annual (survive only for one year) and constitutes the only visible part of the fungus. Each basidiocarp appears as a rounded dense knot of hyphae. It arises from the subterranean mycelium. As the knot grows it bursts through the bark. It gradually increases in size. Soon it becomes differentiated into a short stalk or the stipe terminated by a rounded cap-like structure, the pileus. At this stage the basidiocarp is soft and pliable. Towards maturity it becomes woody, corky or leathery.

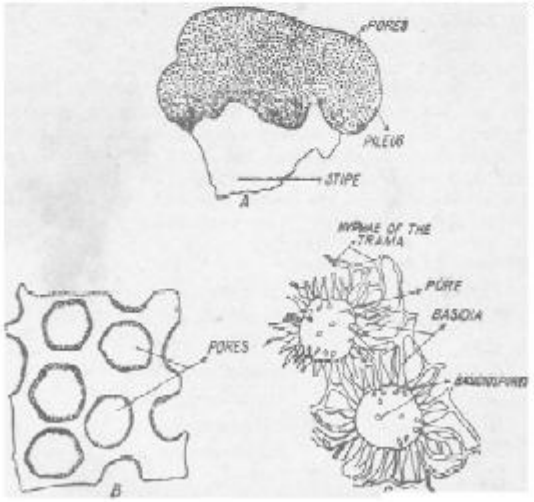
The basidiocarp of *Polyporus gilvus* is usually reflexed and hard to brittle in texture. The upper surface is with shades of yellow, brown or red and is either coarsely hairy or smooth with concentric zonations. Context is thick yellowish-brown and is composed of thick-walled yellowish-brown hyphae. Hymenial surface is yellowish-brown with long uniform or stratified pore tubes. Pores are round and regular. Thick-walled dark-brown setae project into the pore tubes which are lined by basidia.

The stipe of basidiocarp is 2-6 inches long and brown or dark brown in colour. It is composed of innumerable hyphae arranged together in a compact mass. At its top it bears an expanded, brown coloured structure the pileus.

The upper surface of the pileus is brown or lightly coloured, flat with a slightly undulating or smooth surface. It is marked with a few concentric brown or whitish brown rings near the periphery. *Polyporus versicolor* has a zonately

marked pileus. The lower surface of the pileus is smooth and flat. It bears numerous, fine pores in the form of minute circular holes giving porous appearance. Each pore leads inwards into a hollow tube lined by a fertile layer called the hymenium. The hymenium is made up of sterile cells, the cystidia and the spore proudcing club shaped cells, the basidia. The basidia project slightly into the cavity of the tube and are somewhat larger than the cystidia.

NOTES



7: *Polyporus* A; Surface view of pileus From the top, B; ventral side showing pores, C; A portion of the hymenium.

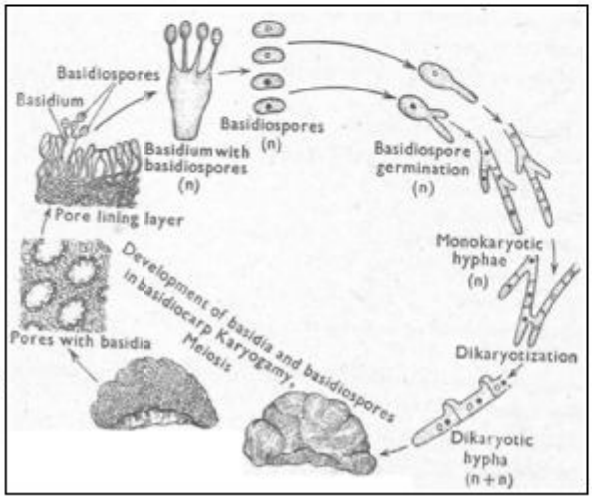


Fig. 11.18: Life cycle of *Polyporus*

sterigmate. Four basidiospores are produced from each basidium raised on a short sterigma. Each sterigma bears a single hyaline oval basidiospore. The basidiospores are tiny, oval structures, white or brownish in colour. The spore output is enormous. A single basidiocarp may produce several billion spores. They escape through the pores and are dispersed by air and insects.

Under suitable conditions each basidiospore germinates to produces monokaryotic primary mycelia. The monokaryotic compatible mycelia, by somatogamy produce dikaryotic secondary mycelium, from which the basidiocarp is developed.

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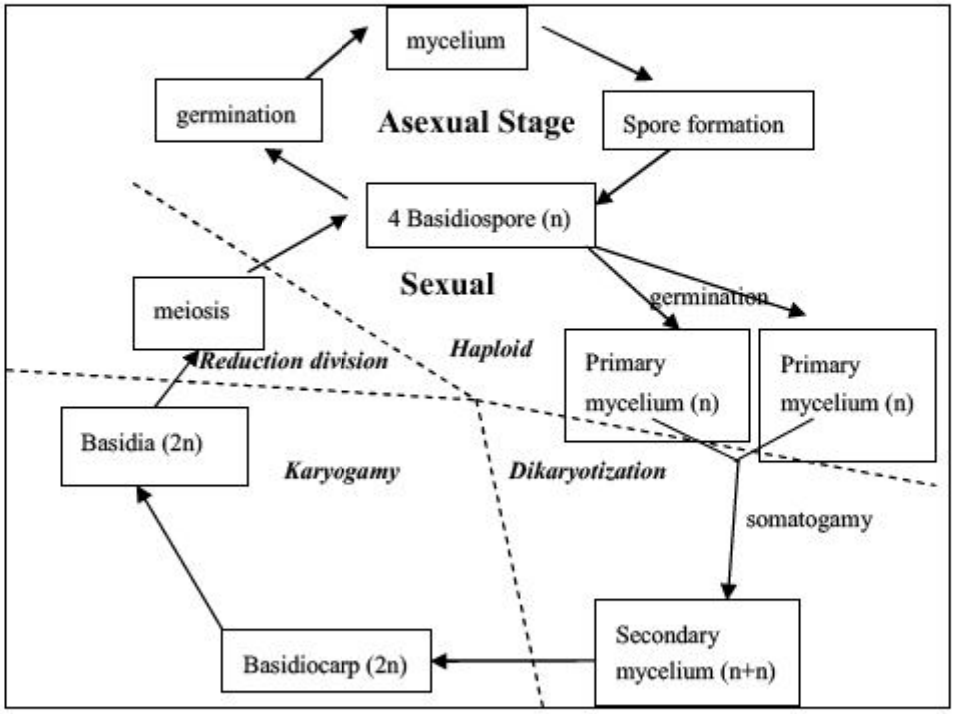


Fig.11.19: Diagrammatic life cycle of *Polyporus*

11.2.2.5 Subdivision- Deuteromycotina

The fungi whose telomorphs (perfect stage) are either absent or not reported are included separately under this group. This includes the conidial states of Ascomycotina, Basidiomycotina and those whose sexual stages have not been correlated. This group is the assemblage of fungi where the spores are formed without nuclear fusion or meiosis. This subdivision is further divided into **three classes; Blastomycetes, Hyphomycetes and Coelomycetes.**

11.2.2.5. a Class- Hyphomycetes

This group includes the major portion of conidial fungi in which the conidia are borne on differentiated or undifferentiated hyphae. Fungi bear conidia on separate or aggregates of hyphae - conidiophores. Only 1 form order

Form order- Moniliales

This form order includes both saprophytes and parasites. Conidia are borne freely on the mycelium or on free conidiophore arising from the mycelium. In some cases conidiophores are grouped into synnemata or sporodochia. Subramaniam (1962) recognized eight different types of spore development and classified the further into eight families based on conidial ontogeny.

Form family- Helminthosporiaceae (Dematiaceae)

It includes imperfect fungi in which both the mycelium and conidia are dark coloured. Conidia are of porospore type i.e. conidia are formed through minute terminal or lateral pores on the wall of the conidiophore. Most of the species are saprophytes. Some are plant pathogens and a few parasitize men and animal.

NOTES

Form genus- *Drechslera* *(Drechslera avenae)*

Systematic position:

Division	Eumycota
Sub division	Deuteromycotina
Class	Hyphomycetes
Form order	Moniliales
Form family	Helminthosporiaceae (Dematiaceae)
Form genus	*Drechslera*

The *Drechslera* species (Biosynonym *Helminthosporium longirostratum* Subram.) are imperfect filamentous fungi whose perfect forms (sexual) belong to the class Ascomycetes (*Pyrenophora*, *Cochliobolus*). Perfect form of *Drechslera avenae* is *Pyrenophora avenae* with systemic position Ascomycotina, loculoascomycetes, pleosporales, pleosporaceae.

The *Drechsleras* are cosmopolitan, dematiaceous filamentous fungi. The genus *Drechslera* includes a dozen of phytopathogenic species which specifically attack cereals, forages and other crops causing crop diseases grouped under the term helminthosporiose. The disease can be propagated by seeds. Phytopathogenic species of *Drechslera* causes Drechslera leaf spot, crown rot, and root rot diseases in grass family. *Drechslera avenae* causes Oat leaf spot, *Drechslera maydis* is the causal agent of Southern corn leaf blight, and *Drechslera sorghicola*, the causal agent of leaf spot on Johnson grass, produce a series of phytotoxic sesterterpenoids. Some species produce mycotoxins that can affect the liver of human and animals. They can cause infections in the eyes, sinusitis, hay fever, and asthma.

NOTES

Diseases caused by the species of *Drechslera* and *Bipolaris* were formerly grouped together as Helminthosporium leaf spot, crown rot, and root rot. Almost all of the species of *Helminthosporium* once classified together belong to this genus. Now, however, they have been segregated into several genera i.e. genera *Bipolaris*, *Drechslera* or *Exserohilum*.

Drechslera species exhibited the most pronounced dissimilarity from the other three helminthosporioid genera (*Bipolaris, Drechslera* and *Exoserohilum)*. They are characterized as having cylindrical (not curved) conidia which germinate from every cell, and have teleomorph in the genus *Pyrenophora*.

The colonies of *Drechslera* are fast growing, suede-like to downy, brown to blackish brown with a black reverse. The shape of the conidia varies. They can be straight, slightly curved, club-shaped, cylindrical, or elliptical. Conidia of *Drechslera* occur individually and have very thick walls. The texture on the surface of the conidia is usually smooth, but occasionally may be warty. The graminicolous species of *Drechslera* form conidia apically and a new apex is formed by subterminal growth. Conidia are formed apically through a pore (poroconidia) in a sympodially elongating geniculate conidiophore (having knee like joints or sharp bends). The conidiophores are simple or branched and produce small, brown multicellular conidia in a sympodial mode.

Conidia of *Drechslera avenae* are pale to dark brown, usually cylindrical or subcylindrical, straight, smooth-walled, with rounded ends. In additions conidia are transversely septate (phragmoconidia), the septa (cross walls) between cells appear to be incomplete and are called pseudosepta. Septa delimits the basal cell formed first during conidium maturation. Germinating of conidia is from any or all cells.

Disease caused by *Drechslera* species produces two types of symptoms in grass family plants; leaf spot and melting-out of the whole plant. Drechslera leaf spot/melting-out symptoms initially appear as leaf spot lesions. The lesions initially appear as small purple coloured dots. As the Leaf spot disease progresses, these lesions turn a gray to tan colour with a dark purple to brown border. In the leaf spotting stage these diseases do not normally cause significant injury to the plant.

During warm and dry weather, the leaf lesion phase decreases (except for *Bipolaris sorokiniana, D. erythrospila* and *D. gigantea*). As temperatures increase, infection may occur in the crown, stems, and roots then gradual browning and thinning or melting-out of grasses with subsequent death of the whole plant. Eventually turning to a straw coloured and death of the plant is known as the melting-out phase of the disease.

NOTES

Leaf spot disease of Oats is the **most important disease is cause by** *Drechslera avenae.* However the disease is no longer a serious pathogen of oats. **Symptoms** of the disease include two phases; the primary phase appears as short brown stripes with purple edges on the emerging leaves. These stripes appear on the first three or four leaves of emerging seedlings. The primary phase of the disease arises from seed-borne infection. Conidia from the early leaf stripes then splash up the plant, producing the secondary leaf spot phase of the disease (splash-borne spores) which appears as red-brown spots with purple margins on leaves.

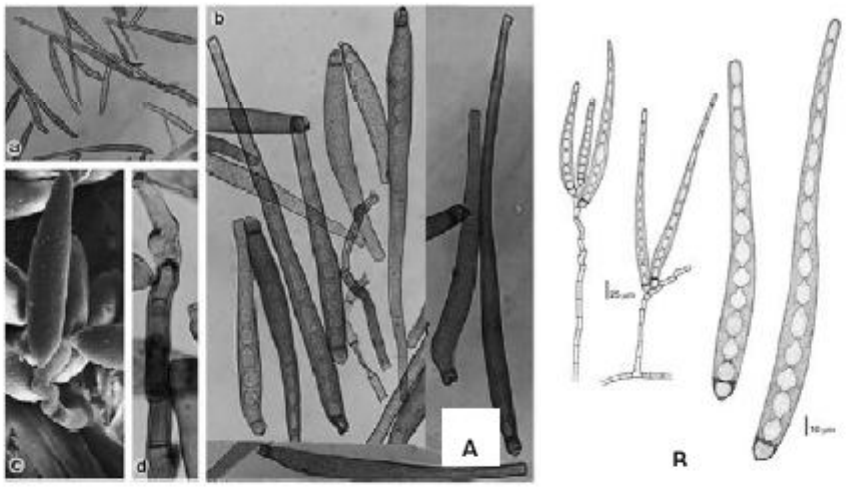


Fig. 11.20 : A; Conidia and conidiophore of *Drechslera species. B;* Conidia and conidiophore of *Drechslera avenae*

NOTES

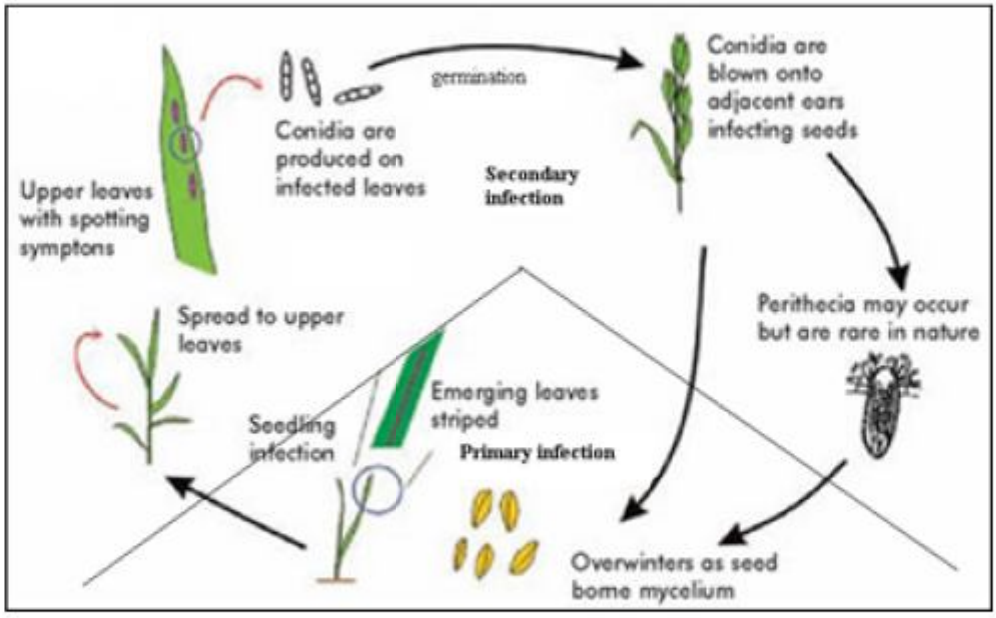


Fig. 11.21: Life cycle of leaf spot disease caused by *Drechslera avenae*

11.2.2.5.b Class: Coelomycetes

Conidia are produced on conidiophores arranged in fructification- pycnidia, pycnothyria, acervuli, cupulate or stroma. Fructifications of Coelomycetes are specialized parenchymatous structures within which conidia are produced. This class is divided into two orders; Sphaeropsidales and Melanconiales

Form Order: Sphaeropsidales

Conidia are produced in pycnidia

Form Family- Sphaerioidaceae

The perfect form belongs to the class Ascomycetes

Form Genus- *Phoma*

Systematic Position:

Kingdom	Mycota
Division	Eumycota
Subdivision	Deuteromycotina
Class	Coelomycetes
Form Order	Sphaeropsidales
Form Family	Sphaerioidaceae
Form Genus	*Phoma*

The *Phoma* species are imperfect filamentous fungi belonging to the class Deuteromycetes. The perfect form of *Phoma* is *Leptosphaeria* whose systemic position is; Ascomycotina, Loculoascomecetes, Pleosporales, Leptosphaeriaceae.

NOTES

The genus *Phoma* is generally considered by most modern mycologists to be taxonomically problematic not only due to ambiguous morphological criteria, but also due to uncertain phylogenetic affinities. The genus is currently linked to three different teleomorph genera. If teleomorphs are known, they reside in *Didymella*, *Leptosphaeria*, or occasionally *Pleospora.* In literature, *Phoma* species have also been associated with other teleomorph genera within the Dothideomycetes (Ascomycotina), including *Mycosphaerella, Fenestella*, *Cucurbitaria*. Furthermore, a range of synanamorphs of *Phoma* spp. have been recognised in *Stagonosporopsis*, *Epicoccum*, *Phialophora* and *Sclerotium.*

The first descriptions of fungi that belong to the genus *Phoma* date back to 1821. The genus name *Phoma* applied to filamentous fungi which were capable of forming pycnidial conidiomata with aseptate, hyaline conidia that could inhabit plant stems. In 1964, eight years after the designation of *Phoma* as a conserved genus name in the International Code of Botanical Nomenclature, the designated type species *Phoma herbarum* was restudied and lectotype material was selected.

Currently *Phoma* species can be defined as filamentous fungi that produce pycnidial conidiomata with monophialidic, doliiform (barrel-like in form) to flask-shaped conidiogenous cells. A collarette is present at the apex of those cells after the production of the first conidium. *In vitro* the hyaline conidia are mainly single-celled, although in several species a small percentage of transversely septate conidia may also be observed.

Phoma species are cosmopolitan in nature. Over 2000 species have been described from soil, as saprophytes, on various plants and as pathogens to plants and humans. Common species of *Phoma* are *P. leonuri* Letendre (perf. st. *Leptosphaeria slovacica* Picb.), *P. macdonaldii* Boerema (perf. st. *Leptosphaeria lindquistii* Frezzi), *P. pedicularis* Fuckel, *P. rubefaciens* Togl. and *P. sydozuii* nom.nov.

The genus *Phoma* is a dematiaceous, dark coloured filamentous fungus having aseptate hyphae with irregular branching. They have world-wide distribution

NOTES

that inhabits the soil and plant material and are ubiquitous (found everywhere) in nature. These fungi may periodically infest plants by attaching themselves to the roots of the plants and colonizing the plant from there. Some species are only known from decaying leaves or wood, whereas others play a role as secondary invaders of weakened plant tissue.

The more ubiquitous species such as *P. herbarum*, *P. glomerata*, *P. pomorum* var. *pomorum* and *P. eupyrena* have been found on inorganic materials; isolates are known from asbestos, cement, oil-paint and plaster (*P. herbarum*), chemicals, paint (*P. glomerata*) and crockery (*P. pomorum* var. *pomorum*). In contrast to these harmless saprobes, more than 50% of the species described so far are known to be able to occur in living tissue, either as opportunists or as primary pathogens.

Several severe vertebrate diseases are also associated with *Phoma*, such as "bovine mycotic mastitis" and "fish-mycosis". Soil associated organisms such as arthropods and nematodes can also be subject to *Phoma* infections. In humans, exposure to some Phoma species can trigger mould allergies, especially when the fungus grows indoors. *Phoma cruris-hominis*, *Phoma herbarum* and *Phoma glomerata* are pathogenic to human and cause respiratory infections and systemic phaeohyphomycosis, a subcutaneous skin infection which causes discoloration of the skin as the fungus grows inside the layers of skin. Animals can also develop phaeohyphomycosis infections. The fungus produces mycotoxins such as aflatoxins, cavoxin, cytochalasin, etc.

The *Phomas* are very common in plants, plant debris and some species are plant pathogens. More than 110 species are known to be primary plant pathogens, mainly specialising on a single plant genus or family. The fungi can cause a condition known as "Phoma blight", characterized by a withering and fading of the leaves of the plant, eventually killing the plant. Phoma blight can be a very serious problem for nurseries, as the fungus may spread across a wide area before people realize what the problem is, and it will happily lie in wait in the soil until plants are returned to the area, causing a recurrence of the initial blight.

The economically most important plant pathogens include the widespread species *P. medicaginis* and the two species that are involved in Black Leg in *Brassicaceae*; *Phoma lingam* and to a lesser extent the unnamed *Phoma* anamorph of *Leptosphaeria biglobosa*. *P. lingam* is regarded to be the most

important pathogen of oilseed rape in the Northern Hemisphere. Phoma black stem of Sunflower is caused by the fungus *Phoma macdonaldii Boerema*. Dark black lesions start on the stem at the base of leaf petioles and spread along stems. Large dark lesions may also form on leaves and flowers. Eventually leaves wilt and dry up and stalks may turn dark brown to black. Small black spots (pycnidia) may be observed on the infected plants.

NOTES

Primary infection of hos4t plant may occur through wounds, through stomata or directly through the epidermis. Initially, the fungal hyphae grow intercellulary through plant tissues. Following this symptomless stage, the fungus becomes necrotrophic. In some cases extradermal mycelium may be formed. After a short period, often dark coloured, mostly globose or flask-shaped pycnidial conidiomata can be observed within the lesions, which are embedded in the plant's epidermis. These pycnidia contain numerous conidia, which ooze in a pale white to pinkish coloured matrix.

Colonies of *Phoma* are flat, spreading, powdery to velvety in texture depending on the species, and often largely submerged in the medium. From the front, the colour is initially white and later becomes olive grey with an occasional tint of pink. From the reverse, it is dark brown to black. Some species (particularly, *P. cruris-hominis* and *P. herbarum*) produce a reddish-purple to yellowish-brown diffusable pigment which is readily visible from the reverse. Phoma mould will happily spread to cover an area if left unchecked.

The hyphae are septate, hyaline to brown. Pycnidia, conidia, and chlamydospores (for some species only) are visualized in the later stages. Colonies of *Phoma* grow rapidly and form large, globose to pyriform, membranous to leathery, darkly pigmented ostiolate pycnidia bearing phialides at their inner lining.

These fungi reproduce asexually. Pycnidia are the asexual fruiting bodies which are 70-100 µm in diameter. The conidiogenous cells (conidia forming cells) of *Phoma* are discrete and line the pycnidial cavity. Conidia are produced in abundance within the pycnidia on narrow thread4-like phialides, which are hardly differentiated from the inner pycnidial wall cells. Pycnidia are devoid of ornamental filaments which differentiate them from *Pyrenochaeta* of Ascomycotina which have setae (rigid hair located on the pycnidia) arising from their upper portion.

In morphology pycnidia of *Phoma* and perithecia of *Chaetomium* resembles but the difference being in that the perithecia or cleistothecia of *Chaetomium* are sexual fruiting bodies which bear ascospores inside whereas pycnidia of *Phoma* are asexual fruiting bodies and bear conidia.

NOTES

The unicellular, transparent, globulous to cylindrical or oval-shaped, small conidia are formed inside the pycnidia. Pycnidia have one to several openings (ostioles) on their surface from which the conidia are released outside. Conidia are usually exuded in a gelatinous mass by the apical ostiole of pycnidia where they aggregate into a very long fuse. Each conidium typically has two oil droplets inside. Some *Phoma* species produce brown chlamydospores that are arranged singly or in chains. These chlamydospores may be unicellular or multicellular and "alternarioid" (resembling *Alternaria*) in appearance.

Sometimes a meiotic cycle (sexual stage) can be observed, besides the asexual one described above. In this stage ascospores are formed in pseudothecial ascomata. If such sexual structures are found in nature, they are mostly observed in the saprobic part of the life cycle. However, such a sexual stage is quite uncommon within this genus, and is presently not known for more than 40 taxa of which many produce the sexual reproductive structures only *in vivo*.

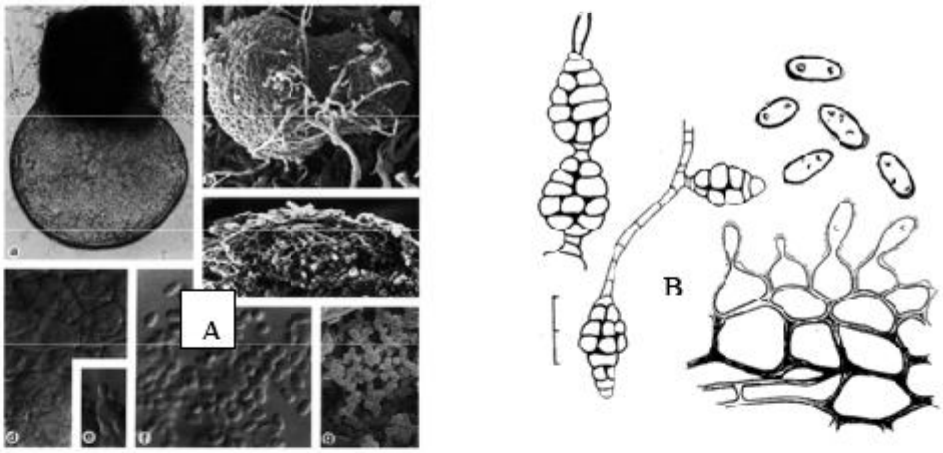


Fig. 11.22: A; a & b Pycnidia, c & d section of Pycnidial Wall, e-g conidiogenous cells and conidia. B; Alternaroid chlamydospores of *P. glomerata*.

Conidia, and in some species mycelial fragments, disperse easily by water-splash, misting or wind, birds or insects and can thus infect new host plants. In absence of a suitable host the fungus may survive periods of stress, such as

drought or extreme cold as saprobes on decaying organic material which is actually residue of plants that were previously infected in the soil.

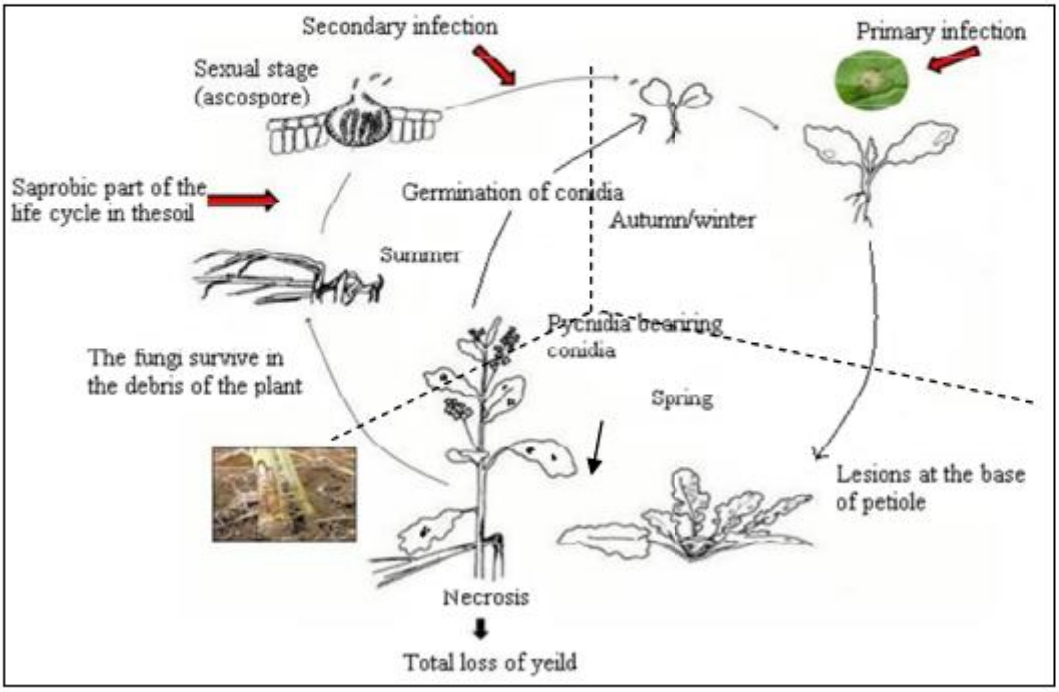


Fig. 11.23: Life cycle of *Phoma lingum*

11.3 Summary

Views on phylogeny of fungi have been based on comparative morphology, cytology, sero-diagnosis and study of fossil records. The belief that fungi are basically no more than algae which in course of evolution have dispensed their chlorophyll, while still held has in recent years been less favoured. Non-chlorophyllous unicellular organisms and protozoans are considered as the origin of fungi based on the similarities of vegetative or reproductive structures.

Fungi are achlorophyllous thallothytes with heterotrophic mode of nutrition. Their cell wall is made up of chitin (except in Chytrids) and reserve food is glycogen. Further classification of fungi is based on vegetative thallus organisation and characteristic spore formation. Plasmodial forms are kept under division Myxomycota and the other with non plasmodial unicellular or mycelial forms are kept under division Eumycota with five subdivisions; Mastigomycotina; motile cells-zoospores present, Zygomycotina; sexual reproduction is by gametangial fusion to give rise to zygospores, Ascomycotina; asci and ascospores are formed as a result of sexual reproduction,

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Basidiomycotina; perfect state spore is basidiospore and Deuteromycotina; telomorph absent.

11.4 Glossary

NOTES

- **Aplanospores** : Non motile spores
- **Autoecious** : Life cycle completed on single host eg. *Puccinia helianthi*.
- **Coprophilous :** Living or growing on dung
- **Dematiaceous :** Dark-colored fungi that produce melanin in their cell walls
- **Geniculate :** Having knee like joints
- **Gymnocarpic** : Hymenium exposed throughout its development not enclosed in protective covering
- **Heteroecious :** Life cycle is completed on two different hosts eg. *Puccinia graminis tritici* requires wheat and Barberry.
- **Lectotype :** A biological specimen that is selected as the type specimen when a holotype was not originally designated.
- **Lignicolous :** Fungi that not only grow on wood but actually cause it to decay.
- **Macrocyclic :** Fungi that produce all five spores (sometimes excluding pycniospores).
  Microcyclic : Fungi that lack pycniospores and aeciospores in their life cycle. **Meiospores:** Spores formed as a result of meiosis.
- **Phaeohyphomycosis** : A group of superficial and deep infections caused by fungi that form pigmented hyphae and yeastlike cells in tissue.
- **Planocyte:** Motile cell.
- **Pleomorphic** : Existence of an organism in two or more distinct morphological forms during the life cycle
- **Sympodial :** Lateral growth pattern in which the apical meristem is terminated.
- **Synanamorphs** : Multiple morphologically distinct anamorph or asexual stages of single fungi.
- **Telomorph :** Perfect or sexual stage

- **Tetrasterigmate :** Basidia bearing four sterigmata.

11.5 Self-Learning Exercise

NOTES

Section –A (Very Short Answer Type Questions)

1. Who proposed non-chlorophyllous unicellular origin of fungi?
2. Fungi are reported since …… period.
3. Holocarpic fungus is : (a) Albugo (b) Agaricus (c) Synchytrium (d) Ustilago
4. In which form reserve food material is stored in fungi?
5. Name the subdivision of fungi having dolipore septum.
6. Name the subdivision of fungi having clamp connection.
7. The fungi whose perfect stage is not known are included under the group ……
8. Members of Mastigomycotina are characterized by the presence of ……
9. Members of Myxomycota are commonly known as ……
10. Who classified all fungi into Mycota and divided it into two divisions; Myxomycota and Eumycota?

Section –B (Short Answer Type Questions)

1. Differentiate between Ascus and Basidium.
2. Why are some fungi grouped under "*Fungi Imperfecti*"?
3. Give systematic position of *Polyporus* on the basis of classification given by Anisworth.
4. What is Zygospore?
5. Write a note on protozoan origin of fungi.
6. What is macrocyclic rust?

Section –C (Long Answer Type Questions)

1. Give an account of classification of fungi given by Anisworth.
2. Describe the characteristic features of Baisidiomycotina.
3. Describe the process of Dikaryotization and Karyogamy in Ascomycotina.

4. Describe the life cycle of *Melampsora*.
5. Describe the general characters and life cycle of *Drechsela*.

Answer Key of Section –A

NOTES

1. Fischer (1892) and Atkinson (1909)
2. Devonian
3. *Synchytrium*
4. Glycogen
5. Basidiomycotina
6. Basidiomycotina
7. Deuteromycotina
8. Motile cells
9. Slime moulds
10. Anisworth

11.6 References and further readings

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Unit - 12

Economic Importances of Fungi, Fungal Diseases, Mycorrhiza

NOTES

Structure of the Unit

12.0 Objectives
12.1 Introduction
12.2 Fungi in Industry
- 12.2.1 Fungi in Brewery
- 12.2.2 Fungi in Food processing industry
- 12.2.3 Fungi in Production of Organic Acids
- 12.2.4. Fungi in Enzyme Production
- 12.2.5 Other Industrial Products

12.3 Fungi as Medicine
12.4 Fungi as Food
- 12.4.1 Fungi Directly as Food
- 12.4.2 Fungi in Food processing

12.5 Fungal diseases
- 12.5.1 Plant Diseases
- 12.5.2 Diseases of Human Beings

12.6 Mycorrhiza
- 12.5.1 Mycorrhiza and Nutrition
- 12.6.2 Mycorrhiza and Water stress
- 12.6.3 Mycorrhiza and Plant diseases
- 12.6.4 Mycorrhiza in Agriculture and Forestry
- 12.6.5 Mycorrhiza and Restoration of Degraded Lands
- 12.6.6 Mycorrhiza and Nitrogen Fixation
- 12.6.7 Mycorrhiza and Primary Productivity
- 12.6.8 Other Beneficial Activities

12.7 Fungi as Biological Control Agents
12.8 Summary
12.9 Glossary
12.10 Self-Learning Exercise
12.11 References and further readings

12.0 Objectives

NOTES

After going through this unit you will be able to understand:

- Importance of fungi as food and medicine in our daily life.
- Use of fungi in industries as source of different industrial products or as raw material.
- Importance of fungi as biocontrol agents especially against nematods, insects, weeds and as control of plant and human pathogens.
- Importance of fungi as mycorrhiza.
- Importance of fungi as pathogens of plants and human.

12.1 Introduction

Fungi are beneficial to us, directly or indirectly, in many ways. Fungi play a significant role in our daily life being our greatest friends as well as foes. Some fungi are of tremendous use to man, while others are highly harmful as they are responsible for many diseases in plants, animals and human beings. Besides keeping our environment clean by removing organic debris, they provide food, medicines and several other useful products and they play an important role in many industries and agriculture as well. Mycorrhizal association of fungi with roots of higher plants play important role in agriculture and forestry. Besides this, use of fungi as biocontrol agents has gained importance in recent years.

12.2 Fungi in Industry

12.2.1 Fungi in Brewery

Alcoholic fermentation with the help of fungi is the basis of brewing industries.

a. **Wine:** Wine grapes have an indigenous yeast flora on their skin. Hence when the juice is pressed it begins to ferment spontaneously. Wine yeasts are races of *Saccharomyces ellipsoideus*. Wine is also produced by fermenting rice with *Aspergillus oryzae*. This method is popular in Japan and many European countries.

b. **Beer**: The brewer uses *Saccharomyces cerevisiae* and S. *carlsburgensis* for brewing of beer from malted barley.

12.2.2 Fungi in Food Processing Industry

a. **In baking industry:** Fermentation of carbohydrates by *Saccharomyces cerevisiae* produces ethyl alcohol and CO_2. Carbon dioxide liberated in this process is used in the preparation of several bakery products such as breads and cakes.

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b. **In cheese industry**: Some species of *Penicillium* are used for maturation of cheese. Two kinds of cheese are ripened and flavoured by filamentous fungi. *P. camembertile, P. rocqueforti* and *P. candidum* are used to impart specific flavours and colour to cheese.

Besides this *Rhizopus, Mucor* and *Antimucor* are used to increase the digestability of rice, wheat and soybean which imparts meat like flavor to the end products of many processed food.

12.2.3 Fungi in Production of Organic Acids

Biochemical activities of several fungi are utilized in the commercial production of organic acids.

a. **Citric acid:** It is produced by fermenting sucrose and molasses by *Aspergillus niger* and *A. wentii* at a pH of 2.2. Citric acid is used in soft drinks and other foods and medicinal preparations. It is a superior sequestering agent and is used in the manufacture of ink, dyeing, electroplating and leather tanning.

b. **Itaconic acid:** It is produced by fermentation of sugars by *Aspergillus itaconicum* and *A. terreus.* It is widely used in the manufacture of alkyl resins, synthetic fibers and plasticizers.

c. **Gluconic acid:** It is produced by fermenting sugars by *Aspergillus niger* and *Penicillium purpurogenum.* It is used in pharmaceutical, food, textile, leather and photographic industries.

d. **Kojic acid:** It is produced by fermentation of sugars by *Aspergillus flavus-oryzae.* It possesses insecticidal and antibiotic properties and is used in the preparation of pyridines, ethers, esters, azodyes, etc.

e. **Gallic acid:** Gallic acid is produced by *Aspergillus sp.* at neutral pH and in submerged cultures. It is synthesized by the hydrolysis of gallotannin present in gall nuts by *Penicillium glaucum* and

Aspergillus gallomyces. It is used in the manufacture of inks and dyes.

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f. Fumaric acid: It is obtained by fermentation of sugars by *Rhizopus stolonifer* or *Rhizopus nigricans*. It is used in the manufacture of alkyl resins and wetting agents.

g. Lactic acid: *Rhizopus arrhizus*, *R. chinensis*, *R. oryzae*, *R. stolonifer* and *Mucor* produce lactic acid.

h. Ustilagic acid: The corn smut fungus *Ustilago zeae* produces this acid. This acid is used as starting material for making macrocyclic musks valuable to the perfume industry.

Besides, several species of *Mucor* and *Rhizopus* are used in the production of oxalic and succinic acids.

12.2.4 Fungi in Enzyme Production:

Many intra- and extracellular enzymes are found in fungi and some are extracted on commercial scale. Fungal enzymes are used in bread-making, production of beer and spirits, food industry, textile, pulp and paper industry etc. Fungi like *Aspergillus niger* and *A. oryzae* have been the most widely exploited sources of fungal enzymes. *Rhizopus* sp. and *Penicillium* sp. are also sources of enzymes.

a. Invertase: The yeast *Saccharomyces cerevisiae* is used for extraction of the enzyme invertase. This enzyme hydrolyses sugars into glucose and fructose and is used in confectionery and paper industry. *Aspergillus niger* and *A. oryzae* also are used as a source of this enzyme.

b. Zymase: The enzyme zymase obtained from *Saccharomyces cerevisiae* in used in the preparation of ethyl alcohol by fermentation of carbohydrates.

c. Amylase: *Aspergillus niger* and *A. oryzae* are used in the production of the enzyme amylase. This enzyme is used in alcohol industry, in manufacture of dextrinized starch and in medicines.

d. Cellulase: Microbial cellulases are of immense importance in industry. Starchy materials such as potatoes and other starchy wastes are converted to fermentable mono and disaccharides by fungal enzymes. *Trichoderma reesli* is used in the production of the

enzyme cellulase, which is used in the preparation of cheese and in saccharification of cellulosic and lignocellulosic wastes together with recycling of hydrolysate for the production of single cell protein, microbial biomass and vitamins like β carotene etc.

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e. **Proteases:** Fungal proteases eg. Casein which is used in cheese industry and the one which is used in bread making is obtained from *Aspergillus oryzae.*

Fungi are also used in the production of other important enzymes like lipase, pectinases, glucose oxidase and lactase.

f. **Plant growth regulators**: *Fusarium,* anamorph of the fungus *Gibberella fujikuori* (causal agent of 'Foolish seedling disease' belonging to Ascomycotina), produces 'gibberellins'. The diseased plant grows abnormally fast and dies. Gibberellins are a group of phytotoxic mycotoxins. They have been used successfully in regulating growth of plants. They are used to reduce the time needed for malting barley (used in brewing of beer), to improve the quality of malt and to increase the yield of vegetables as well as to allow their early marketing.

12.2.5 Other Industrial Products

a. **Ethyl alcohol**: To obtain ethyl from molasses *Saccharomyces cerevisiae* is used more commonly. *S. auamenses* and *Schizosaccharomyces pombe* can also be employed. To obtain alcohol from whey, *Candida pseudotropicalis* is used.

b. **Glycerol** is produced using *Saccharomyces cereviswe* and S. *ellipsoides.*

Besides all the industrial products fungi are also used for the production of amino acids, nucleic acids and nucleotides. These are extracted from yeasts and occasionally from filamentous fungi. Submerged cultures of *Blizkeslea trispora* yield β carotene.

12.3 Fungi as Medicine

Several fungi are used in the production of medicines.

a. **Ergot**: Ergot alkaloids produced as secondary metabolites by

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Claviceps paspali and C. *puspurea* are a group of mycotoxins. They are remarkable for their wide spread and fatal poisoning of people eating bread from contaminated grains. This is known as ergotism.

Commercial ergot is prepared from the sclerotia *of Claviceps purpurea*. It contains some alkdoids which are used to induce uterine contraction for abortion, in the treatment of menstrual disorders and check to haemorrhages. However, excess of ergot leads to serious convulsions or a gangrenous condition that may result in loss of limbs.

Other beneficial activities of these alkaloids include its use in obstetrics and also to treat migraine headache, hypertension, serotinin-related disturbances, to inhibit prolactin release, in treating agalactorrhoea and to disrupt implantation in early pregnancy.

New treatments in Parkinsonism and cancer of the breast have also been noted. Lysergic acid diethylamide (LSD) synthesized from these alkaloids is of some therapeutic value in the hands of psychiatrists, though it has become a sociological problem since drug-addicts use it for its psychotropic hallucinogenic properties.

b. **Ephedrine**: It is synthesized from benzaldehyde by the action of yeast and is used in treatment of asthama and nasal troubles.

c. **Steroids**: Steroids are complex organic compounds, effective against rheumatoid arthritis, allergic, dermatologic and other diseases. They are used as anaesthetic and antifertility agents. Steroids are adrenal cortical and gonadal hormones and their derivatives. Their extraction from biological systems is highly expensive. A wide variety of fungi have the capacity of synthesizing many steroids; for instance, cortisone is prepared by fermentation of glycosides by *Rhizopus nigricans* and Asper*gillus niger.*

d. **Vitamins**: Vitamins are accessory micronutrients, which are required by living organisms for their proper growth. Several yeasts, including *Saccharomyces cerevisiae* are good source of vitamin B-complex. Ergosterol, a precursor of vitamin D, is synthesized from some moulds and yeasts. *Eremothemium ashbyii* is a rich source of vitamin B_{12}, whereas vitamin A is extracted from *Rhodotorula*

gracilis. Ashbya gossypi and *Eremothecium ashbyii,* when grown in liquid culture, yield upto 6g/lit riboflavin.

e. **Antibiotics**: Antibiotics are metabolic substances produced by some living organisms which are injurious to other living beings. The wonder drug **Penicillin** which is a β-lactum antibiotic, occupies a significant place in the field of medicine because it was the first antibiotic that was discovered and extracted by Alexander Fleming in 1944 for the first time from *Penicillium notatum.* This antibiotic was subsequently used during the Second World War (1939-1945) as the first wonder drug. This antibiotic is obtained on a large scale from *Penicillium chrysogenum.*

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Another β-lactum antibiotic **Cephalosporin** is produced by *Cephalosporium acremonium.* Both these β-lactum antibiotics are active against Gram +ve bacteria by inhibiting enzymes involved in cell wall synthesis. However, recently the Actinomycete genera, *Streptomyces* and *Nocardia* are also reported to produce β-lactum antibiotics.

Tetracyclins are family of antibiotics having broad spectrum of action and therapeutic value. Tetracyclins which include Chlorotetracyclin, oxytetracyclin and tetracycline are obtained from species of *Streptomyces.*

Species of *Streptomyces* also produce *Streptomycin* which was discovered by Waksman (1943). This antibiotic is active against G-ve organisms like *E. coli*, *Pseudomonas aeroginosa* and *Serraia marcescens*.

Table 1: Some important antibiotics obtained from fungi

S. No.	Fungi	Antibiotic
1.	*Penicillium notatum, P. chrysogenum*	Penicillin
2.	*Aspergillus proliferans*	Proliferin
3.	*Penicillium chrysogenum*	Isopenicillin N
4.	*Aspergillus giganteus*	L-sarcin
5.	*Mucor remannianus*	Ramycin

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6.	*Psalliota campestris*	Campestrin
7.	*Ustilago maydis*	Ustilagic acid
8.	*Chaetomium cochloides*	Chaetomin
9.	*Claviceps purpurea*	Ergotin
10.	*Penicillium citrinum*	Citrinin
11.	*Aspergillus niger*	Jawaharene
12.	*Gibberella baccata*	Baccatin A
13.	*Cephalosporium* spp.	Cephalosporin
14.	*Aspergillus fumigatus*	Fumagillin
15.	*Trichothecium roseum*	Trichothecin
16.	*Trichoderma* spp.	Gliotoxin
17.	*Penicillium puberulum*	Puberulic acid
18.	*Penicillium nigricans, P. urticae,* *P. griseofulvum*	Griseofulvin

f. **Active agents against human pathogens**: Several fungi are active against human pathogens; for instance, spread of *Candida albicans* is prevented by the extract of *Tricholoma saponaceum*. Mushrooms like *Lentinus edodes, Flammulina velutipes, Agaricus bisporus, Volvariella volvacea,* and *Boletus edulis* possess anti tumour properties. Many edible mushrooms (e.g., *Lentinus edodes, Agaricus bisporus)* have the ability to lower blood cholesterol.

g. **Other medicinal usage:** Many fungi like the puffballs are used in traditional medicines for their antibiotic properties. Spores of the giant puffballs were used to arrest blood flow from wounds and piles. Before spore formation they are edible. The smoke from dried puffballs is used as anaesthetic for human as well as bees.

Another important compound is **Cyclosporin**, which is produced by

Tolypocladium inflatum (Churchile, 2001). This is of great significance in the biomedical science since it is used as an immunosuppressive agent in human organ transplant. This is also reported to be produced by *Cylindrocarpon lucidum.* In heart transplantation it can block white cells that cause rejection but not those fighting infectious microbes. It has been associated with improvement in the effectiveness of kidney and liver transplant.

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Stone in 1993 in Montana has isolated and identified a new fungal species that can produce **Taxol**, a drug currently obtained from bark of a Yew tree, which is shown to be a promise in treatment of ovarian cancer.

Zearelanone(estrogen) produced by *Gibberella zeae* (Ascomycotina) is an estrogen and is used as an anabolic agent in cattle and sheep to improve both growth and feed efficiency.

Hypocholesteremic activity (to inhibit cholesterol formation in liver of rat) has been found in **Citrinin**, a metabolite of *Pythium ultemum* (Mastigomycotina), and with **Compactin**, an antifungal agent produced by *Penicillium brevicompactam* and *P. citrinum.*

Monoascus ruber produces a non-toxic metabolite **Monocolin-K**. This is structurally similar to Compactin but is four to five times more active than Compactin. **Menivolin** is a product of *Aspergillus terreus,* which is identical to Monocolin-K. The dihydroderivatives of Menivolin and Compactin have been isolated from *Aspergillus terreus* and *Penicillium citrillum,* respectively. They, in their activities, resemble their parent components. **Lovostatum** from *Aspergillus* is a cholesterol inhibitor.

A synthetic drug **Clofibrate** is used for hyperlipidemia, (coronary heart disease in human beings). This has marginal activity and side-effects. A similar antibiotic compound **Ascofuranone** produced by *Ascochyta viciae* is orally active in rats reducing serum cholesterol triglycerides, phospholipids, free fatty acids and cardiac cholesterol content. The side-effects of Clofibrate, hepatomegaly is not induced by Ascofuranone. It shows only weak acute toxicity in mice and rats.

Caterpillar fungus *Cordyceps sinensis* is used by the Chinese for several hundreds of years. It increases athletic performances, increases oxygen uptake of lungs while reducing bronchial inflammation and works as an expectorant. It relieves exhaustion, night sweats, and sexual impotency and

is used as a sedative. It also reduces uterine fibroids.

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A compound known as **K-76 monocarboxylic acid**, a sesquiterpine derivative that is an oxidation product of the natural compound produced by *Stachybotrys complementi* has specific action i.e. there is no inhibition of trypsin or plasmin. K-76 monocarboxylic acid acts by inhibiting formation of the chemotactic factor for poly morpho nuclear leukocytes in human complement serum. It inhibits nephrotoxic nephritis in rats and may be useful in immune complex diseases, allergy and inflammation.

12.4 Fungi as Food

Fungi fruit bodies have been used as food since times immemorial and esteemed as delicacies.

12.4.1 Fungi Directly as Food

a. Mushrooms: Mushrooms are preferred for food because of their fairly large protein contents (21-30%). They are also rich in vitamins, carbohydrates, minerals, amino acids and are good sources of vitamins like thiamin, riboflavin, niacin and ascorbic acid. The above ground fruit bodies of the morels and several mushrooms (e.g., *Agaricus bisporus, Amanita vaginata, Boletus edulis, Clavatia gigantea, Morchella, Volvaria, Volvariella volvacea)* are used as food. The *Morchella* spp. are also highly prized edible fungi. *Morchella esculenta* is grown in Punjab and Kashmir on commercial scale. *Agaricus bisporus,* the white button mushroom is cultivated all over the world. *Agaricus campestris* is cultivated in many areas of north and south India. *Agaricus brunnescens (*meadow mushroom), *Lentinus edodes (*shitake), *Pleurotus* sp. (oyster mushroom), *Volvariella volvacea* (Paddy straw mushroom) and *Tricholoma magnivelare* (Matsutake or pine mushroom) is commonly collected and cultivated in different parts of the world as edible mushrooms.

Truffles *(Tuber* sp.), which grow underground as root parasites are considered delectable delicacies.

Some smuts and rusts are also eaten in different parts of India and world. *Ustilago esculenta,* a smut fungus, parasitic on wild rice *(Zizania aquatica)* is eaten in Taiwan. Similarly, galls of *Ustilago mayidis* on maize are also eaten. In India, three rust fungi are considered edible: the aecial

stage of *Puccinia caricis* on *Urtica parviflora,* aecial stage of *Ravenelia esculenta* on *Acacia eburnea,* and aecial stage of *Chrysomyxa* sp. on *Picea alba.*

b. Single cell proteins (SCP): The food yeasts are of great importance as an important source of vitamin B and D. These are included under single cell proteins. These serve as protein source in human foods or animal feeds because they contain carbohydrates, lipids, vitamins, minerals and non-protein nitrogen material such as nucleic acids. *Saccharomyces, Endomyces, Rhodotorula Torulopsis* are particularly rich in proteins and hence they are mixed in incomplete livestock food. **Single-cell protein** (SCP) obtained from yeast, species of *Aspergillus, Penicillium, Fusarium, Neurospora* and *Candida* is a complete substitute for conventional protein foods. *Candida utilis* can convert sulfite waste liquor from pulp and paper industry into valuable foodstuffs containing protein and fat required by humans and animals.

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The baker's yeast, *Saccharomyces cerevisiae,* is grown with molasses as the carbon and energy source and ammonium salts as nitrogen sources. *Paecilomyces varioti* also is grown on sulfite waste liquor. *Fusarium graminearum* is grown on glucose as SCP. SCP is also produced by growing *Kluyveromyces fragilis* and *Penicillium cyclopium* on lactose.

12.4.2 Fungi in Food Processing

Fungi are being employed in the processing of certain food products as agents responsible for characteristic odour, flavour or texture. Besides this some foods like soybeans and cassava although rich in nutrients, cannot be easily digested by man. These are made easily palatable by fermenting fungi. Soybeans are fermented by species of *Rhizopus* (e.g. *R. oligosporus, R. oryzae* and *R. arrhizus)* to prepare '*Tempeh*', a food which is more digestible and tasty. Similarly, a popular food, '*sufu*' is produced from species of *Mucor* and *Antimucor. Rhizopus, Mucor* and *Actinomucor* are used to increase the digestibility of rice, wheat, and soybeans.

In Japan and China *Aspergillus flavus-oryzae* group has long been variously used in the processing of a number of food products. The '*Koji*' of Far East has filamentous fungi in addition to yeast and lactic acid bacteria. '*Miso*' of Japan, China and Philippines has the yeast *Saccharomyces rouxii* and *Aspergillus oryzae.*

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'Ang-kak' contains *Monoascus purpureus* and *'Shoyu'* has two yeasts, a filamentous fungus and a bacterium. The raw materials used for these several 'ferments' are rice or soyabean. These, after fermentation, are drunk as alcoholic liquids. An example of this is the famous Japanese rice wine *'sake'*.

Two kinds of cheese are ripened and flavoured by filamentous fungi. The characteristic changes that occur in the outer layers of Camembert and Brie cheese are due to *Penicillium camemberti. Penicillium roqueforti* grows inside Roquefort and other cheese ripening them. The blue colours of these blue cheeses are due to conidia of *Penicillium,* which give them blue veined appearance.

Saccharomyces cerevisiae and its strains are used in the making of bread. Strains of these are selected for optimal baking properties like high carbon dioxide production for raising the dough and also for their contribution to the flavour of bread.

'Incaparina' foods developed by The Institute of Nutrition of Central America and Panama, consist of corn (26%), cotton seed flour (38%), sorghum (26%), food yeast (3%) minerals and vitamins.

Northern Utilization Research and Development Division of USDA has developed protein cake by combining wheat, barley, oats, and rice and soybean flour cooked and fermented with the help of *Rhizopus oligosporus.* This cake is rich in niacin and riboflavin.

12.5 Fungal Diseases in Plants and Human

There are many fungal activities which are harmful to mankind. Fungi incite many diseases in plants, animals and human beings. They cause considerable loss to food, vegetable and fruit crops. They destroy valuable timbers and cause spoilage of food and many other useful articles.

12.5.1 Plant Diseases

Most of the parasitic fungi cause diseases in plants, especially to flowering plants. The common fungal diseases of plants are smuts, rusts, mildews, blights, rots and wilts. They are responsible for destroying crops worth billions of rupees. They may result even into a catastrophe if allowed to run their course unchecked. Disastrous Irish potato famine of 1845-49

caused by *Phytophthora infestans* was responsible for taking lives of approximately one million people. Similarly, tobacco yield was reduced by over 60% in North Africa and Middle East in 1962 because of the infection of *Peronospora tabacina*. In England, over five million elm trees were destroyed during 1967-77 because of the infection of *Ceratocystis ulmi*.

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Damping off, a common disease in germinating seeds and seedlings are caused by *Pythium debaryanum* and *Rhizoctonia solani* although other species like *Fusarium*, *Botrytis* and *Phytophthora* also can cause damping off disease.

Root rot or foot rot is caused by species of Deuteromycotina or Mycelia strerilia. *Rhizoctonia crocorum* with its telomorph *Helicobasidium purpureum* causes violet root rot of sugarbeet. *Thielaviopsis basicola* causes black root rot of Tobacco, peas, tomatoes etc.

The most common and important fungus that causes wilts is imperfect fungus *Fusarium*.

The causal agents of downy mildews belong to Peronosporales of the Mastigomycotina whereas powdery mildews belong to a single family Erysiphaceae of the order Erysiphales of Ascomycotina. Blights are caused by members of Peronosporales, eg. Late blight of Potato caused by *Phytophthora infestans*.

Rusts are caused by members of order Uredinales and smuts by the members of order ustilaginales of Basidiomycetous fungi. *Puccinia* and *Ustilago* (Basidiomycotina) cause the rusts and smuts respectively of cereals and other plants. Rusts are obligate parasites and attack Angiosperms, Gymnosperms and some ferns. They are identified by brown or black coloured pustules on the stem and leaves which represent different spore stages on the host. Smuts are identified by sooty black masses of spores that are produced in place of grain in the host.

There are so many fungi that cause leaf spot disease in plants. Majority of fungi that causes leaf spot belong to the Deuteromycotina whose perfect stage belong to Ascomycotina. For example, Cercospora leaf spot of groundnut, Helminthosporium leaf spot of oats and barley.

Some important plant diseases caused by fungi are listed in Table 2.

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Table 2 : Some common plant diseases caused by fungi

S.No.	Fungi	Disease
1	*Albugo candida*	White rust of crucifers
2	*Alternaria solani*	Early blight of potato
3	*Cercospora personata*	Tikka disease of groundnut
4	*Colletotrichum fulcatum*	Red rot of sugarcane
5	*Erysiphe graminis*	Powdery mildew of wheat
6	*Erysiphe polygoni*	Powdery mildew of peas
7	*Fusarium udum*	Wilt of arhar
8	*Haemelia vastatrix*	Leaf rust of coffee
9	*Peronospora pisi*	Downy mildew of peas
10	*Phytophthora infestans*	Late blight of potato
11	*Plasmodiophora brassicae*	Club root disease of crucifer
12	*Protomyces macrosporus*	Stem gall of coriander
13	*Puccinia graminis tritici*	Black rust of wheat
14	*Pyricularia oryzae*	Blast disease of rice
15	*Pythium aphenodermatum*	Stem rot of papaya
16	*Sclerospora graminicola*	Green ear of bajra
17	*Sphacelotheca sorghii*	Grain smut of jowar
18	*Synchytrium endobioticum*	Wart disease of potato
19	*Tolyposporium penicillari*	Smut of bajra
20	*Urocystis tritici*	Flag smut of wheat
21	*Ustilago hordei*	Covered smut of barley
22	*Ustilago kolleri*	Covered smut of oat
23	*Ustilago nuda*	Loose smut of barley
24	*Ustilago scitamineae*	Whip smut of sugarcane
25	*Ustilago tritici*	Loose smut of wheat

Forms like *Plasmodiophora brassicae* (Plasmodiophoromycetes) cause club root of cabbage. *Spongospora subterranea* belonging to the same group causes powdery scab of potato. *Synchytrium endobioticum* (Mastigomycotina) causes black wart of potato. *Plasmopara viticola* causes the downy mildew of grapes. *Taphrina deformans* (Ascomycotina) cause peach leaf curl.

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12.5.2 Diseases of Human beings

Several fungi infect human beings, causing diseases of skin, respiratory tract, lungs, viscera, nasal sinuses, eye, liver and kidney.

In Dermatophytosis fungal pathogen colonizes nails or hairs of human and cause superficial mycosis. Species of Deuteromycotina; *Microsporum, Trichopyton* and *Epidermophyton* cause dermatophytoses in man and animals. *Tinea pedis* is the causal agents of a disease known as athlete's foot. *Tinea curtis* (Jockey itch, dhobi itch, ringworm of groin), *Tinea barbae* ('ring worm' of beard, barbers itch), Tinea capitis ('ring worm' of scalp) are also well known skin dsiease causing fungi.

There are also some fungi that cause subcutaneous mycosis in man. For example; the chief excitant of deep mycoses (Madura mycoses or Madura foot) is soil inhabiting fungi *Madurella mycetomi.* The disease is very common in Maharashtra, Andhra Pradesh, Bihar and Rajasthan especially in farmers who walk bare foot.

Some fungi cause systemic mycosis in human. These are fungal infections that occur in deep tissues of body. For example; Aspergillosis of the lung is caused by *Aspergillus fumigatus,* cryptococcsis by *Cryptococcus neoformans* and histoplasmosis by *Histoplasma capsultum.*

Besides these, there are species of *Aspergillus* and other fungi which cause allergy in human beings. These allergens are found distributed in the air and, when inhaled, causes allergic rhinitis and asthma. Wind-borne spores of several fungi (e.g., *Alternaria, Aspergillus, Chaetomium, Helminthosporium, Monilia, Phoma, Trichoderma)* are allergic and cause distressing symptoms.

Mucormycosi or Phycomycosis is a group of mycosis caused by members of Zygomycotina; *Absidia, Mucor, Rhizopus, Basidiobolus and Entomophthora.*

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Some common diseases caused by fungi in human beings are listed in Table 3.

Table 3: Some common Diseases of Human beings caused by fungi

S.No.	Fungi	Disease
1.	*Aspergillus flavus. A. jumigatus, A. niger*	Aspergillosis
2	*Blastomyces dermalitidis*	Blastomycosis
3	*Candida albicans*	Candidiasis
4	*Cladosporium corrionii*	Chromomycosis
5	*Coccidiodes immitis*	Coccidiomycosis
6	*Lipomyces neojormans*	Cryptococcosis
7	*Geotrichum candidum*	Geotrichosis
8	*Histoplasma capsulatum*	Histoplasmosis
9	*Mucor pusillus*	Neuritis
10	*Trichophyton purpurewn*	Onychomycosis
11	*Sporotrichum schenkii*	Sporotrichosis

12.6 Mycorrhiza

A mutualistic symbiotic association between fungal hyphae and roots of higher plants is known as mycorrhiza. They are categorised into ectotrophic and endotrophic mycorrhiza. Ectrotrophic mycorrhizae are restricted to woody shrubs and trees whereas endotrophic forms (VAM) are found associated with more than 90% of the earth's vegetation. The ectotrophic mycorrhizal fungi are mostly forms belonging to the higher fungi, especially more of Basidiomycotina members and a few Ascomycotina members. On the contrary, the VAM fungi belong to the lower fungi, the Glomales of the Zygomycotina. Mycorrhizal associations are beneficial to plants in that they solubilize phosphates and transport them to plants. It also helps in the transport of water and minerals and accelerates nitrogen fixation in legumes. Because of these activities, mycorrhizae are important in forestry, agriculture and horticulture.

Several fungi, like species of *Rhizoctonia, Phoma, Tricholoma, Boletus, Phallus, Scleroderma* and *Amanita* form mycorrhizal relationships with higher plants. The fungal partner of the mycorrhiza obtains food from the roots of higher plant and in return it supplies mineral elements to the other partner. Mycorrhiza is important organs of water absorption for the plants growing in dry conditions and plays a dominant role, particularly in the uptake of less- mobile plant nutrients.

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12.6.1 Mycorrhiza and Nutrition

Hayman (1983) postulated that VAM hyphae in organic connection with the root extend beyond the zone of phosphate depletion, which develops in phosphate deficient soils. This is so since mycorrhiza absorbs phosphate ions faster than they can diffuse through soil to replenish the supply at the root surface. The transport of phosphate in mycorrhizal plant takes place in three phases; (a)uptake by fungal hyphae in soil, (b) its movement into the hyphae inside the root cortex through entry points and (c) its resultant release through arbuscules into the host plant. Fungal hyphae could dissolve rock phosphate because of greater physical contact between phpsphate particles and hyphae than between the roots of host plant and rock phosphate particles.

The uptake of other elements like Cu and Zn also is increased by mycorrhizal plants. Normally these elements are diffused from soil into plant roots.

12.6.2 Mycorrhiza and Water Stress

Duddridge *et al*., (1980) reported increased uptake of water by ectomycorrhizal fungi. Mycorrhizal plants are also less subject to transpiration stresses compared to non-mycorrhizal plants. Mycorrhizal fungi improve water relation of host plants by increasing root hydraulic conductivity increasing transpiration rate and lowering stomatal resistance by altering the balance of hormones.

12.6.3 Mycorrhiza and Plant Diseases

Zak (1964), Marx (1973) and Schonbeck (1979) have reported the increased resistance of plants inoculated with VAM to root pathogens. Increased resistance has been shown to fungal root rots and wilts by host plants that were inoculated with VAM (Scheneck and Kellam, 1979).

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Citrus seedlings infected with *Phytophthora* shows better growth in mycorrhizal compared to non-mycorrhizal plants (Davis and Menge, 1981). This was so because mycorrhizal seedlings were capable of absorbing more nutrients. It is quite possible that VAM fungus elicit a resistance mechanism in host, which may inhibit subsequent infection by pathogen. In some cases mycorrhiza may promote the development of plant diseases.

Nematode diseases also reported to be reduced in plants with mycorrhizal infection (Cooper and Grandison, 1987).

12.6.4 Mycorrhiza in Agriculture and Forestry

The vast occurrence of VAM compared to other symbiotic associations indicates a greater potential for practical applications. VAM fungi are beneficial in low input agricultural systems of tropical acidic infertile soils. Ectomycorrhizal inoculants, on the other hand, are beneficial in forestry and industry. There is a great potential for increasing the efficiency of growth of agricultural crops by mycorrhizal inoculation and management in semi-arid and tropical regions. Even though the role of mycorrhizae is basically the same in these zones, as in temperate climates (Mikola, 1987), the semi-arid and tropical zone presents different problems. Management strategies may need alternate approaches to those adopted in developed countries.

Mosse (1986) suggest use of mycorrhizae is especially appropriate to the development of sustainable systems of agriculture. Mycorrhizal inoculants have tremendous value because of their ability to improve the efficiency and sustainability of crop yields in areas of low soil fertility. Ectomycorrhiza can be raised in aseptic cultures easily whereas VAM inoculum can be raised only on rootstocks.

12.6.5 Mycorrhiza and Restoration of Degraded Lands

Commercial applications of VAM are useful in situations where the natural populations of VAM fungi have been destroyed due to fumigation or in regions of disturbance. Restoration of disturbed lands also is possible using VAM fungi. Restoration of arid shrub-grasslands following severe disturbance can be promoted by planting shrub islands (patch planting) of VAM species, which will serve as foci to disperse infection.

12.6.6 Mycorrhiza and Nitrogen Fixation

Many vascular plants possess both mycorrhizae and N-fixing symbiotic organs. Since the roots, in fact, are usually also infected by mycorrhizal fungi, a new concept of mycorrhizosphere has been introduced. Relationships between mycorrhizal fungi and N-fixing bacteria of the mycorrhizosphere are poorly known.

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Mycorrhizae also contain nitrogen fixing bacteria which fix atmospheric nitrogen. N-fixing bacteria have been found even inside the fungal mantle of ectomycorrhizae. After the nitrogen fixing bacteria in the mycorrhizae harvest nitrogen from the air, the nitrogen is used both by the fungus and the host tree. The most common trees in this type of relationship are woody plants particularly Pine, Fir, Spruce, Larch, Douglas fir and Hemlock. These trees depend on these mycorrhizae forming fungi for nutrient uptake.

Increased uptake and accumulation of phosphorus and other ions like Cu, and Zn helps in enhancing nitrogen fixation in leguminous crops.

12.6.7 Mycorrhiza and Primary Productivity

Mycorrhiza play significant role in nutrient cycling, productivity and plant succession in ecosystem. They contribute to the organic matter turnover and nutrient cycling in forest ecosystems. Mycorrhizal fungal biomass is almost 15% of the net primary production, most of which enter soil organic matter pool annually.

12.6.8 Other Beneficial Activities

They are useful for *ex vitro* establishment of tissue culture plantlets (Sivaprasad *et al., 1995).*

To sum up, mycorrhiza seems to have evolved as survival mechanism for both the fungus and its plant partner especially under stress conditions.

There are several benefits because of this relationship:

(a) Increased nutrients and water absorption through improved absorption area.

(b) Increased nutrient mobilization through biological weathering.

(c) Increase in feeder root longevity by provision of biological deterrent to root infection by soil borne pathogens (Duchesne *et al.,* 1989; Marx, 1973)

(d) Translocation of N, P. K, Ca and Zn to the plant.

(e) Ectomycorrhizal hyphae penetrate the upper layers of forest floor and minerals mobilized in this zone can be absorbed before they reach sub-soil system.

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(f) Some complex minerals and organic substrates being soiled and degraded are made available to plants.

(g) Through strategies like use of surplus carbohydrates by providing physical barrier and by producing antibiotics they provide protection against attack of pathogens (Duchesne *et al.,* 1989; Garrido *et al.,* 1982; Tsantrizos *et al.,* 1991).

(h) Provides growth hormones like auxins, gibberellins and growth regulators like B vitamins to the host (Gopinathan and Raman, 1992; Ho, 1987; Kraigher *et al.,* 1991). The fungus is also reported to take over cytokinin synthesis in plants at root tip (Miller, 1971).

(i) Increases tolerance of plants to adverse condition like water, pH, temperature, heavy metal and toxin stress (Dixon *et al.,* 1994; Gardner and Malajczak, 1988; Marx and Artman, 1979; Osonuki *et al.,* 1991, Peiffer and Bloss, 1988).

(j) Provide protection to delicate root tissues from attack by pathogens by utilizing surplus carbohydrates, by making physical barrier and by secreting antibiotics (Tsantrizose *et al.,* 1991).

(k) Mycorrhizal fungi also produce hormones which encourage the production of new root tips of the tree and therefore increase the tree's useful life span.

Because of the several benefits, they give to host plant they are used in:

a) nurseries to inoculate seedlings that are to be planted,

b) *ex vitro* establishment of tissue culture plantlets (Sivaprased *et al., 1995),*

c) low input agricultural systems in tropical acidic and infertile soils,

d) increased efficiency of growth of agricultural crops in semi arid and tropical region.

Thus VAM fungal inoculants have tremendous value because of their

ability to improve the efficiency and sustainability of crop yields in areas of low soil fertility.

12.7 Fungi as Biological Control Agents

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Fungi are used as agents of biological control and are also utilized for controlling soil borne organisms like amoeba and nematodes. Drechsler (1937) reported that there are some predacious fungi in the soil. They trap and destroy the nematodes (eel worms). Some species of these predatory soil fungi form loops on the mycelium. These loops act as nooses. They tighten and strangle the nematodes as they try to pass through. The mycelium later sends out special hyphae to absorb nutrition from the captive. Some predatory soil fungi produce conidia which are sticky. As the nematodes pass through the soil, the sticky conidia stick to their bodies. There the conidia germinate to produce hyphae which penetrate into the tissues of the host and absorb nourishment.

For instance, *Nematophthora gyrophila* is capable to control effectively *Heterodera avenae,* a cereal cyst nematode. Nematophagus fungi like *Arthrobotrys* and *Bactylella* are used in the control of nematodes. Entomogenous fungi like *Entomophthora,* which grows on flies or *Cordyceps* sp. on beetles, serve to control these pests.

Fungi play an important role in biological control of plant diseases; for instance, *Trichoderma lignorum* suppresses the growth of root rot fungus, *Pythium* and the growth of *Rhizoctonia solani* can be checked by *Penicillium vermiculatum* and *Rhizoctonia oryzae. Gliocladium roseum* is used to control *Sclerotinia* diseases. *Trichoderma harzianum* is used to control blight of tomato and peanuts caused by *Sclerotium rolfsii.*

Fungal pathogens play an important role in nature in the reduction of weeds. The strategy of using fungal plant pathogens in biological control of weeds involves a classic tactic and a bioherbicide tactic. The first approach involves the introduction of a foreign plant pathogen, while the latter envisages the development of endemic pathogens and using them as microbial weed killers (bioherbicides). Pathogens are multiplied *in vitro* and applied as herbicides so that each individual weed plant is heavily inoculated with infectious propagules. For instance, *Septogloeum gillis, Wallrothiella arecuthdoii* and *Colletotrichum gloeosporioides* have the ability to attack mistletoes (*Arecuthobium* spp.) at all stages of

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development. Similarly, the growth of the weed, *Eupatorium adenophorum* can be controlled by *Cercospora eupatorii* and *Colletotrichum destructive* can be used as a biocontrol agent for dodder.

Some common fungal inhabitants of the soil help to combat diseases caused by soil borne fungi. *Trichoderma lignorum,* and *Gliocladium fimbriatum* are found in damp soils. They have an inhibitory effect on the growth of the mycelium of *Pythium.* They serve to suppress fungi causing the damping off disease of the seedlings and thereby influence favorably the growth of crops.

Several fungi are active against human pathogens; for instance, spread of *Candida albicans,* causal agent of candidiasis is prevented by the extract of *Tricholoma saponaceum.*

Some fungi produce diseases among annoying insects harmful to crop and thus help to destroy them and keep them in check. Many insect pests can be controlled by the use of fungi. For example; *Fusarium oxysporum, Aschersonia aleyroidis, Cordyceps melonthae* etc.

12.8 Summary

Fungi are beneficial to us in many ways. In our daily life fungi play important role as food, medicine and many industrial products. Fungi are used in brewery (eg. wine & bear), food processing industry (bakery products, cheese etc.) and directly as food (mushrooms, Truffles) since ancient time. Fungi are also used as single cell proteins for human and livestock.

Besides these, many organic acids, enzymes, growth regulators and other industrial products like ethyl alcohol and Glycerine are produced with the help of fungi. Medicinal use of fungi includes antibiotics (Penicillin, Cephalosporin etc.), ergot, ephedrine, steroids, vitamins and as active agents against human pathogens.

Most of the parasitic fungi cause diseases in plants, especially to flowering plants. The common fungal diseases of plants are smuts, rusts, mildews, blights, rots and wilts. They are responsible for destroying crops worth billions of rupees. There are several fungi that infect human beings, causing diseases of skin, respiratory tract, lungs, viscera, nasal sinuses, eye, liver and kidney.

Mycorrhizal association is a mutualistic symbiotic association between fungal hyphae and roots of higher plants which is beneficial to plants in many ways. Mycorrhiza solubilize phosphates and transport them to plants. It also helps in the transport of water and minerals and accelerates nitrogen fixation in legumes. Because of these activities, mycorrhizae are important in forestry, agriculture and horticulture.

NOTES

Mycorrhiza are important organs of water absorption for the plants growing in dry conditions thus helping to withstand water stress and plays a dominant role, particularly in the uptake of less mobile plant nutrients. Mycorrhiza helps to control plant diseases by increasing resistence against nematodes and other root pathogens. VAM suppress soil borne pathogens. Importance of mycorrhiza in the restoration of degraded lands is a new area.

VAM fungi are significant since they confer physiological benefits on the plant by promoting uptake and accumulation of phosphorus and other ions like Cu, and Zn thus enhancing nitrogen fixation in leguminous crops also. VAM are resistant to water stress and transplantation stress.

Fungi are used as agents of biological control against nematodes, insects, plant and human pathogenic fungi.

12.9 Glossary

- **Anamorph:** Imperfect or asexual stage of fungi.
- **Dermatophytosis:** A fungal disease in which fungi colonize dead cutaneous tissues like nail or hair.
- **Hallucinogenic**: Capable of producing hallucinations (the alleged perception of an object when no object is present)
- **Mycosis:** Disease caused by fungi.
- **Systemic mycosis**: Fungal infections that occur in deep tissues of body.
- **VAM:** Vesicular-arbuscular mycorrhizas, are mycorrhizas whose hyphae enter into the plant cells, producing structures that are either balloon-like (vesicles) or dichotomously branching invaginations (arbuscules).

12.10 Self-Learning Exercise

Section –A (Very Short Answer Type Questions)

NOTES

1. Which fungus is used in baking of bread?
2. Which of the following is used as human food? (a) *Agaricus* (b) *Coprinus* (c) *Amanita* (d) All the above
3. In Japan wine is prepared by fermenting rice with……
4. Name a species of fungus which is a source of antibiotic.
5. Name the causal organism of early blight of Potato.
6. Name the fungus which is responsible for Athlete foot disease in man.
7. Club root disease of crucifer is caused by ……
8. *Amanita phalloides* is a poisonous mushroom. True/False
9. Name the fungus famous for ergotine which is used to check bleeding.
10. Name the fungus which is source enzyme in invertase and zymase.

Section –B (Short Answer Type Questions)

1. Write a note on edible fungi.
2. Write a note on importance of fungi as medicine.
3. How fungi are important in the biological control of plant diseases.
4. Write a note on importance of fungi in alcoholic fermentation.
5. Write a note on use of fungi in agriculture.

Section –C (Long Answer Type Questions)

1. Give an account of the economic importance of fungi.
2. Write a detail note on fungi as plant pathogen.
3. Write a note on importance of fungi in Industry.
4. Fungi are not only our foes, but friends also. Discuss.

Answer Key of Section –A

1. *Saccharomyces cerevisiae*
2. *Agaricus*
3. *Aspergillus oryzae*
4. *Penicillium notatum*
5. *Alternaria solani*
6. *Tinea rubrum*
7. *Plasmodiophora brassicae*
8. False
9. *Claviceps purpurea*
10. *Saccharomyces cerevisiae*

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Unit - 13

Bryophyta : An Introduction

NOTES

Structure of the unit

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13.1 Introduction
13.2 General Characters of Bryophytes
13.3 Range of Thallus in Bryophytes
13.3.1. Hepaticopsida
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13.3.3 Bryopsida
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13.6 Alternation of Generation in Bryophytes
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13.6.2 Sporophyte
13.6.3 Alternation of Generation
13.7 Classification of Bryophytes
13.8 Economic Importance of Bryophytes
13.9 Summary
13.10 Glossary
13.11 Self-Learning Exercise
13.12 References and further readings

13.0 Objectives

After going through this unit you will be able to:

- List of general characters of Bryophyta.
- Range of thallus and distribution of Bryophyta.
- Reproduction and life cycle of Bryophyta.
- Classification and Economic importance of Bryophyta.

13.1 Introduction

Bryophyta are considered as the amphibions of plant kingdom as they can not complete their life cycle in absence of water. They are also called as the first land plants, however, these initial land plants could not grow as a dominant vegetation on a large area of land as well as they could not form the climax vegetation in ecological succession. The general features of Bryophytes which made them to survive without much water and established them as land plants are as follows:

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13.2 General Characters of Bryophtes

1. These are first land plants having green thalloid or leafy plant body. These are small rarely becoming more than five inches.
2. The vegetative structure has well developed rhizoidal system which makes them fit to get attached to the damp soil. Rhizoids act as roots as they help in attachment of plant and act as absorbing organs.
3. Vegetative body grows well in damp, shady humid areas but for sexual reproduction water is essential. The antherozoids are motile and reach neck of archegonia swimming in water.
4. Plant body is devoid of true root, stem and leaves. The thallus is simple, prostrate, however in mosses the plant body is erect having a central axis and some leaf like appendages.
5. The dominant part in the life cycle is gametophytic phase which is independent and helps in sexual reproduction.
6. The multicellular sex organs are of advanced oogamoas type covered with a sterile jacket.
7. In Bryophytes, vascular system (xylem and pholem) is absent.
8. Female sex organs are the archegonia which developed for the first time in Bryophytes.
9. Male sex organs are antheridia in which motile antherozods develop.
10. The fertilized egg is protected from the environmental hazards. It obtains water and nutrition from the parent plant and latter forms the embryo.
11. Water is essential for fertilization.

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12. There is no dormancy in the embryo. It starts germinating soon after it is formed.
13. The first division of the zygote is transverse. Apex of embryo is formed from outer cell. It is called as exoscopic type of embryogeny.
14. Venter of archegonia forms a protective covering for developing embryo known as calyptra.
15. The embryo by repeated mitotic divisions forms a spore producing organ known as sporogonium.
16. The simple sporophyte is dependent on the gametophytic plant for its nutrition and protection.
17. Meiosis occurs in the sporogonium or sporophyte which forms many small non motile spores called gonospores or meiospores.
18. All the meiospores are morphologically and physiologically alike hence are known as homospores.
19. Spore either germinates to form a gametophytic plant directly or it produces a protonema which forms the thallus.
20. Alternation of generation is of heterologous haplodiplontic type.
21. The protonema may develop secondary protonema. The former may be developed into a single gametophytic plant or a number of such plants may be formed from single protonema.

13.3 Range of Thallus in Bryophyta

Bryophytes are the primitive land plants which have a thalloid or a leafy plant body. Most of the species are terrestrial in nature though few are aquatic species for example *Riccia fluitans, Ricciocarpus natans, R. abuensis* etc: There are around 960 genera with almost 24,000 species in Bryophyta. The size range from a few millimeters to almost 40 cm-in-length. The gametophytic plant body is attached on the substratum with the help of rhizoids. Like roots they perform the dual function of attachment and absorption.

Structure of Thallus in Bryophyta

In early and primitive species of Bryophyta the thallus is quite a compact structure growing prostrate on the ground. The maximum Bryophytes however have a better differentiated body i,e. it has a leafy gametophyte made up of stem

and leaf like structures fixed to the substratum with the help of branched, multicellular rhizoids.

Thalloid plant body is found in advanced forms -while in some other liverworts like primitive Metzgeriales, Takakiales, Calobryales Jungermanniales etc.The gametophytic plant body is leafy in nature with a central axis (stem) and green appendages' (leaves). In these forms there are 'three rows of leaves, two are lateral and one is present on the ventral side. In prostrate leafy forms the ventral leaves are termed as amphigastria. It is observed, that these leaves got reduced and finally disappeared for example in *Fossombronia* there are only two lateral rows of leaves, this suggests that might be the thalloid forms have evolved from The leafy forms by reduction of leaves.

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The above view is supported by a member Schiffneria of Metzgeriales which depicts the transitional stage between the thalloid and the leafy forms. Here the plant body in its vegetative phase is thalloid. During reproductive phase, from the ventral surface of thallus arise leafy shoot which bears the sex organs.

The range of thalli in various groups like Hepaticopsida, Anthocerotopsida and Bryopsida is described below—

13.3.1 Hepaticopsida

(i) Marchantiales - The thallus in this order is quite small, fleshy in nature and dorsiventrally flattened. It is green, independent, prostrate dichotomously branched. It is attached to the substratum with the help of rhizoids which may be simple or tuberculate. It has scales also on the lower surface which are multicellular plate like structures. These help in protecting the growing point situated on the thallus. These are differently arranged in various groups like-

***Riccia*-In one row**

Targionia, Reboalia –(Two rows -on either side of midrib.)

Marchantia—Two to four rows (on either side of midrib.)

Corsinea—Scattered unevenly on ventral side of the thallus.

The rapid growth of dichotomous thallus imparts it a rossette form. Thallus branches are termed as thallus lobes. These differ according to the species and could be linear, wedge/shaped. Lobes are thick in the centre and gradually thinning towards the margin. The thick central part is called as midrib. The upper surface of the thallus has a groove called as median groove or furrow.

The lobed thallus has a notch in its each lobe, this is apical in position hence termed apical notch. This bears the growing point. The dorsal surface has many polygonal areas which are porus. These are called as areolae. Vascular system is totally lacking in all members of Bryophyta.

NOTES

Thallus of *Targionia*

These gametophytic plants are simple, with strap shaped thallus, very less dichotomously branched. It has simple and tuberculate rhizoids and simple or appendaged scales. The air pores are present on the dorsal surface. These could be simple or raised on few layers of concentric cells. Many adventitious shoots are seen on the ventral surface.

ii. Metzgeriales

The plant body in this order is very different in various members for example-

a) **Thalloid** - Gametophytic plant body with dichotomous branching and wavymargin is seen in *Pellia* and *Riccardia* etc.

b) **Leafy** - Gametophytic plant body is annual, 'foliose in nature, and light green in colour. The leafy structures occur on both sides of the axis. Smooth walled rhizoids arising from the midrib of the ventral surface attach the plant to the substratum. Tuberculate rhizoids and ventral scales are not found in this group for example *Fossombronia*.

iii) Jungermaniales

These liverworts include an axis bearing leafy structure. This leafy Gametophyte is termed as thallus due to its simple structure and no internal vasculature and differentiation of tissues. It is dorsiventrally flattened like all other members of Hepaticopsida. The branching is always of the monopodial type. Air chambers, air pores, scales and tuberculate rhizoids are absent. Only simple unicellular rhizoids are present which fix the gametophyte to the substratum.

The arrangement of leaves on the axis is of the following types-

(a) **Anisophyllous leaves** - *Porella*-2 dorsolateral rows and one row of reduced ventral leaves (amphigastria)

(b) **Isophyllous leaves**—*Herberta*—Three row of redially arranged leaves.

(c) **Distichous leaves**—*Radula*—Amphigastria and two lateral rows ventrally present.

Takakiales

In this the gametophytic plant body which is deep green in colour, is differentiated into a prostrate rhizoidless, rhizome like structure giving off erect leafy branches which are radially symmetrical 1 to 1.5 cm tall gametophores. The rhizome is attached to the substratum with the help of branches produced on the prostrate system which enter the soil and fix the plant, these are known as stolons. The leafy appendages which are isophyllous are termed as `phyllids' or 'polymorphous leaves' these are spirally attached on the gametophores.

NOTES

Calobryales

Here the gametophytes are quite small divided into subterranean rhizometous structure, leafy aerial part, the gametophore. The leaves which are spirally arranged on the axis in three ventral rows could be of isophyllous or anisophyllous type.

The members of this order lack rhizoids and the plant is fixed in the soil with the help of a branched, rhizometous body for example *Calobryum.*

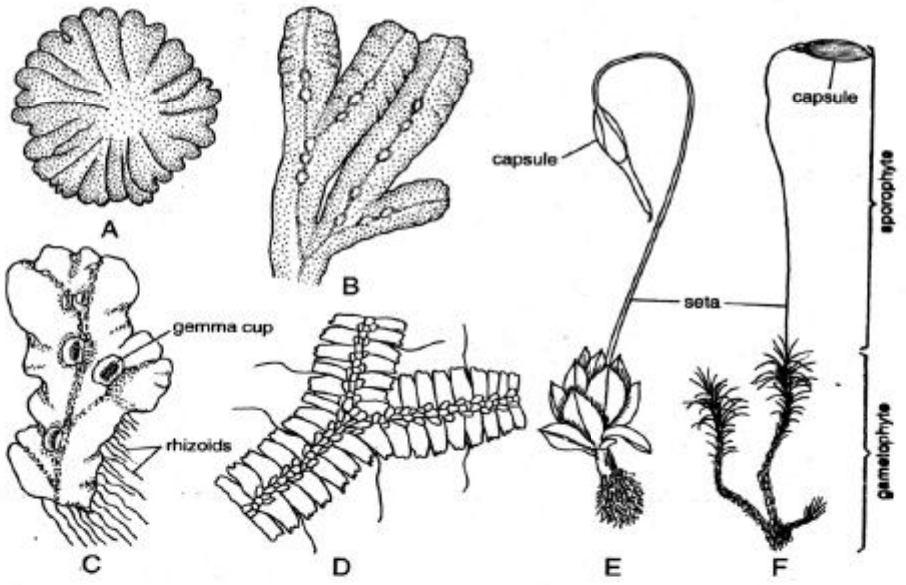


Fig. 13.1:Various Types of Thallus A-B: *Riccia*, C: *Marchantia*, D:*Porella*

E: *Funaria*, F: *Polytrichum*

13.3.2 Anthocerotopsida

The members of this group are called as 'hornworts.' They are seen growing in moist shady places. The thalloid plant body is simple, yellowish to dark green,

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dorsiventrally flattened, fleshy, lobed and gametophytic in nature. Midrib is not very distinct in these members. The upper surface of the thallus could be either smooth or rough. The ventral surface is without scales and tuberculate rhizoids. Simple unicellular smooth walled rhizoids arise on the ventral surface which fix the thallus to the substratum and help in the absorption of water and minerals required by the plant. The thallus does not show much internal differentiation. Some small cavities are seen in the thallus which has blue green algae *Nostoc i*n them. The single chloroplast has a pyrenoid.

13.3.3 Bryopsida

Sphagnales

The members of this group are commonly known as Musci or mosses. These are perennial plants which are erect, yellowish to pale green in colour. They may be of different colours also for example—*Sphagnum rubellum*—Red, *S. plumulosum*—Pink

The plant body of *Sphagnum* starts from a juvenile stage the protonema, this grows to form an irregularly lobed structure which looks like a thallus. It has multicellular rhizoids at its base by which this structure is fixed to the substratum. The margin of the lobed protonema gives rise to the erect, leafy gametophytic plant body i.e. the gametophore. The gametophore has a length of about one foot and the diameter of 1-2 mm hence it gets support to stand erect by growing in groups. The axis is freely branched. Both the main axis and the branches bear numerous small leaves. At the apex of the main stem the apical meristem is protected by a group of small branches called as 'coma' or `comal tuft'. The erect plant bears two kinds of branches:

(i) **Divergent branches**—These grow in horizontal position.

(ii) **Drooping branches**—These hang down or droop down and lie parallel to the axis.

Andreales

The gametophytic plant body is very small growing in groups on siliceous rocks or in its crevices. It is black, bluish green or brown in colour. The aerial part of the plant grows out of the thalloid prostrate protonema. The leafy gametophore is also prostrate in nature. The branching is of sympodial type.

The rhizoids are flattened cell plates, which enter the rock crevices and anchor the plant successfully. The leaves present on the axis are small and spirally arranged in three rows.

Funariales

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The plant body has a juvenile stage the branched protonema which gives rise to the leafy gametophore. It has an erect leafy axis which is attached to the substratum with the help of rhizoids having oblique septa (characteristic of mosses). The axis which is almost 13 mm in height bears spirally arranged leafy expansions. These are similar to small angiospermic plants but the basic difference is that the gametophores of Funariales lack vascular system.

Buxbaumiales

The members of this group are peculiar and different from other members of Musci. The gametophytic plant body arising from persistent protonema is heterothallic and is partly saprophytic growing on rotten wood. Axis is absent and the male plant is represented by one bract having a globular antheridium while the female plant has two to four rows of small lanceolate bracts or leafy structures bearing a single archegonium.

Polytrichales

The subterranean protonema gives rise to the gametophytic leafy shoot or the gametophores which develop two structures at maturity. The rhizome like structure bears three rows of small colourless scale leaves and many rhizoidal strands which remain clumped together. These help in fixation of the gametophytic erect plant. The leafy shoot may reach a height 45 cm. The axis could be branched or unbranched. *Potytrichum* with sporophyte bears small scaly and leafy out growth on the lower side of the axis while the upper part bears spirally arranged green foliage leafy expansions.

From the above discussion it could be concluded that the range of thallus in Bryophyta is quite less as all the three groups have almost similar kind of growth patterns. The leafy forms being primitive and by the loss of leafy structures the thalloid forms evolved and got distributed from the Arctic to the tropical regions of the world.

13.4 Distribution of Bryophytes

NOTES

For a luxuriant Bryophytic community there must be a good amount of moisture, a good amount of shade and comfortable coolness. The distribution of species varies according to the adaptation of the species to different variation of these conditions.

1. The Himalayas spreading from Kashmir to the East of India reaching Burma: climatic conditions vary greatly along the Himalayas. Rainfall is heavier in the outer Himalayas and gradually decreasing towards inner Himalayas. In the Terrain along with tropical forest, dense growth of Bryophytes is formed.
2. The Indus-Gang plain: Tropical bryophytes are formed here but they are quickly disappearing. The Ganetic delta mangroves are practically devoid of Bryophytes as the Bryophytes avoid saltish water.
3. Central India is generally dry and Bryophytes which can withstand some amount of drought are only expected here.
4. South India Nilgiris and Palni hills are rich in tropical and subtropical Bryophytes.

Distribution of different Genera/Species of Bryophytes

The *Genus* Marchantia consists of about 65 species distributed pretty well over the world. *Marchantia polymorpha* is one of the most widely distributed members of hepaticopsida. About eleven species have been reported from India (Chopra 1943) growing mainly in the Himalayas.

Pellia is represented by three species; *P. epiphylla, P. endividiacfolia and P. neesiana* with are wide spread in the North Temperate Zone. The fourth species *P. columtriana* has been described by Krajina and Bryoshaw (1951) from British Columbia. Arnell (1956) and Jones (1958) recognized a fifth species *P. borealis.* Kashyap (1929) stated that the first three species are said to occur in the Himalayas, but he could not come across specimens which could be definitely referred to *P. neesiana.* According to him P endiviaefolia is common throughout the western and kumaon Himalayas from 5000 to 8000 feet while *P. epiphylla* is quite common in Sikkim and Eastern Himalayas.

Anthoceros with about 200 species is cosmopolitan but occurs mainly in temperate and tropical regions. About 25 species have been recorded from India.

Sphagnum is almost cosmopolitan, extending from the tropics North and South through temperate zones to sub-arctic and sub-Antarctic regions. They are particularly wide spread in Northen Circumpolar regions, where they occupy an immense extent of marsh land and form important association. Brutel (1931) has enumerated about 10 species of sphagnum in India, but Sharma (1949) has described 17 species mainly from the Himalayas.

13.5 Reproduction in Bryophyta

Bryophytes the lower plants are popularly called as the first land plants. They generally propagate by vegetative means and grow in dense groups. They are found in the same place in any vegetative community year after year normally forming carpet vegetation of that area. In vegetative reproduction, no gametes or fusion is found therefore meiotic division is absent. The new plants developed from parent gametophytic plant are always gametophytes. Koren (1899) understood the importance of vegetative reproduction in Bryophytes for the first time and explained different type of vegetative methods found in Bryopsida (Moss). Later on, Cavers (1930) described various vegetative methods commonly found in Hepaticopsida (Liverworts) in detail.

13.5.1 Vegetative Reproduction

The following types of vegetative reproduction are found in bryophytes.

1. Fragmentation of older parts of the thallus

This type of vegetative reproduction is found in thalloid as well as is leafy member of Bryophytes. The basal thalloid part of the plant separates from the rest of the main plant after progressive death and decay, leaving two separated young proximal parts at the dichotomy of the older plant. Both detached proximal parts grow as individual plants. Likewise, the basal older part of the leafy bryophytes separates from the rest of the plant. The upper two separated branches start growing as two independent plants.

2. Adventitious branches

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The lower ventral part of the thallus of some liverworts like *Targionia, Riccia fluitans, Anthoceros'* and *Marchantia* develop adventitious branches. Usually they originate from the midrib portions. Each branch grows separate and develops as an independent plant. These adventitious branches develop from upper dorsal surfaces in *Pellia*. They grow from the stalk and disc of the female gametophore in *Marchantia paimata*.

3. Vegetative Reproduction by Protonema in Mosses

In Mosses the haploid spore germinates to form a structure called as Protonemal filaments. Each cell of protonema is capable of producing a new plant in *Funaria*. The protonema has buds which develop into a new thallus. Sometimes primary protonema develops secondary protonema as in *Funaria hygrometrica.*

Each gametophore developed from protonema cell forms an independent gametophytic plant. One protonema may either give rise to a single gametophyte or many gametophytic plants depending on the type of species.

4. Propagation by Persistent Growing Apices

In many species like *Riccia* and *Anthoceros* the complete thalloid part of the gametophytic plant except their tips, decay due to unfavorable conditions. The living tip becomes fleshy and thick due to stored food material. These pass off their unfavorable period successfully embedded in the mud: When favorable period comes each buried living tip grows out to form a new thallus.

5. Tubers

After the rainy season tubers' are found as perennating organs. They are generally found in liverworts. Each tuber is a fleshy rounded ball like structure which has single growing point. It has stored food material to ward off unfavorable conditions. It has a thick protective layer. Each tuber germinates in favorable condition and grows into an independent plant. The tubers could be sessile as in *Riccia* or stalked as in some species of *Anthoceros*. They could develop on the base or margins of thallus.

6. Propagation by Cladia

This type of propogation is mostly found in leafy member of Bryophytes. The detached branched part of the leafy gametophyte is called cladia. This is a

separated brood branch. Cladia can be a leaf cladia or stem cladia. *Bryopteris fruiticulosa* is an example of producing leaf cladia from leaves and stem cladia from stem.

7. Propagation by innovation in *Sphagnum*

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In *Sphagnum*, innovation branches are formed as a means of vegetative reproduction. Any branch of the thallus grows upwards increases in size and grows very fast to attain the size of the main branch. This innovation branch gets detached and grows as an individual plant. Due to this type vegetative propagation *Sphagnum* multiples very fast, and increases the amount of *Sphagnum* bogs.

8. Gemmae Formation in Bryophytes

Vegetative reproduction by gemmae is common in Bryophytes. It is present in liverworts as well as in leafy Bryophytes. Each gemmae is specialized perennating organ. It is green stalked muticellular. It has various shapes depending on different species of Bryophytes. Generally they are formed in abundance is members of Hepaticopsida while they are rare in Anthocerotopsida.

Among Hepaticopsida, gemmae are present in the order Marchantiales, Metazeriales and Jungermanniales. In *Marchantia*, Gemmae are present inside the gemma cup. Each cup consist of about 13-16 gemmae. The upper margin of cup is fringed. Each gemmae is a small, disc like biconvex structure which is attached to the base of the cup through a small stalk. The basal part of the cup has many mucilaginous hair which are hygroscopic in nature. After absorbing water they swell and play an important role in dehiscence of gemmae from the gemma cup. Gemmae consists of chlorophyllous cells, oil cells and rhizoidal cells. Later two notches having growing points are also present in gemmae of *Marchantia*. The gemmae germinate from lateral notch End forms a new gametophytic plant.

Gemmae are also found in members of Metzeriales such as *Ricardia multifitida* and *Metzeria fruitculosa*. In *Blasia pusilla* gemmae develops at the tip of flask shaped receptacle. It is two celled ground nut like is *Ricardia mulnfitida*.

Gemmae Formation in Mosses

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Multicellular egg shaped gemmae are formed on a short stalk in mosses. These are called protonemal gemmae. In some species like *Webra prolifera*, gemmae are formed on gemmiferous receptacle. They could be formed as a group of gemmae at the tip of leaves for example *Volata phyllathus,* they may be present in the margins or from the dorsal surface of the thallus in *Anthoceros propaguhferous*, *A. glandulosus* and *A. fomiosae.*

Stolon formation

Stoloniferous branches develop from the basal part of the stem. They may bear small scaly leaves and survive beneath the soil surface. Under favourable conditions tips of stolon grows upright and forms a new thallus.

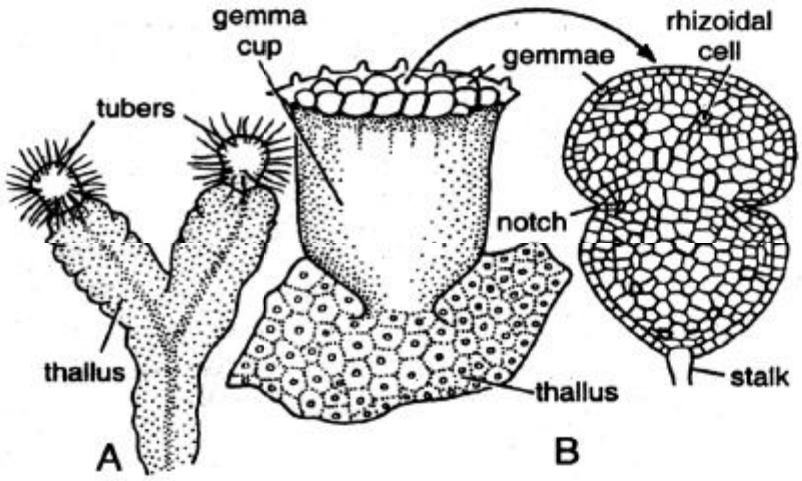


Fig. 13.2 : Vegetative Reproduction A; Tubers, B; Gemmae

13.5.2 Sexual Reproduction

Sexual reproduction is found in gametopytic generation of Bryophytes. It is of oogamous type. The sex organs are present on gametophytic plants. Antheridia and archegonia are called as male and female sex organs. Both sex organs are multicellular, complex in structure and protected by sterile jacket. In Bryophytes sex organ may be produced on the same Plant or on different plants. i.e. the thallus could be monocious or dioecious.

Antheridium

The male sex organ is antheridium. It may be elongated, globose or club shaped in structure seated on a short or long stalk. Many times it is found embedded in the gametophytic thallus. The number of antherdia in the antheridial chamber could be one as in *Marchantia* or many as in each antherdial chamber has a narrow opening called as an ostiole. In *Anthoceros*, antheridial chambers are closed. Each antheridium is one cell thick, which plays an important role in protecting the androcyte mother cells. The androcyte mother cells are fertile cubical cells which divide diagonally to produce two antherozoid cells called as androcytes. These soon metamorphose into two antherozoids (one from each androcyte). These are produced in unlimited numbers. Each antherozoid is a small curved slender and motile structure. It has an elongated nucleus and a pair Whiplash flagella at it anterior and a small vesicle at the posterior end.

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Table 13.1: The shape of gemmae in various species of Bryophyta is as follows

Genera	Order	Shape
1. *Marchantia polymorpha*	Marchantiales	Green lense shaped, biconvex structure, Stalk attaches it to bottom of gemmae cup.
2. *Blassia pusilla*	Metzeriales	In flasked structure sub-spherical gemmae are present.
3. Ricardia Multifitida	Metzeriales	Two celled gemmae present.
4. Metzeria fruitida	Metzeriales	Any external cell of thallus forms two celled gemmae
5. *Radulla complanata*	Jungermanniales	Discoid gemmae are present.
6. *Bryum erythrocarpum*	Bryopsida	Gemmae formed on the rhizoids of leafy stems.
7. *Bryum rubens*	Bryopsids	In the axil of leaf at the base of stem round gemmae is present.

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Development of Antheridium

Any superficial cell situated near the growing point of the thallus is responsible for the development of antheridia. The superficial cell enlarges in size and becomes papillose. It has relatively denser cytoplasm and a large nucleus. This is called as antheridial initial.

Antheridial initial divides by transverse wall to form two cells lying one above the other in two rows. The upper cell is called as outer cell whereas the lowermost basal cell. The outer cell again divides by transverse division and produces upper primary antheridial cell and lower primary stalk cell whereas; the lowermost basal cell forms stalk which is deeply embedded in the gametophytic thallus. Thus, three celled filamentous body is formed (i) basal cell (ii) intermediate primary stalk cell and (iii) upper most primary antheridial cell. This structure soon turns into five celled structure by transverse division. The last two cells form 2 primary antheridial cells, 2 primary stalk cells and basal cell.

The upper two primary antherdial cells undergo two successive vertical divisions. The second division occurs at right angle to the first. The first division produces 4 cells in which 2 cell lying in the upper and 2 in lower tier. The second division forms 8 cells, 4 in the upper and 4 in lower the tier.

The 8 celled antheridium divides by periclinal division parallel to periphery in both the tiers, resulting in the formation of an outer layer of eight sterile wall initials encircling the inner eight fertile primary androgonial cell. The latter undergoes a few more divisions irregularly to produce a mass of cubical cells. These are the small androgonial cells. The last division of the latter produces sperm mother cells called spermatocytes or androcytes. Simultaneously with the development of antheridium wall initials undergo anticlinal divisions to produce one celled thick sterile jacket around the mature antheridium. Each androcyte mother cell produces two triangular androcytes by diagonal division which metamorphoses into small, curved biflagellated antherozoids. The neighbouring cells grow upwards forming antheridial chambers which may or may not be open at its anterior end.

Riccia and *Pellia* are monoecious where the male and female reproductive organs are present on the same plant. In *Marchantia* and *Ricardia* they are dioecious where both sex organs are found on different thallus. The antheridia are stalked in *Riccia* and present in antheridial chambers which are produced on

the dorsal of the thallus. In *Marchantia*, a specialized branch called antheridiophore is developed bearing antheridia. This is an exetention of midrib that grows Upward. It produces a peltate disc at its apex bearing a number of antheridial chambers bearing single stalked antheridium at its base.

NOTES

In leafy members of Bryophytes stalked antheridia are present in between perigonial bracts. They are present in groups at the apical portion of branch in *Funaria, Pogonatum* and *Polytrichum* etc. paraphysis are present among them. Each paraphysis is a multicellular leaf like sterile structure which is unicellular at its basal part but broad and 2-3 celled thick in apical portion. Paraphysis is spathulate in *Polytrichum* whereas their terminal cell is spherical in *Funaria.*

Table13.2: Various shapes of Antheridia in different species

S.No.	Species	Shape of Antheridia
1	*Riccia*	Antheridia develop on the dorsal surface in the median groove two or three cells away from the apical cell Antheridia are rounded stalked structures.
2.	*Marchantia*	These develop on special branches called as *antheridiophore.* Antheridia are stalked structures.
3	*Anthoceros*	Antheridia develop through a sub-superficial cell i.e. they are endogenous in origin. These are found in antheridial chambers either singly or in groups
4	*Sphagnum*	Antheridia develop in the axil of leaves present on antheridial branches. These are present near the terminal comal tufts. Antheridia are round with a long stalk.
5	*Funaria*	Antheridia develop terminally on male branches in the axil of bracts. These are long club shaped stalked structures.

NOTES

Archegonium

The female reproductive organ is called as archegonium. It is a flask shaped structure. The basal portion of this flask is large and swollen known as venter. The upper part is the tubular neck. Neck is protected by sterile cells (5 or 6 rows) jacket cells. The height of neck cell varies in different species of Bryophytes (6-9 celled height). An axial row of canal cells is present in the central part. The basal swollen venter has venter canal cell and an egg. Thus, an archegonium of Bryophytes has the following parts-

1. Cover cell - Generally four- cover cells are situated in the terminal part of the archegonium.
2. Neck - Central neck canal cell, surrounded by jacket.
3. Venter - Venter canal cell and egg.

Development of Archegonia

Development the archegonia starts from any superficial cell situated near the growing point of the thallus. This superficial cell enlarges and becomes papilla like. This is called as archegonial initial. It has denser cytoplasm and a relatively large nucleus. Archegonial initial cell grows and protrudes out of the thallus and divides by transverse division to form an upper and a lower cell. The Upper cell is called archegonial mother cell which forms the archegonium. The lower basal cell remains undivided and takes no part in further development of archegonium. The former enlarges in size and divides by three concentric vertical division separating three sterile peripheral initials encircling the central fertile cell called primary axial cell. Each of the three peripheral initials undergoes second vertical divisions resulting in formation of six peripheral cells called jacket initials.

The primary axial cell divides transversely to form upper primary cover cell and central cell. Each jacket initial also divides by transverse division and forms two tiers of six cells each. The upper tier of six peripheral cells form neck initials whereas the lower tier forms venter initial. Both divide further by transverse division to form multicellular neck cells. The height of each row of neck cells is variable depending on the species. The venter initials divides and redivides by

transverse, anticlinal and periclinal division and produces 18-20 celled thick jacket around venter region.

The central cell also undergoes transverse division to produce upper Primary neck canal cell and a lower venter cell. Primary neck canal cell divides by transverse division to form 4-8 neck canal cells. The primary cover cell produces 4 lower cells by two successive vertical divisions. Primary venter cell forms upper venter cell and an egg cell by transverse division.

Fertilization

Water is important in Bryophytes for dehiscence of sex organs and for fertilization. Potassium and protein that is present in mucilaginous substance. in the neck of archegonia helps to attract antherozoids. The Movement of antherozoids towards. neck of archegonia caused by the chemical attraction is called chemotactic movement. Out of many antherozoids finally one, gets success in reaching the egg. It fuses with the egg and forms zygote. This diploid zygote soon secretes thick wall around itself and forms the oospore. Zygote is the first cell of the sporophytic generation which eventually develops into the sporophytic plant.

Table 13. 3: Various Shapes of Archegonia in Different species

1	*Riccia*	These develop on the dorsal surface of thallus. Archegonium is a flask shaped structure having a stalk, swollen venter portion with egg and upper elongated narrow neck. Neck has 4-6 neck canal cells. Jacket is made up of 6-9 vertical rows of cells. Four cover cells are present.
2	*Marchantia*	Archegonia are borne on archegoniophore in acropetal manner. It has a swollen venter and a narrow elongated neck. It is in a pendulous position attached to the ventral surface of archegonial disc by a small

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		stalk.
3	*Anthoceros*	In this archegonia arise in acropetal manner on the dorsal surface of the thallus. Archegonia lie in slight depression surrounded by mound of mucilage. Swollen venter has a small venter canal cell and egg cell. Neck is made up of six vertical rows of neck cells.
4	*Sphagnum*	These develop on the terminal part of archegonial branches either singly or in groups protected by sterile perichaetial leaves. It is an elongated stalked structure with a twisted narrow neck and swollen lower venter region, 8-10, neck canal cells Venter canal cell and egg cell are present
5	*Funaria*	These develop on archegonial branches which arise laterally at the base of male branch surrounded by perichaetial leaves. Archegonium is 'stalked, has long neck and enlarged venter. Neck, is obliquely placed due to tortion. 6-8 neck canal cells, venter canal cell and egg are present.

13.6 Alternation of Generation in Bryophytes

The word alternation of generation was first used by 'Hofmeister in 1851. In life cycle of plants during one phase the nucleus consists of a single set of chromosomes. This phase is called as haploid. The other phase consists of two sets of chromosomes hence it is called as diploid. Therefore, the life cycle is basically a nuclear cycle. In lower organisms such as algae the diploid zygote divides immediately meiotically and produces haploid cells. These germinate to form a new thallus in this way the life cycle continues.

The zygote in higher organisms could divide meiotically immediately producing haploid cells or after some time. Thus, diploid conditions depict an independent existence. The haploid and diploid phases could be morphologically identical or different from each other. The multicellular haploid plant is termed as gametophyte whereas the diploid plant is called as sporophyte.

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13.6.1 Gametophyte

the gametophytic plant is haploid having 'n' set of chromosomes. It always reproduces by sexual means forming male and female gametes. These gametes are produced in sex organs known as antheridia and archegonia. The gametophytic generation ends when, during sexual reproduction by the fusion of male and female gametes diploid zygote is formed.

13.6.2 Sporophyte

The sporophyte is a diploid plant with 2n set of chromosomes. The sporophyte (2n) always produces spores (n) after meiotic division. These spores are formed in spore producing organs. There is no sexual reproduction in sporophytes, Sporophytic generation ends after reduction division in the spore mother cells which gives rise to haploid spores.

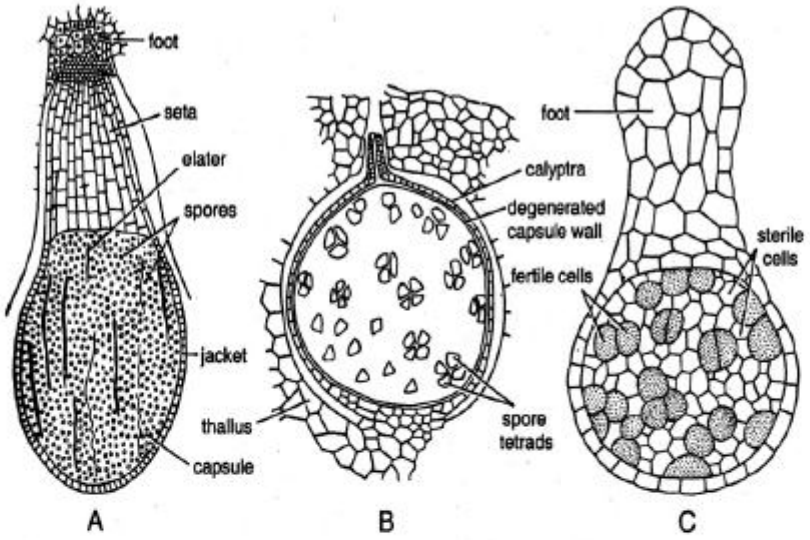


Fig. 13.3 : Structure of Sporophyte A: *Marchantia,* B: *Riccia,* C: *Corsinia*

13.6.3 Alternation of Generation

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Regular alternation of gametophytic and sporopytic generation is called alternation of generation. In Bryophytes both these generations are morphologically different.

Sporophytic generation in Bryophytes: this is diploid generation (2n) which bears spore producing organs. In Byrophyta sporophytic generation is partly or completely dependent on the gametphytic generation for food. This phase is short lived. It does not reproduce by means of sexual reproduction instead, it produces spore mother cells that divide by reduction division and forms haploid spores in spore producing organs. Thus, sporophytic generation ends with meiosis. Thus, sporophytic generation lies between fertilization i.e. syngamy and meiosis i.e. reduction division.

Gametophytic generation in Bryophytes In Bryophytes, the main plant is gametophyte, independent and long lived generation. This is the haploid of phase (n) which reproduces by means of sexual reproduction. It produces reproductive organs such as antheridia, and archegonia which forms antherozoids and eggs respectively. The union of male and female gametes results in the formation of a diploid zygote which develops into another alternate generation a sporophyte (2n). Thus gametophytic generation lies between meiosis to fertilization.

Table 13.4 : Comparison between two generations of Bryophytes

S.No.	Gametophytic generation	Sporophytic generation
1	This is haploid phase of the plant.	This is diploid phase of the plant.
2	It is independent.	It is partially or completely dependent on gametophytic plant for nutrition.
3	They get food materials from the substratum with the help of rhizoids.	They get food from the gametophytic tissue with the help of foot.

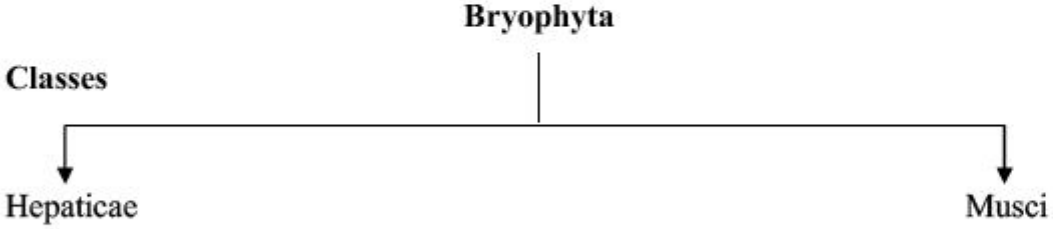
4	It is long lived main generation.	It is short lived alternative generation
5	Sexual reproduction present.	Sexual reproduction absent.
6	Sex organs antheridia and archegonia are formed.	Spore mother cells are formed in spore producing organs.
7	Male and female gametes are produced by mitotic division.	Haploid spores formed after meiotic division in spore mother cells during sporogenesis.
8	The gametophytic generation ends with the fusion between male and female gametes i.e. after fertilization.	Sporophytic generation ends after meiotic division, Haploid spores formed these germinate to form gametophytic thallus.

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13.7 Classification of Bryophyta

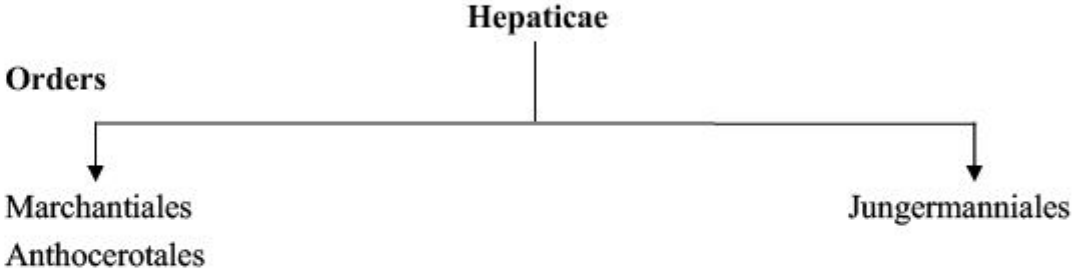
Braun was the first Scientist to coin the term Bryophyta in 1864. In 1879 Schimper gave Bryophyta the rank of Division. Engler in 1886 suggested to place all the groups above the level of thallophyta in Embryophyta. Bryophyta were the first land plants in which embryo were formed. In 1879 Schimper gave Bryophyta the rank of Division.

Eichler in 1883 classified Bryophyta into two sub-groups. These are considered as classes of Bryophyta.



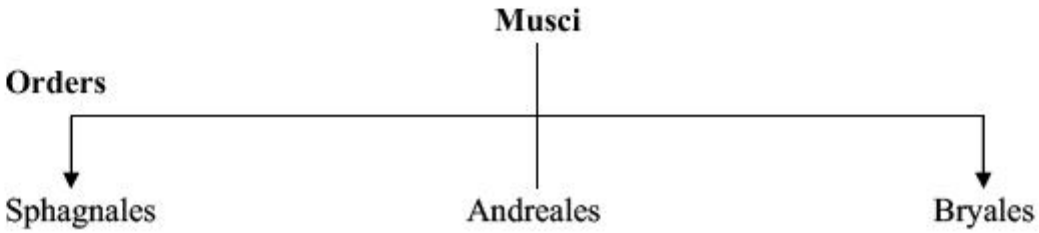
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Engler 1892 classified Hepaticae into three orders-

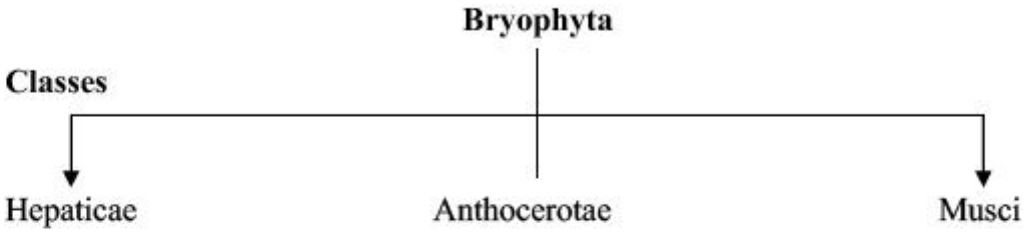


Underwood (1894), Gayet (1897) studied the characters of Anthocerotales and found them to be quite different from Hepaticae. They suggested that Anthocerotales should be separated from Hepaticeae.

Wettestcin (1933), Bower (1935) Campbell (1940) classified Musci into following three orders.



Takhtajan (1953), Smith (1938-155) classified Bryophyta into following three classes:



Following the International rules of Botanical Nomenclature -Rothmaler changed the names of classes as-

Hepaticeae —Hepaticopsida

Anthocerotae — Anthocerotopsida

Musci — Bryopsida

Characters of three classes Hepaticopsida, Anthocerotopsida and Bryopsida as classified by Smith are as follows—

Table Important features of three classes of Bryophyta

S.No.	Hepaticopsida	Anthocerotopsida	Bryopsida
1.	Plant body thalloid or foliose	Dorsiventrally flattened thallus.	Gametophytic plant prostrate thalloid or filamentous
2.	Aseptate rhizoids, simple and tuberculate	Aseptate simple rhizoids present.	Multicellular rhizoids with oblique septa present.
3.	Scales present on ventral surface	Scales absent.	Absent
4.	Chloroplast present Pyrenoids absent	Chloroplast, with pyrenoid present.	Chloroplast present
5.	Oil bodies present	Oil bodies present	Absent
6.	On dorsal side of thallus superficial cells form sex organs	On dorsal side of thallus sex organs embedded in thallus.	Superficial cells give rise to sex organs.
7.	Simple sporophyte may be differentiated into foot, seta and capsule.	Sporophyte has foot, and capsule. Meristematic tissue present	Sporophyte forms foot, seta, and capsule. Stomata Present.
8.	Endothecium forms sporogenous cells	Sporogenous tissue develops from	Sporgenous tissue develops from

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		amphithecium	Endothecium
9.	Columella absent	Columella present	Columella present.
10.	Elaters can be present	Pseudo elaters present.	Absent
11.	Dehiscence of capsule simple	Dehiscence of capsule by forming two to four longitudinal valves.	Dehiscence with the help of annulus and operculum

13.8 Economic Importance of Bryophyta

The bryophytes in general are of little Economic importance. Some masses provide food for herbivorous mammals, birds and other animals. On the whole none of them is directly important to man except some species of Sphagnum. Species of Sphagnum grow and multiply enormously in water thus filling the ponds and lakes with its growth. The barren sheet of water is converted into a solid land. The peat has long been used as fuel. Dried specimens of Sphagnum are used as an absorbent in surgical dressings, as a packing material to increase the water retaining property of certain poor types of soils and as a means of trtaining high soil acidity required by certain decorative and economically important plant (as garden mulch) Flowers packed in moistened peat mosses keep fresh for a considerable period.

Response of bryophytes to air pollution has been studied by many researchers' particulars larky with regard to mosses and hepatics to some extent. Knowledge gained from such student a number of bryophytes can be used as reliably as that of Lichens in measuring pollution in industrial and urban areas. Panda (1978(suggested that the use of Bryophytes as Bryophytes as Bryo-smeters i.e., instruments for measuring phytotoxic air

Geologically the masses are of considerable importance as soil formers in soil formers in soil production and soil conservation. They provide essential steps in the development of the soil. The mosses grow on barren soils/ Tjeu a;pmg wotj tje ;ocjems grow even on dry rocks where growth of higher plants is impossible.

In the course of time their bodies die and decay forming humus and the humus increases the fertility of the soil. Eventually humus containing soil becomes favorable for the growth of higher plants. Even forests grow on such soils.

The mosses usually form dense, extensive mats on the soil which diminish the force of falling rain and thus prevent soil erosion, The rhizoids absorb large quantities of water are so firmly intermingled around the soil particles that there can be little erosion even on a steep hill side.

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13.9 Summary

The Brtiogttes form a natural group where the common plant body is a gametophyte, whereas in Trachaeophytes the common plant is a sporophyte. They represent a phase in evolution when plants migrated from water to land, water is much necessary for the completion of their life history that we may describe them as the amphibians among plants. The Bryophytic gametophyte is either a thallose structure or becomes foliose in the foliose Hepatics and the Mosses. In masses there is also a temporary filamentous from of the gametophyte, called the protonema, the gametophytic body is green with chlorophyll and possesses rhizoids and scales for absorption although it may be able to absorb through its whole surface. In the foliose forms, especially in the mosses, the terms 'stem' and lead are often applied to the organs. The Bryophyte gametophytes are independent autophytes. The sex organs antheridia and Archegonia. The embryo develops within the venter of the archegonium and ultimately develops into sporophyte.

Division Bryophyta was divided into 3 classes Hipaticopsida, Anthocerotopsida and Bryopsida. Regarding distribution of Bryophytes there must be a good amount of moisture, a good amount of shade and comfortable coolness. The distribution of the species varies according to the adaptation of the species to different variation of these conditions. The Bryophytes are of little economic importance except some species of *Sphagnum*.

13.10 Glossary

- ***Abaxial surface:*** The side of a lateral organ, e.g., leaf, away from the axis. (Dorsal).

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- ***Adaxial:*** The side of a lateral organ nearest to the main axis. (Ventral).
- **Antheridial cell:** A cell which divides to form the antheridium.
- ***Antheridium:*** The male sex organ of cryptogams.
- ***Antherozoid (spermatozoid):*** Small, motile male gamete with flagella.
- ***Apogamy:*** The production of a sporophyte from a gametophyte directly, without syngamy or sexual fusion.
- ***Apospory:*** The production of a gametophyte from a sporophyte directly, without formation of spores.
- ***Rhizoides:*** Single or many-celled hair like structure which attach the gametophytes of bryophytes and pteridophytes to the substratum, and perform the function of roots.
- ***Rosette:*** Rose like in pattern.
- ***Suspensor:*** A filament of cells forming a temporary organ, in some pteridophytes and most spermatophytes, that forces the growing embryo deep into the tissue of the female gametophyte.
- **Thallose:** non-vascular plant body form; resembling thallus; describes group of liverworts that are not leafy.
- **Thallus** (pl. **thalli**)**:** non-vascular plant body, usually considered flat and dorsiventrally oriented, as in *Marchantia*; plant body lacking roots, stems, or leaves; body type of algae, fungi, some liverworts (non-leafy), and gametophytes of lower vascular plants
- ***Ventral.*** In lateral organs- the side nearest to the main axis. In dorsiventral organs- the lower surface.
- ***Venter canal cell.*** A small cell above the oosphere in the upper part of the venter of an archegonium.
- ***Whorl.*** A group or circle of similar plant parts all inserted at same level.

- ***Zygote.*** The fertilized egg before it undergoes further differentiation.

13.11 Self-Learning Exercise

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Section -A (Very Short Answer Type Questions)

1. Write an essay on General Characters of Bryophytes.
2. Write notes on classification of Bryophytes and mention about the distribution of Bryophytes.
3. Write an account of General Characteristic features of bryophytes and add note on their Economic importance.

Section -B (Short Answer Type Questions)

1. What is a Gametophyte?
2. Write briefly about Sporophyte.
3. Write about the distribution of Bryophytes.
4. What is the economic Importance of Bryophytes?

13.12 References and further readings

- Puri, P. 1980. Bryophytes. Atma Ram & Sons, Delhi
- Geissler and Greene SW (1982) Bryophyte Taxonomy, methods, practices and floristic exploration. J Cramer, Germany.
- Richardson DHS (1981) The Biology of mosses. John Wiley & Sons, Inc New York
- Vashishta, P.C. 1985. Gymnosperm. S.Chand & Company Ltd. New Delhi.
- R. N. Chopra 1988. Biology of Bryophyta, New Age International.

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Unit - 14

General Account of *Plagiochasma, Pellia, Notothylas*

Structure of the unit

14.0 Objectives
14.1 Introduction
14.2 General Characters of Marchantiales
14.3. General Characters of Jungermanniales
14.4 General Characters of Anthocerotales
14.5 *Plagiochasma*
14.5.1 Gametophyte : External Structure
14.5.2 Gametophyte : Internal Structure
14.5.3 Reproduction
14.5.4 Sporophyte
14.6 *Pellia*
14.6.1 Gametophyte : Structure
14.6.2 Reproduction
14.6.3 Sporophyte
14.6.4 Life Cycle
14.7 *Notothylas*
14.7.1 Gametophyte : Structure
14.7.2 Reproduction
14.7.3 Sporophyte
14.8 Summary
14.9 Glossary
14.10 Self-Learning Exercise
14.11 References and further readings

14.0 Objectives

After going through this unit you will be able to:

- Describe the general characters of Marchantiales, Jungermanniales and Anthocerotales.
- Describe the structure of *Pellia, Plagiochasma* and *Notothylas.*
- Discuss about the reproduction of *Pellia, Plagiochasma* and *Notothylas.*
- Discuss about the structure of sporophyte of *Pellia, Plagiochasma* and *Notothylas.*

NOTES

14.1 Introduction

A liverwort is a flowerless, spore-producing plant with the spores produced in small capsules. Bryophytes have a **gametophyte** stage and a **sporophyte** stage. The spore capsule (possibly with a supporting stalk, or **seta**) is the sporophyte and this grows from the gametophyte stage.

Dorsiventrally differentiated gametophytes which are either simply thallose or with leaf like appendages and are always nerveless. Internal tissues are homogenous or differentiated and sex organs are borne terminally or developed from superficial dorsal cells. Sporophyte differentiated in to foot, seta and capsule- always of limited growth.

The aim of this Unit is simply to describe the features you can see in a liverwort.

14.2 General Characters of Marchantiales

General Characters of Marchantiales

(1) The gametophytic plant body is thalloid, dorsiventrally differentiated and dichotomously branched.

(2) In many forms large polygonal areas, known as areoles, are present on the dorsal surface of the thallus.

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(3) The ventral surface of the thallus bears rhizoids (smooth walled and tuberculate) and scales (except for some aquatic species). The arrangement of scales varies in different genera; for example, they occur in a single row on the margins of the thallus *(Riccia),* in a single row on either side of the midrib *(Reboulia* and *Targionia),* in 2-4 rows on either side of the midrib *(Marchantia),* or are distributed irregularly on the entire ventral surface of the thallus *(Corsinia).*

(4) Internally, the thallus is differentiated into a dorsal photosynthetic and ventral storage region. In *Dumortiera, Monoselenium* and *Monoclea* the differentiation of tissues is poor.

(5) Sex organs are either distributed on the dorsal surface of the thallus (e.g., *Riccia)* or are borne on distinct receptacles (e.g., *Marchantia, Reboulia).* The receptacles may be stalked (e.g., *Marchantia)* or sessile (e.g., *Reboulia).*

(6) Antheridia and archegonia develop in antheridial and archegonial chambers respectively. Each chamber has only a single sex organ.

(7) The neck of the archegonium consists of six vertical rows of neck cells.

(8) The capsule wall is invariably a single layer of sterile cells (unistratose)

14.3 General Characters of Jungermanniales

Jungermanniales are the leafy or thalloid liverworts as the gametophytes of these are of a false nature. The sporophyte is differentiated in to foot, capsule and seta, which is much elongated.

There are about 8000 species and 200 genera in this group. On the basis of the position of archegonia they are divided in to two groups. (a) Anacrogynae and (b) Acrogynae. *Pellia* belongs to the Anacrogynous Jungermanniales. *Pellia* included in the family Codoniaceae by Cavers and afterwards Evans raised it to individual family Pelliaceae.

General Characters

1. Jungermanniales are the largest order of Hepaticopsida with about 244 genera and 9000 species.

2. The plant body is a thallus or a leafy axis.
3. The rhizoids are smooth walled.
4. Scales are absent.
5. The antheridia are globose or sub-globose.
6. The jacket of archegonial neck is in five vertical rows of cells and as broad as the venter.
7. The jacket of capsule is 2 or more cells in thickness (multi stratose).
8. The spore mother cells become deeply four lobed before the first nuclear division.
9. The archegonium gives rise to spores and elaters.
10. The sporangium is with foot, seta and capsule. Seta is much elongated at maturity.
11. The mature capsule dehisces by four valves.

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14.4 General Characters of Anthocerotales

The class Anthocerotopsida is a small group of Bryophyta and is represented by genera and 300 species, widely distributed in both the temperate and tropical region* of the world. The characteristic features of the class are as follows.

(1) The gametophyte is flat, dorsiventral, lobed and thalloid.

(2) The thallus is attached to the substratum with the help of smooth walled rhizoids. Tuberculate rhizoids and scales are absent.

(3) The thallus has a uniform internal organization and is not differentiated into photosynthetic and storage regions. The cells have many chloroplasts with pyrenoids.

(4) Air pores and air chambers are absent but intercellular mucilage cavities are present which open on the ventral surface by slit-like slime pores.

(5) Sex organs are embedded in the thallus. Antheridia develop on the dorsal surface from the hypodermal cells. They occur singly or in groups in antheridial chambers.

(6) Archegonia develop from dorsal epidermal cells.

(7) The sporophyte is differentiated into a long cylindrical capsule, a small, meristematic seta and a bulbous foot.

(8) The capsule wall is 4-6 layered and the epidermis has stomata.

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(9) Sporogenous tissue develops from the amphithecium.

(10) Elaters do not have thickening bands and as such are called pseudoelaters.

14.5 Plagiochasma

Systematic Position

Class - Hepaticopsida

Order - Marchantiales

Family - Marchantiaceae

The genus *Plagiochasma* is represented by about 20 species, widely distributed in most parts of the world. Some 10 species of the genus occur in India. Most of the Indian species are xeromorphic and are more adapted to drier habitats. *P. appendiculatum* occurs in the plains of South India, Gujarat, Rajasthan and Madhya Pradesh. *P. simlensis* is found near water pools and streams in Simla hills and *P. articulatum* inhabits alpine region in the Himalayas at an altitude of about 4,500 meters.

Plagiochasma appendiculatum, P. articulatum, P. simlensis, P. intermedium, P. cordatum and P. quadricorrzutum are some common Indian species. Of these, *P. articulatum, P. simlensis, P. cordatum find P. quadricornutum* are endemic to India.

14.5.1 Gametophyte : External Structure

The plant body is large, prostrate, dorsiventral, thalloid and is of variable shape. It is oblong-obovate in *P. articulation*, obcordate in *P. appendiculatum* and (1 linear-elongate in *P. intermedium* and *P. simlensis*. The dichotomously branched thallus is dark green in colour, and its dorsal surface has an indistinct midrib. The ventral surface bears scales and rhizoids along the median line. The scales are of appendiculate type. The number and shape of the appendages vary in different species, e.g., there is only one appendage in *P. appendiculatum* and *P. simlensis* and two in *P. articulatum* and *P. intermedium*. The appendages are rotund (e.g., *P. appendiculatum*) or acicular (e.g., *P. simlensis*) in shape. The scales are multicellular and one cell in thickness. They occur in a single

overlapping row on either side of the median line. They protect the growing apex of the thallus. The unicellular rhizoids are of two types: (i) smooth walled, and (ii) tuberculate. The inner wall of the smooth walled rhizoids is smooth while those of the tuberculate rhizoids has peg-like ingrowths, which appear as small circular dots in surface view.The rhizoids help in anchorage and absorption of water and nutrients from the substratum. The growing point of the thallus is situated in a notch at the apex.

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During xeric conditions, the thallus forms characteristic apical innovations (adventitious branches) which help in vegetative propagation. Sex organs are borne on special receptacles present on the dorsal surface of the mature thallus. The male receptacles (antheridiophores) are sessile and have a characteristic horse shoe shape. The female receptacles (archegoniophores) have a short stalk and are disc like. They initiate in subterminal position along the median line but are subsequently pushed to the dorsal surface due to the growth of the thallus.

14.5.2 Gametophyte : Internal Structure

In a transverse section the thallus of *Plagiochasma* shows three distinct regions: (i) epidermal region, (ii) photosynthetic region, (iii) storage region.

[i] Epidermal region

This region includes both the dorsal and ventral epidermis. The dorsal (upper) epidermis forms a uniseriate covering over the photosynthetic region. It is interrupted by simple pores that are connected internally with air chambers. The air pores are slightly raised above the surface of the thallus. Each pore is surrounded by 3-8 concentric rings, each with 6-8 cells. The ventral (lower) epidermis follows the storage region. It is made up of thin-walled cells. Many cells of the lower epidermis give rise to rhizoids and scales.

[ii] Photosynthetic region

It consists of an irregular network of complex air chamber system. The walls of the air chambers are made up of a single layer of chlorophyllous cells. The air chambers are empty, i.e., without any photosynthetic filaments. They are interconnected through narrow passages. This region of the thallus is mainly concerned with the manufacture of food and is also called assimilatory region.

[iii] Storage region

The photosynthetic region is followed by a well-developed storage region made up of parenchymatous cells. These cells are rich in starch grains and reserve

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food material. Inter or intracellular mycorrhiza is occasionally present in the storage region.

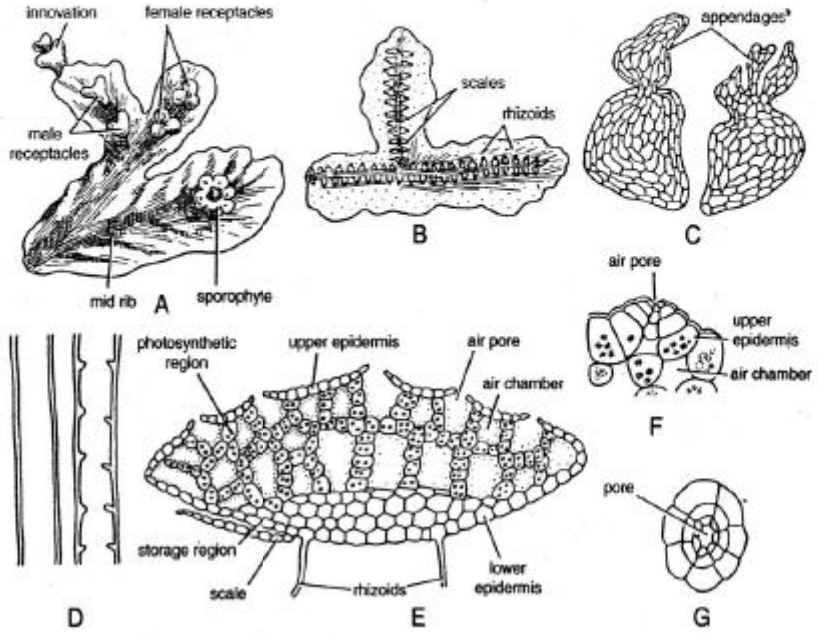


Fig. 14.1 : *Plagiochasma:* Structure of Thallus with Rhizoids and Scales

14.5.3 Reproduction

Plagiochasma reproduces both vegetative and by sexual methods.

[I] Vegetative Reproduction

Vegetative reproduction usually takes place by means of certain adventitious branches, known as innovations. These branches develop at the apex of the thallus. When detached from the parent thallus, they grow into new independent thalli.

[II] Sexual Reproduction Plants may be homothallic (e.g., *P. appendiculatum)* or heterothallic (e.g., *P. intermedium*, *P. articulatum, P. cordatum, P. quadricornutum*). Sex organs develop on specialized structures, known as receptacles. Both the male and female receptacles are distinctly dorsal in many species (e.g., *P. appendiculatum),* hence the vegetative growth of the thallus never stops. But in some species receptacles are terminal and the apical adventitious shoot develops after they have formed (*e.g., P. articulatum).* In such cases there is always a distinct line of articulation between the old and new

adventitious lobe. The onset of the reproductive phase is associated with the change in the metabolic status of the gametophyte.

1. Male Receptacle. Male receptacles usually appear in early growing season on the dorsal surface of the thallus. They are sessile and typically horse shoe-shaped a shape attributed to the presence of two growing points in the receptacle. The internal structure of the receptacle is similar to that of the thallus. It contains several antheridial chambers, each with a single antheridium. Each antheridial chamber opens on the surface of the receptacle by a pore. A number of simple pores are also present on the receptacle and they open internally into air chambers. Antheridia develop acropetally on the surface of the male receptacle.

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(a) Structure of Antheridium. The mature antheridium is a club-shaped structure attached to the base of the antheridial cavity by a multicellular stalk. It has one-cell thick jacket layer of elongated or isodiametric cells which encloses a mass of androcyte cells. The androcyte cells metamorphose into slender filiform antherozoids. Each antherozoid has two flagella attached to its anterior end.

Development of Antheridium

Antheridial initial divides by transverse wall to form two cells lying one above the other in two rows. The upper cell is called as outer cell whereas the lowermost basal cell. The outer cell again divides by transverse division and produces upper primary antheridial cell and lower primary stalk cell whereas; the lowermost basal cell forms stalk which is deeply embedded in the gametophytic thallus. Thus, three celled filamentous body is formed (a) basal cell (b) intermediate primary stalk cell and (c) upper most primary antheridial cell. This structure soon turns into five celled structure by transverse division. The last two cells form 2 primary antheridial cells, 2 primary stalk cells and basal cell.

The upper two primary antherdial cells undergo two successive vertical divisions. The second division occurs at right angle to the first. The first division produces 4 cells in which 2 cell lying in the upper and 2 in lower tier. The second division forms 8 cells, 4 in the upper and 4 in lower the tier.

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The 8 celled antheridium divides by periclinal division parallel to periphery in both the tiers, resulting in the formation of an outer layer of eight sterile wall initials encircling the inner eight fertile primary androgonial cell. The latter undergoes a few more divisions irregularly to produce a mass of cubical cells. These are the small androgonial cells. The last division of the latter produces sperm mother cells called spermatocytes or androcytes. Simultaneously with the development of antheridium wall initials undergo anticlinal divisions to produce one celled thick sterile jacket around the mature antheridium. Each androcyte mother cell produces two triangular androcytes by diagonal division which metamorphoses into small, curved biflagellated antherozoids. The neighbouring cells grow upwards forming antheridial chambers which may or may not be open at its anterior end.

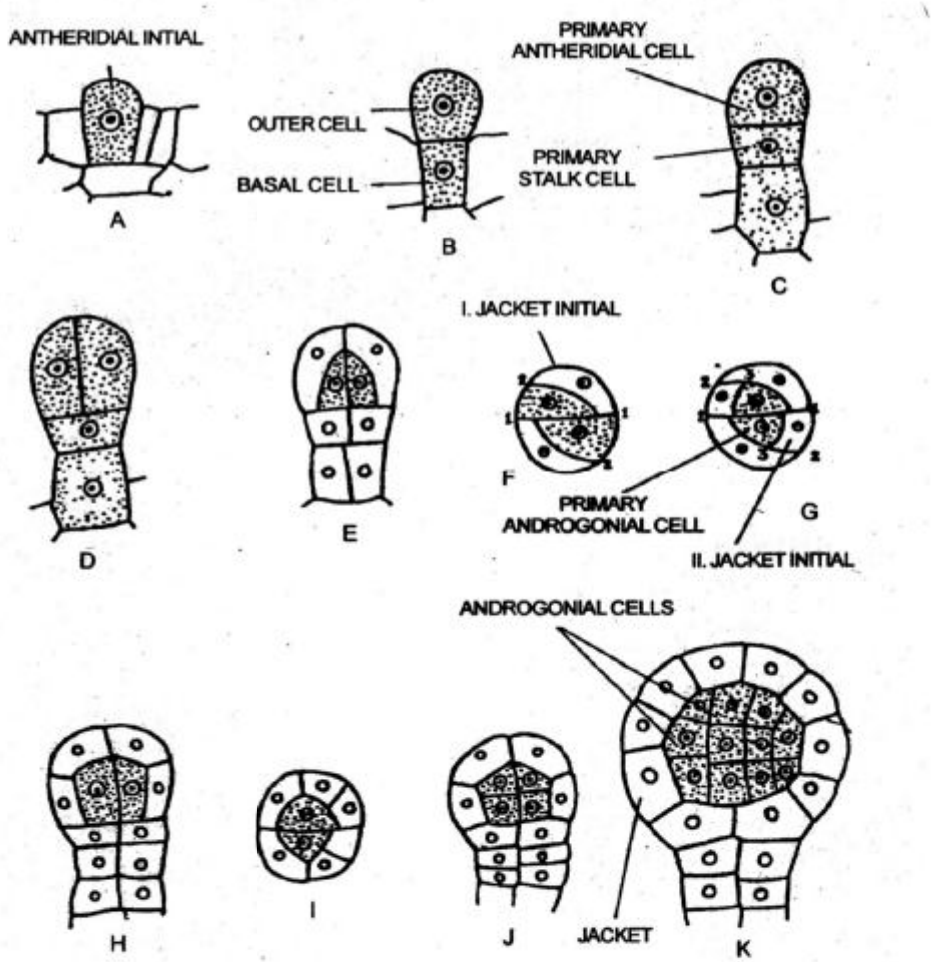


Fig. 14.2 : *Plagiochasma* Various steps of Development of Antheridium

(b) Dehiscence of Antheridium. Water enters inside the antheridial chamber through the pore, and some jacket cells at the distal part of the antheridium disintegrate as soon as they come in contact with water. This leads to the rupture of the antheridium and a mass of androcytes emerges in a long smokelike column. On reaching the surface, the androcyte mass breaks up into individual androcytes. The antherozoids are liberated from the androcytes within few minutes.

2. Female Receptacle. The archegonia are present on special upright branches known as archegoniophores or carpocephalum. They are sessile or stalked. Archegoniophores arise in the midrib region, close to the apex, on the dorsal surface of the thallus. They do not involve the apical cell and as such are sub-terminal in position. The mature archegoniophores are, however, pushed back on the dorsal surface due to subsequent growth of the thallus.

The archegoniophore consists of a short stalk and a terminal disc. There is no rhizoidal furrow on the stalk as in *Marchantia.* The archegoniophore is encircled by minute, ovate to linear scales organised in a compound imbricate manner. The disc of the receptacle is 2-9 lobed and there is only one archegonium on each lobe. The anatomy of the archegoniophore is similar to that of the thallus, but it has barrel-shaped air pores.

(a) Position of Archegonia on Archegoniophore: On the young receptacle the archegonia are borne acropetally on the upper surface of the disc, and the necks of archegonia are directed upward. After fertilization, due to rapid growth of the central part of the disc, the archegonia come to lie on the flanks of the disc with their necks placed horizontally, i.e., parallel to the lobes of the receptacle.

(b) Structure of Archegonium: Archegonia lie in grooves formed by the overgrowth of the involucre. A mature archegonium is a flask shaped structure attached to the lobe of the disc by a short stalk. It has a broad venter and a narrow neck. The venter contains a large egg and a venter canal cell. The neck of the archegonium is composed of six vertical rows of cells and it has 8-9 neck canal cells. There are four cover cells at the tip of the neck. Shortly before fertilization, the neck canal cells and the venter canal cell disintegrate to form a mucilagenous mass. This mucilagenous mass absorbs water and swells up thus

separating the cover cells apart.

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Development of Archegonia

Development the archegonia starts from any superficial cell situated near the growing point of the thallus. This superficial cell enlarges and becomes papilla like. This is called as archegonial initial. It has denser cytoplasm and a relatively large nucleus. Archegonial initial cell grows and protrudes out of the thallus and divides by transverse division to form an upper and a lower cell. The Upper cell is called archegonial mother cell which forms the archegonium. The lower basal cell remains undivided and takes no part in further development of archegonium. The former enlarges in size and divides by three concentric vertical division separating three sterile peripheral initials encircling the central fertile cell called primary axial cell. Each of the three peripheral initials undergoes second vertical divisions resulting in formation of six peripheral cells called jacket initials.

The primary axial cell divides transversely to form upper primary cover cell and central cell. Each jacket initial also divides by transverse division and forms two tiers of six cells each. The upper tier of six peripheral cells form neck initials whereas the lower tier forms venter initial. Both divide further by transverse division to form multicellular neck cells. The height of each row of neck cells is variable depending on the species. The venter initials divides and redivides by transverse, anticlinal and periclinal division and produces 18-20 celled thick jacket around venter region.

The central cell also undergoes transverse division to produce upper Primary neck canal cell and a lower venter cell. Primary neck canal cell divides by transverse division to form 4-8 neck canal cells. The primary cover cell produces 4 lower cells by two successive vertical divisions. Primary venter cell forms upper venter cell and an egg cell by transverse division.

***3. Fertilization*:** Antherozoids are carried to the archegonia by splashes of rain water or by water currents. Several antherozoids reach an archegonium but only one unites with the egg to form the oospore. At the time of fertilization there are

slow circulatory movements of the neck of the archegonium and this facilitates the process of fertilization.

14.5.4 Sporophyte

The diploid oospore is the mother cell of the sporophytic phase. It secretes a cell wall and increases in size until it almost fills the cavity of the venter. It eventually develops into a sporophyte.

The oospore divides first by a transverse wall, forming an outer epibasal cell and an inner hypobasal cell. The epibasal cell divides again by a transverse wall and as such a 3- celled filamentous embryo is formed. The upper cell of this filamentous embryo eventually gives rise to the capsule, the middle to the seta, and the lower to the foot. All the three cells of the filamentous embryo divide transversely. The derivatives of the middle and the lower cells then divide vertically. Thus at this stage the embryo has only a single tier of cells in the upper region and two or more tiers of cells in the middle and lower regions.

The cells of the upper region of the embryo divide periclinally, differentiating a single-layered outer amphithecium from the inner endothecium. The cells of the amphithecium divide only anticlinally and form a single-layered jacket of the capsule. The jacket cells are thin-walled and are almost uniform throughout. The endothecium divides repeatedly in all planes and gives rise to archesporium, which forms the sporogenous tissue. Each undifferentiated cell of the sporogenous tissue divides to form two daughter cells. One of the daughter cells gives rise to one or more spore mother cells and the other acts as elater mother cell (such division of sporogenous cell into fertile and sterile cells is designated as "spore-elater division"). The spore mother cell, by a reduction division, gives rise to a tetrad of haploid spores whereas the elater mother cell elongates and forms the elater. The elater develops characteristic helical thickenings on its walls.

The cells of the middle region divide almost exclusively in one plane and give rise to a short seta, composed of several vertical rows of cells. As the sporophyte matures, there is a sudden increase in the length of seta due to elongation of its cells. As seta grows in length, it ruptures the calyptra and pushes out the capsule.

The cells of the lower region of the embryo divide in all possible planes, forming

a thick bulbous foot. The foot serves as an anchorage and absorbing organ.

Accompanied with the development of the sporophyte, some important changes occur in the gametophytic tissue surrounding the archegonium. The cells of the venter wall get stimulated by fertilization and they divide to form a calyptra. The calyptra is composed of two or more cell layers and it surrounds the sporophyte till maturity.

NOTES

[II] Structure of Mature Sporophyte

The sporophyte of *Plagiochasma* is differentiated into a bulbous foot, a short seta and a spherical capsule.

1. Foot. It is the basal bulbous part of the sporophyte, composed of thin walled parenchymatous cells. It is an anchoring and absorbing organ of the sporophyte and derives nutrients from the gametophyte.

2. Seta. It is present between the foot and the capsule. It is composed of several vertical rows of parenchymatous cells.

3. Capsule. The capsule is a nearly spherical structure. It has a single layered jacket of thin walled cells, enclosing spores and elaters. The spore wall is differentiated into three layers, the outermost perinium shows reticulate ornamentation. The elaters are long, narrow, spindle-shaped cells with 2-4 spiral thickening bands. in P. *intermedium* thickening bands are absent and instead the elaters are uniformly thickened. The elaters are hygroscopic and they coil and uncoil with the changes in atmospheric humidity. Thus they help in separation and scattering of spores.

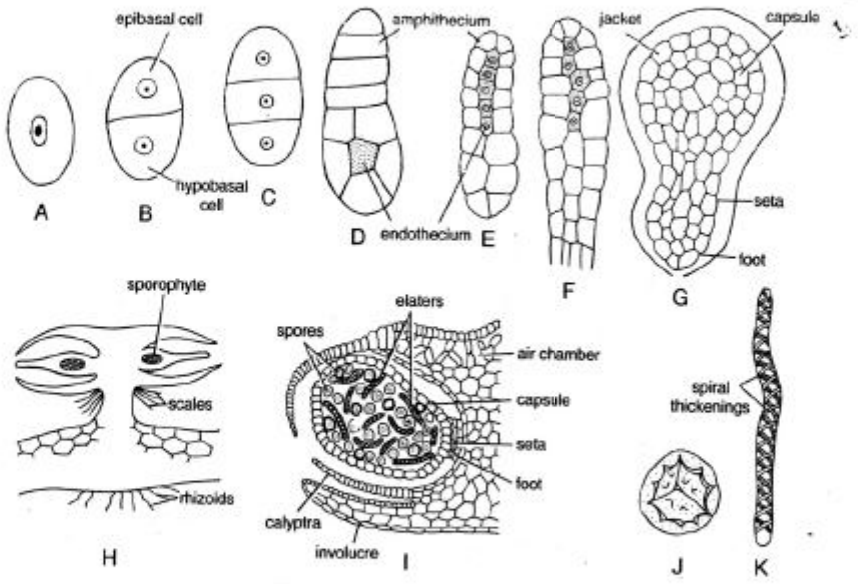


Fig. 14.3: *Plagiochasma:* Development of Sporophyte

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[III] Dehiscence of Capsule

At maturity of the capsule, the upper part of the jacket breaks irregularly but the lower portion remains intact like a cup. The dispersal of spores is assisted by elaters which show hygroscopic movements. These movements are due to unequal expansion of the cellulose wall and the spiral bands of the elaters.

Young Gametophyte

Spores germinate immediately after dispersal, if favorable conditions are available. They are viable for about six months under storage conditions. They absorb water from the substratum and increase in size considerably. Then the spore divides into a large germ tube cell and a small germ rhizoidal cell. As the germ tube elongates, chloroplasts and oil bodies make their appearance. The germ tube divides repeatedly and forms a germ plate. An apical cell is differentiated at the apex of the germ plate and through the activity of this apical cell a new thallus is formed. The first rhizoid develops from the germ rhizoidal cell.

14.6 *Pellia*

Pellia is an anacrogynous genus of thalloid form of the family Pelliaceae of Jungermanniales. There are about 4 species of *Pellia* and of these 3 are available in India, *P. epiphilla, P. fabroniana (P calycina) and P. neesii.*

Usually occur on moist soils or on rocks by the side of ditches and springs,

growing as green patches among mosses or grasses

14.6.1 Gametophyte : Structure

NOTES

External Characters: The plant body is thin dorsiventral, prostrate, dichotomously branched with somewhat wavy margin. Dorsal surface is smooth with thick at the mid rib. The thallus terminates in to a notch where the growing point is situated. On the ventral surface smooth unicellular rhizoids are present below the mid rib. Scales and pegged rhizoids are absent.

Internal Structure: Internal structure of the gametophyte is simple, mainly consists of parenchymatous cells with a mid rib made up of many cells in thickness; the marginal region is single cell in thickness. The cells of marginal region and the upper cells of mid rib with chloroplasts. Starch grains are present in all the cells. In the lower surface unicellular, smooth walled rhizoids are present in the mid rib region (some internal thickenings or bands are present in some species of *Pellia*).

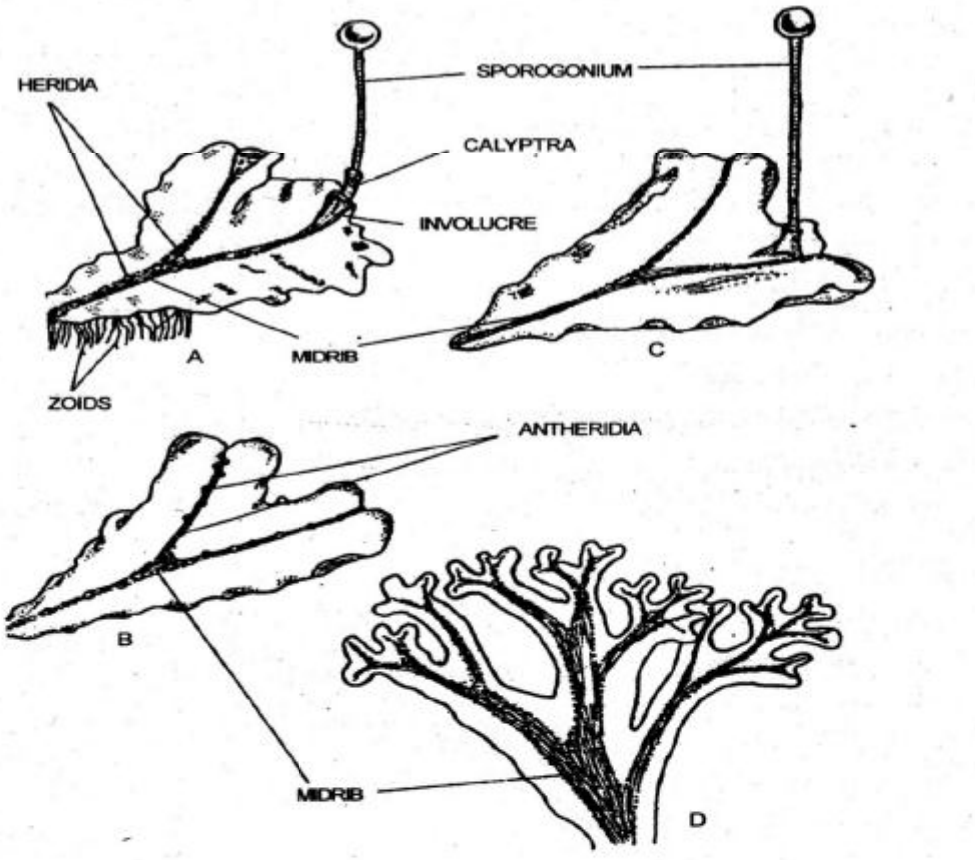


Fig. 14.4: *Pellia* External Features of Gametophyte

14.6.2 Reproduction

Reproduction takes place by vegetative & sexual means.

Vegetative Reproduction: *Pellia* produces adventitious branches which arise on the dorsal surface near the margin. These branches separate from the plant and develop in to individual plants. By death and decay of the thallus the young branches will develop in to new plants.

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Sexual Reproduction: Pellia may be monoecious or dioecious. The sex organs are formed in two or more rows on the dorsal side of mid rib.

Antheridia: Antheridia are born on the dorsal surface of the thallus along the mid rib. Their position is indicated by projections and each projection marks the antheridial cavity in which single antheridium is present.

Development of the Antheridium: A superficial cell forms antheridial initial and it divides to form a basal cell and outer cell. The basal cells remains in the tissue while the outer cell divides to form primary antheridial cell and primary stalk cell, the primary stalk cell gives raise to the stalk of the antheridium. The primary antheridial cell divides vertically and then periclinally and forms the first jacket initial and inner primary androgonial cell. At this stage two central primary androgonial cells surrounded by four jacket initials. The two androgonial initials divide to form androgonial cells which form androgonial mother cells. Each androcyte mother cell divides diagonally and form the two androcytes. Each androcyte metamorphoses into spirally coiled biflagellate antherozoid. The mature antheridium comes in contact with water, its wall is ruptured at the apex and mucilaginous mass of antherozoids are liberated.

Archegonia: The archegonia are formed in groups of four to twelve at the anterior end of the branch. The group of archegonia is protected by an involucre. The archegonium formed by a superficial cell; it first divides in to a basal cell and outer cell. The outer cell produce primary axial cell and three peripheral initials among which two divides again to form five jacket initials. These by transverse division form neck initials and venter initials, these form the neck region and venter region respectively.

The primary axial cell divides to form primary cover cell and lower central cell. Central cell divides to form neck canal cells and primary venter cell. The neck canal cell divides to form 6 to 8 neck canal cells while primary venter cell divides to form four cover cells.

At maturation the archegonium has a multicellular stalk, a dilated venter and a long neck (The venter becomes two cells in thickness).

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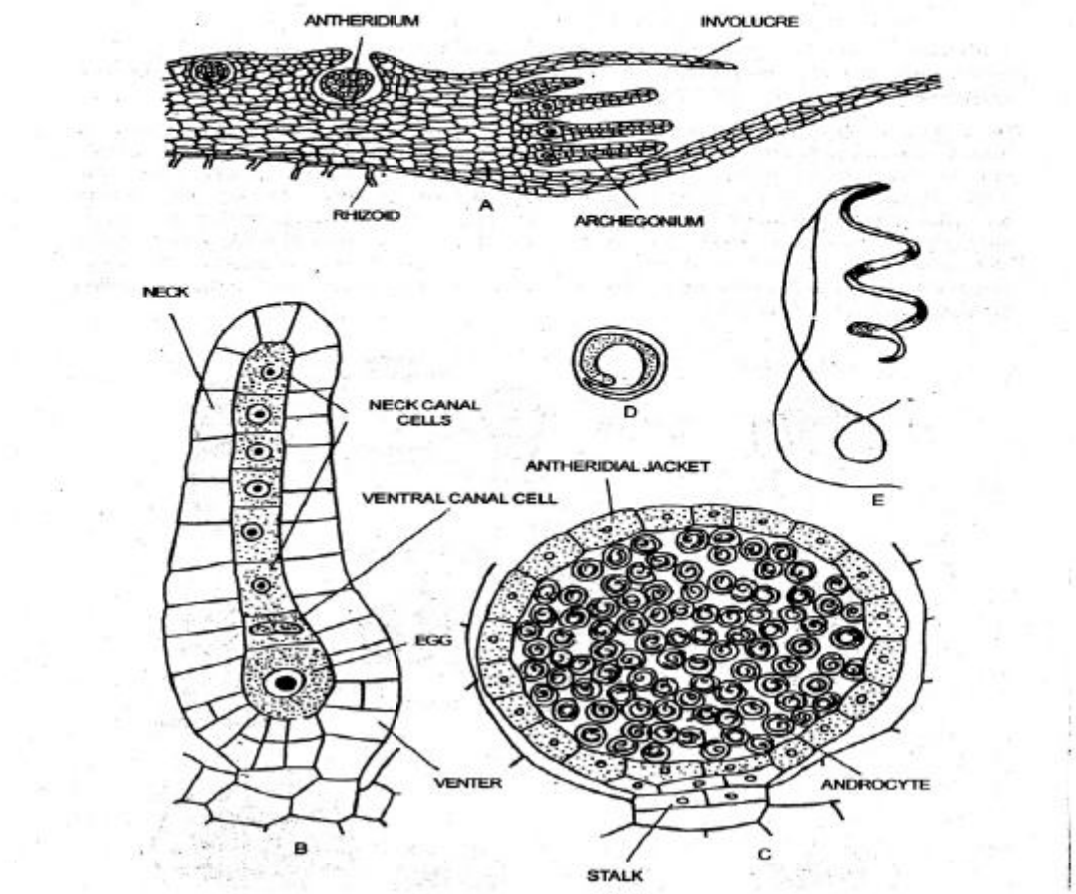


Fig. 14.5 : *Pellia* Thallus with Sex Organs: Antheridium and Archegonium

Fertilization : The liberated antherozoids swim in a film of water and reach the archegonium and attracted by the mucilaginous substance produced by the disintegration of the neck canal cells and ventral canal cells. One of the antherozoid reaches the egg and fuses with egg to form a zygote.

14.6.3 Sporophyte: The zygote secretes a wall and begins to increase in size. The cell wall of the venter grows and develops in to the calyptra which covers the young sporangium.

Zygote divides to form upper epibasal and lower hypobasal cell. The hypobasal cell doesn't involve in division and form the suspensor and acts as haustorium. In the epibasal cell first division is vertical and second is transverse forming four cells. Again by vertical division form eight cells of two tiers of four each. From the lower four cells foot and seta are formed. The foot develops like a collar below the seta.

The upper four cells undergo periclinal division and form inner endothecium and outer amphithecium. Endothecium divide further to form the archesporium cells

which develop in to sporogenous tissue. Earlier there are sterile larger cells at the base of the capsule which develop spiral thickenings and form the elaterophore to which elaters are attached. The remaining cells of sporogenous tissue develop spore mother cells and elaters and these elaters develop spiral thickenings in them and elongate in size.

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The mature sporangium consists of foot, seta and capsule. The foot is conical in form and it is produced like a collar around the seta. The seta consists of regular longitudinal rows of cells which are short in young condition but during the maturity the cells are very much elongated. The capsule is a spherical body and the outer jacket is composed of two or more layers of cells. The jacket provide with four lines of thin walled cells which denotes the line of dehiscence (Fig.12.9)

Dehiscence of Capsule: When the capsule is fully matured the seta elongates and ruptures the calyptra and carry the capsule in the air. The capsule wall splits in to four valves at the dehiscence line and exposing the elaterophore which holds the spore and elaters for some time and then the spores flicked out to a short distance.

New Gametophyte: The spore of *Pellia* germinates while they are in the capsule. Each spore develops in to a small, few celled chloroplasts containing ellipsoidal structure. Ultimately the spore wall disintegrates and spores are set free. Each spore after falling on a suitable substratum develops in to gametophytic young *Pellia* plant.

14.6.4. Life Cycle

The life cycle of *Pellia* consists of two generations, the sexual gametophyte and the asexual sporophyte. The two alternate with each other. The sporophyte connected with sexual gametophyte plant throughout its life and depends upon it for its nutrition.

The sexual plant is independent; it is thin, flat, green and dichotomously branched thallus. Each thallus lobe has a broad thickened median mid rib. The surface of the thallus is smooth. The ventral surface has no scales, and with numerous smooth walled rhizoids at the mid rib region. Internally the thallus shows similar type of cells except the dorsal and ventral surface cells which are rich in chloroplasts. There are no air chambers and air pores.

The thallus may be monoecious or dioecious. The male sex organs are antheridia and they are born on the upper surface of the thallus either scattered or in two or more rows. Each antheridium lies in a pit, it is shortly stalked and has a globular

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body with a single layer of antheridial wall which encloses a mass of androcytes. The androcytes are metamorphosed in to 178 a biflagellate, spirally coiled spermatozoids or sperms. The flagella are inserted at the anterior end. The archegonia occur in clusters on the upper surface of the thallus just below the growing apex, and they are flask shaped. Archegonial neck consists of five vertical rows of neck cells. The neck is filled with 6 to 9 neck canal cells. The venter is two cells thick. in the venter a large egg and a small venter canal cell are present. The sperms and eggs are the last structures of gametophyte generation. The gametophyte (sexual) generation is with haploid number of chromosomes. Then fertilization takes place in between egg and spermatozoid and a zygote is formed which is the first stage of the sporophyte generation. By repeated mitotic divisions it forms the sporogonium or the sporophyte; it is with diploid number of chromosomes in its cells. It is differentiated in to a foot, long seta and a spherical capsule. The capsule shows greater sterilization of the potentially fertile tissue. The capsule wall is two or more cells in thickness. The sporogenous cells are differentiated in to the spore mother cells, the free elaters and the cluster of sessile elaters. The spore mother cells are last clusters of sporophyte generation. They undergo meiosis and form tetrads of spores. The ripened capsule dehisces in a regular manner; it opens by cleavages at four lines of dehiscence right up to the base in to valves. The basal elaterophore holding the mass of spores and elaters. The elaters help in the dispersal of spores. The sporophyte generation thus consists of the zygote, sporangium and the spore mother cells. It ends with meiosis of spore mother cells. The haploid spores are the first stages of gametophyte. Thus the two generations occur one after the other and shows "alternation of generations".

14.7 *Notothylas*

Notothylas is another interesting genus of the order Anthocerotales which possesses some peculiarities of its own. It is often placed in the family Anthocerotaceae.

Distribution and Habitat

Notothylas includes about 11 species and is distributed in tropical and temperate regions four species *(N. indica, N. levieri, N. chaudhurii* and *N. javanicus)* have been reported from India. It usually grows in damp, shady places, either on moist rocks or earth, or on the walls and floors of old buildings.

14.7.1 The Gametophyte

External Structure

The gametophyte plant body is a thallus which is prostrate, and delicate. It is usually light green or yellowish in colour. The outline of the thallus is orbicular or suborbicular or somewhat circular. The thallus is lobed and the lobe margins may be entire, serrate or fimbriate. On the ventral surface there are found only the smooth-walled rhizoids, the tuberculate rhizoids and scales being absent.

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Internal Structure

Like *Pellia,* there is very little differentiation of tissues. The thickness of the thallus in the middle varies from 6 to 8 cells, gradually thinning out to I to 3 cells towards the margin. The internal cells are twice as big as the cells of the upper and lower limiting layers. The structure of the cell is the same as in *Pellia.* The mucilage cavities containing the *Nostoc* colonies are commonly found but in some species, such as *N. javanicus,* the thallus is solid, and there is no trace of mucilage cavities.\

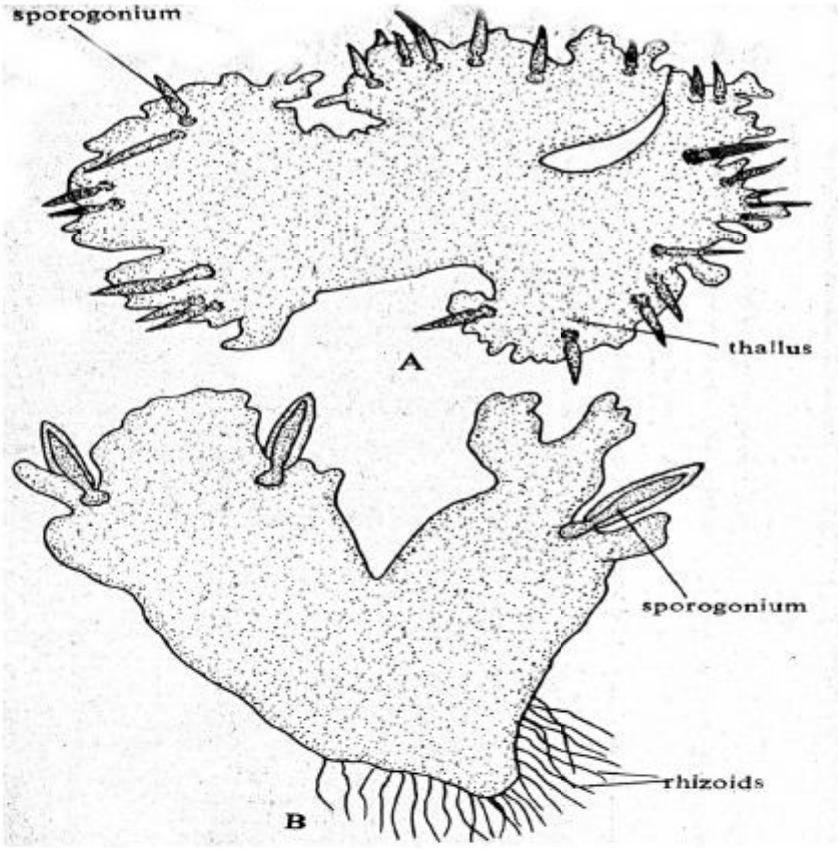


Fig. 14.6: *Notothylas* External Features of Gametophyte

14.7.2 Sexual Reproduction

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Notothylas may be monoecious or dioecious. All the 3 Indian species, viz., *N. indica, N. levieri and N. chaudhurii* are monoecious and protandrous.

The Antheridium: The antheridia are developed endogenously, and are usually formed near the growing point. The usual number of antheridia inside an antheridial chamber is 3 to 4, but sometimes as many as six may be met with.

Development of the Antheridium

Antheridia occur singly or in group within closed cavities, known as antheridial chamber. These chambers develop on the dorsal surface of the thallus, but they do not open on the thallus.

A superficial dorsal cell, lying close to the growing apex, divides by a periclinal wall into an outer roof initial and an inner antheridial initial. The antheridial initial is thus endogenous rather than superficial as in outer bryophytes. A mucilaginous cavity soon develops between the roof initial and the antheridial initial and this cavity enlarges to form an antheridial chamber.

The first division of the roof initial is by a periclinal wall, followed by many anticlinal divisions. This results in the formation of a two layered roof of the antheridial chamber.

The antheridial initial becomes almost spherical before it divides. In some species of *Notothylas,* this cell develops directly into a single antheridium, wheras in others it divides vertically into 2-4 or more daughter cells and each of these cells forms an antheridium. The antheridial intial undergoes two vertical divisions at right angles to each other and thus four cells are formed. Now, a transverse wall is laid down across all the four cells resulting in eight cells, arranged in two tiers of four each. The cells of the lower tier are called stalk cells; they divide by transverse walls and form a multicellular stalk of the antheridium.

The cells of the upper tier form the body of the antheridium. They divide by a transverse wall and form an 8-celled octant. Each cell of the octant then divides by a curved periclinal wall so that eight outer primary jacket cells are differentiated from the eight inner primary androgonial cells. The primary jacket cells divide only anticlinally and form a single layed wall (jacket) of the

antheridium. The jacket cells contain chloroplast and as such the mature antheridium is green in colour. The primary androgonial cells undergo many regular divisions to form a mass of androcyte mother cells. The androcyte mother cell divides to form two androcytes, each of these metamorphoses into a biflagellate antherozoid.

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The Archegonium

Archegonium. Archegonium arises in acropetal secquence on the dorsal surface of the thallus. In monoecious species, they are formed on the same thallus which had borne antheridia.

Development of the Archegonium: Archegonium develops from a single superficial dorsal cells that lies immediately behind the growing apex. The archegonial initial divides by a transverse wall to form an outer primary archegonial cell and an inner primary stalk cell. But according to Mehra and Handoo (1953), the archegonial initial directly functions as primary archegonial cell.

The primary archegonial cell, by three intersecting periclinal devisions, forms a central cell surrounded by three peripheral jacket initials. The jacket initials divide transversely, forming two tiers of three cells each. The cells of the upper tier divide anticlinally and form six cells. The latter undergo repeated transverse divisions and form the neck of the archegonium which is thus composed of six vertical rows of sterile neck cells. Since the archegonium is embedded in the tissue of the gametophytes, the neck cells are not distinguishable from those of the thallus. The cells of lower tier, by transverse and vertical divisions, form the venter wall.

Accompanied with the development of the neck and venter wall, the central cell, known as primary axial cell, divides transversely to form two cells of almost equal size. The lower daughter cell functions as primary venter cell. The upper daughter cell again divides transversely and differentiates into an upper cover initial and a lower primary neck canal cell. The cover initial divides by two vertical walls at right angles to each other and forms a rosette of four cover cells at the tip of the neck. The primary neck canal cell, by repeated transverse divisions, forms 4-6 or rarely more neck canal cells. The primary venter cell divides by a transverse wall to form an upper small venter canal cell and lower large egg cell.

14.7.3 Sporophyte

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Development: The development of the sporogonium varies in differentspecies. The first division wall in the zygote may be transverse, e.g., in *N.indica* and *N. orbicularis*; or it may be longitudinal such as in *N. javanicus,N. levieri* and *N. breutelii*. In *N. indica,* the transverse division of the zygote is followed by two succeeding vertical walls, at right-angles to each other and to the primary wall, and an eight-celled embryo is formed. Then by a transverse wall in the upper cells 3 tiers, of four cells each, are formed. In *N. levieri* the first longitudinal division is followed by a transverse division and four cells are formed, of which the two upper cells are larger than the lower ones. Presumably a verticalwall is next laid down and an eight-celled embryo is formed. Later on by transverse divisions in the upper cells only, three tiers of four cells each are formed in this species also.

Of the three tiers, the lower two usually produce the foot, while the uppermost tier forms the capsule and an intermediate zone (seta). Next periclinal walls are laid down in the cells of the upper-most tier and separate a central endothecium from the peripheral amphithecium.

In most species, such as *N. indica, N. orbicularis* and *N. javanicus* the amphithecium divides by a periclinal wall into an inner and outer layer. The former gives rise to the archesporium and the latter to the wall of the capsule. In *N. indica and N. orbicularis* the entire endothecium produces the columella.

Dehiscence of Sporogonia: The structure of the sporogonium in *Notothylas* is far less favourable for effective spore dispersal than *Anthoceros* on account of the horizontal position of the sporogonium, its enclosing involucre, small elaters, absent or little developed columella. In *N. indica* and *N. levieri* Pande observed that the sporogonia open like a follicle (i.e., dehiscence takes place along one suture only) but in some cases they may dehisce along both sutures. Capsules of *N. orbicularis* dehisce by two to four valves.

14.8 Summary

Plagiochasma is one of the main genera of Marchantiales. The plant body of *Plagiochasma* is green dorsiventral, dichotomously branched thallus with mid rib. On the dorsal side polygonal or rhomboidal areas with air pores are present.

Small shallow gemma cups with frilled margins are present near the mid rib, the cup contains numerous gemmae.

The gametophyte produces the sex organs antheridia and archegonia on disc shaped receptacles known as antheridiopore and archegoniophore, born on male and female plants respectively. Hence *Plagiochasma* is dioecious. The antheridia produce biflagellate spermatozoids (sperms) by the spermatozoid mother cells. The archegonium produce an egg, one venter canal cell and four neck canal cells. A zygote is formed after fertilization by the fusion of and egg. The diploid zygote develops in to an embryo which further develops in to a sporangium. It consists of three regions the foot, seta and capsule. The capsule produce spores after the meiotic division of spore mother cells. When the capsule fully matured the spores are liberate outside, each spore develops in to a young gametophyte. Thus the gametophytic phase alternates with the sporophytic phase in the life cycle of *Plagiochasma.*

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Pellia belongs to the family Pelliaceae in anacrogynous jungermanniales. There are about four species all over the world. In India three species are available. The plant body is dichotomously branched, dorsiventral thalloid structure. The dorsal surface is smooth with a mid rib. On the ventral surface smooth walled rhizoids are present. There are no air chambers and air pores in the internal structure, all cells are uniformly distributed except the upper and lower layers with chloroplasts.

Plants are monoecious or dioecious. Antheridia are borne on the dorsal side along the mid rib region. Each antheridium is with short stalk and globose body lies in the pit. Biflagellate spermatozoids are produced in the antheridium. Archegonia occur in clusters on the dorsal side near the growing apex. Each archegonium consists of venter and neck. In the venter an egg and venter canal cell are present, there are about 6 to 9 neck canal cells are present. Fertilization takes place between the egg and spermatozoid. The diploid zygote by repeated divisions forms the sporogonium with foot, along seta and capsule. In the capsule the spore mother cells undergo meiosis and form the spores and elaters. When the capsule matures it opens by cleavage and liberates spores with the help of elaters. The spore falls on suitable substratum and develops in to young gametophyte.

A general survey of the gametophyte and sporophyte generations of Anthocerotales leads to the conclusions that the group has features in

common with the Algae on the one hand and to other groups of Embryophyta on the other

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All the facts enumerated above suggest that the Anthocerotales are a distinct but synthetic group of plants. campbell (1928) suggested that despite the similarities between the sporophytes of such liverworts as *Sphaerocarpus*, *Cyathodium and Fossombronia* and the Anthocerotales, "The fact that the primary sporogenous tissue in the Anthocerotales always arises from the amphithecium, while in all other liverworts it is developed from the endothecium, would seem to be a radical difference" Pande (1934), however, suggested that the species of *Notothylas*, like *N. levieeri*, from a connecting link between the Anthocerotales and Hepapticopsida. He states, "This fact suggests a close relationship between the two groups and favors the retention of the Anthocerotales in the Hepaticae" The separation of Anthocerotales, however, is not based on this character alone, and the characters in which they differ from the members of Hepaticopsida are both gametohytic and sporophytic.

In addition the sporophytes of Anthocerotales also show probable lines of biological progress in the following directions.

The presence of complex photosynthetic mechanism, consisting of intercellular spaces in the green tissue and an epidermis with functional stomata, may suggest the beginning of the physiological independence of the sporophyte.

14.9 Glossary

- **Asexual:** referring to reproduction without union of gametes, such as gemmae in *Marchantia.*
- **Bryophyta:** phylum of mosses (previously defined to include liverworts); have embryos and lack organized, lignified vascular tissue; have alternation of generations with dependent sporophyte.
- **Bryophyte:** member of phylum Bryophyta; also used to refer collectively to mosses, liverworts, and hornworts.
- **Bryopsida:** class of Bryophyta including majority of mosses, all except Sphagnopsida, Takakiopsida, Andreaeopsida, Andreaeobryopsida, and Polytrichopsida.
- **Bulbiform:** describes swollen cells found in some grass leaves.

- **Capsule:** sporangium of bryophyte; terminal spore-producing part of sporophyte.
- **Columella** (pl. **columellae**)**:** central sterile portion in sporogenous region of capsule in mosses, hornworts.
- **Dioicous:** having male and female reproductive structures on separate gametophyte Individuals; corresponds to dioecious in sporophytes.
- **Embryo** (pl. **embryos**)**:** multicellular developing organism in archegonium or seed; characteristic of plant kingdom.
- **Dichotomous:** branching into two parts; describes forked branching, as in thallus of *Marchantia.*
- **Gametophore:** gametangium-bearing stalk; used to refer to upright gametophyte plant produced from protonema.
- **Gametophyte generation:** haploid (1n) generation that reproduces by gametes in plants; in bryophytes dominant generation.
- **Gemma:** Organ of vegetative reproduction, consisting of one to many cells that becomes detached from parent plant and develop into new plant.
- **Gemmae cup:** cup-like structure producing gemmae; found in*Marchantia.*
- **Genera:** plural of genus.
- **Generation:** term applied to sporophyte (2n) and gametophyte (1n) phases of plant life cycle.
- **Hornwort:** common name for phylum of thallose plants (**Anthocerotophyta**) with photosynthetic, hornlike capsule.
- **Involucre:** protective sheath of tissue of thallus origin surrounding single antheridium, archegonium, or sporophyte; e.g. *Pellia*
- **Liverwort:** common name of Marchantiophyta (=Hepatophyta).
- group of bryophytes with dorsiventrally oriented leafy or thalloid plant bodies
- **Neck canal cell:** cell of archegonium neck that will disintegrate and liquefy when archegonium is mature.

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14.10 Self-Learning Exercise

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Section -A (Very Short Answer Type Questions)

1. Write briefly about the general characters of *Marchantiales*.
2. Write about the external and internal structure of *Plagiochasma* with the help of diagrams.
3. Explain the different types of reproduction in *Plagiochasma* with the help of diagrams.
4. Write briefly about the life cycle of *Plagiochasma.*
5. Briefly explain the general characters and classification of Jangermanniales.
6. Discuss about the external and internal structure of *Pellia* with the help of diagrams.
7. Explain different types of reproduction in *Pellia* with the help of diagrams.
8. Write about the life cycle of *Notothylas.*
9. What is the role of elaters in bryophytes?
10. Write about the vegetative reproduction in *Plagiochasma.*

Section -B (Short Answer Type Questions)

1. Explain the general characters of Marchantiales.
2. Write about the external characters of *Plagiochasma* with a diagram.
3. Write briefly about the internal structure of the thallus of *Notothylas.*
4. What are the different types of asexual reproduction in Plagiochasma?
5. List out the general characters of Jungermanniales.
6. Discuss about the external structure of *Pellia* with a diagram.
7. Write about the internal structure of *Pellia* with a diagram.

Section -C (Long Answer Type Questions)

1. Give a comparative account of the morphology of *Pellia* and *Plagiochasma*.
2. Describe the thallus structure of *Plagiochasma* and compare it with that of *Notothylas.*

3. With the helpf of labelled diagrams describe the external and internal structures of the thallus of *Plagiochasma*.

4. With the help of labelled diagrams describe the structures of the antheridiophore and archegoniophore of *Plagiochasma* and compare it with that of *Pellia.*

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5. Describe the development and structure of the sporophyte of *Marchantia.*

6. Describe the structure of the sporophyte of *Riccia* and compare it with that of *Marchantia and Plagiochasma*.

7. Describe the post-fertilization changes in the archegoniophore of *Plagiochasma.*

Answer Key of Section-A

1. Why the sporophyte of *Riccia* is considered to be primitive?

2. The thallus structure of *Plagiochasma* is complex in comparison to that of *Riccia.* Explain giving suitable reasons.

3. Draw a labelled diagram of the longitudinal section of the mature archegoniophore of *Plagiochasma.*

4. Describe briefly the development of archegonium in *Pellia.*

5. How many protective layers are present around the sporophyte of *Plagiochasma* and what is their origin?

6. The air pores of *Plagiochasma* are not called stomata. Why?

7. Describe briefly the structure of gemma cup of *Marchantia.*

8. How will you differentiate between the Antheridiophore and archegoniophore of *Plagiochasma?*

9. How will you differentiate the thallus of *Notothylas* and *Plagiochasma* on the basis of their internal structure?

10 Describe briefly the structure of female receptacle of *Plagiochasma.*

Answer Key of Section-B

1. Name the protective layers of sporophyte of *Plagiochasma* from outside to inside.

2. Is the sporophyte of *Pellia* wholly dependent for its nutrition on the gametophyte?

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3. In what succession sex organs are developed in *Plagiochasma*?
4. Whether *Plagiochasma* is a monoecious or dioecious plant?
5. How many vertical rows of cells constitute the neck of archegonium in Notothylas?
6. When does the thallus of *Plagiochasma* develops innovations?
7. How can you identify the male receptacles of *Plagiochasma?*
8. What is the position of neck of archegonia in the female receptacle of *Plagiochasma?*
9. What is spore-elater division?

14.11 References and further readings

- Vashishta, P.C. 1985. Gymnosperm. S.Chand & Company Ltd. New Delhi.
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- Geissler and Greene SW (1982) Bryophyte Taxonomy, methods, practices and floristic exploration. J Cramer, Germany.
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Unit - 15

General Account of *Sphaghum*, *Polytrichum*

NOTES

Structure of the Unit

15.0 Objectives
15.1 Introduction
15.2 General Characters of Sphagnales
15.3 General Characters of Funariales
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- 15.5.3 Reproduction
- 15.5.4 The Antheridium
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15.6 *Polytrichum*
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15.7 Economic and Ecological Importance of Bryophyta
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15.0 Objectives

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After going through this unit you will be able to:

- Describe the general characters of Sphagnales, Funariales and Polytrichales.
- Describe the structure of *Sphagnum and Polytrichum*.
- Discuss about the reproduction of *Sphagnum and Polytrichum.*
- Describe about the development of Antheridium and Archegonium of *Sphagnum and Polytrichum.*

15.1 Introduction

A class of plants within the Bryophyta comprising the mosses, which are found in both damp (including freshwater) and drier situations. Mosses possess erect or prostrate leafless stems, which give rise to leafless stalks bearing capsules. Spores formed in the capsules are released and grow to produce new plants.

Bryopsida is the largest class of Bryophyta. It consists of about 660 genera and 14,500 species distributed all over the world. Plants are known as mosses. Bryopsida is devided into 3 subclasses, Sphagnidae, Andreadae and Bryidae. The subclass Sphagnidae is having only one order sphagnales. The gametophyte is differentiated into 2 stages, 1) a branched prostrate juvenile filamentous thalloid stage; peritonea a transitory stage and (2) an erect leafy shoot, the gametophores. The 376ntermodal376s consists of stem and spirally arranged leaves and bears the sex organs. The rhizoids are multicellular branched and provided with oblique cross walls. The sporogonium consists of foot, seta and capsule.

15.2 General Characters of Sphagnales

Shagnales includes only family and one genus with 336 species. The protonema is thallose one cell in thickness. The rhizoids are multicellular rhizoids with oblique septa. The protonema develops one 376ntermodal376s. The leaves lack midrib and composed of two types of cells, the narrow, green living cells and large hyaline dead cells. The branches arise in lateral fascicles in the axils of leaves. The antheridia are lateral and develop in the axils of leaves of an antheridial branch. The archegonia are terminal. The archesporium is formed

from the amphithecium of the embryo. The endothecium forms the columella which does not penetrate the spore bearing layer. The capsule opens by an operculum but no peristome. The sporogenium is elevated by a special gametophytic structure, the pseudopodium which functionally replaces seta of higher bryopsida.

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15.3 General Characters of Funariales

The sub-class Bryidae is the most highly evolved group of bryophytes, and its members are khown as true mosses. It includes about 14,000 species representing some 675 genera the following are the characteristic features of this group:

(1) The leaves are more one cell in thickness; they possess a distinct midrib.

(2) The embryo has two growing points, located in the hypobasal and epibasal halves of the two celled proembryo. Each growing point of the proembryo has its own apical cell with two cutting faces.

(3) The sporophyte has a distinct foot, a well developed seta and a capsule.

(4) The archesporium develops from the outer layer of the endothecium.

(5) The spore sac is surrounded by septate air chambers.

(6) In most of the genera the capsule has a characteristic operculum and peristomial teeth.

(7) The protonema is usually filamentous and produces leafy gametophores.

The life-history of *Polytrichum* is described here as representatives of the sub-class Bryidae.

15.4 General Characters of Polytrichales

The *Polytrichales,* embracing a comparatively fewer number of genera than the Funariales, comprise the most highly specialized members of the Bryopsida. There is a single family, the Polytrichaceae, which includes 15 genera and 350 species widely distributed in the world. *Polytrichum*, a cosmopolitan genus, is found mainly in temperate and tropical countries. The plant inhabits a wide range of substratum from dry woods to lake and pond margins.

The Polytrichales are characterized by tall, perennial gametophores with narrow leaves that have longitudinal lamellae on the adaxial surface of the midrib. The capsule is erect to horizontal. The peristome originates from a single annular

series of cells in the inner zone of amphithecium and consists of a ring of 32 to 64 short pyramidal teeth. The top of the columella expands into a thin membranous drum-head, the epiphragm which covers the mouth of the capsule. The 378ntermoda is cucullate, either smooth, spinulose or hairy.

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15.5 *Sphagnum*

Class	:	Bryopsida
Sub Class	:	Sphagnidae
Order	:	Sphagnales
Family	:	Sphagnaceae
Genus	:	*Sphagnum*(Dill.)

The common names of *Sphagnum* are 'bog moss', turf moss' and ' peat moss'. Species of *Sphagnum* are aquatic or semi-aquatic which grows in dense masses or in cushions in ponds, swamps, lake margins, and wet hill sides. *Sphagnum* is perennial and the upper part continues to grow while the lower part dies away without disintegration. Thus constantly increasing the mass of dead gametophores which accumulates and it is known as peat, hence the name peat moss.

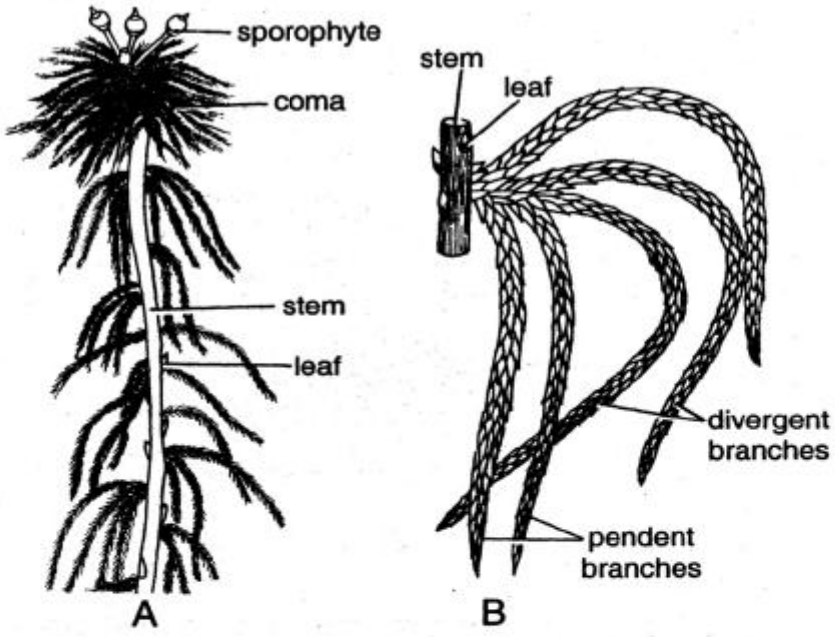


Fig. 15.1 : *Sphagnum* External Features of Gametophyte

15.5.1 Occurrence and Distribution

Sphagnum, with approximately 336 species, is worldwide in distribution extending from the tropics, north and south through temperate zones to sub-arctic and sub-Antarctic regions. The plants are particularly widespread in northern circumpolar regions where they cover a large area of marsh land and form important association.

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Sphagnum grows in extreme moist conditions as semi-aquatic or submerged aquatic plants in ponds, swamps, lake margins or other moist places as moist heaths, moor lands and wet hilly sides. It usually grows in soft water regions containing very small quantities of lime. In India, it occurs in the Himalayas on the wet dripping rocks and on the sides of furrows cut by the fast flowing streams. Because of the general habitats of the different species of *Sphagnum*, the familiar common names, bog moss, turf moss and peat moss have been applied to the genus.

15.5.2 The Mature Gametophyte

External Structure : The gametophytic phase starts with the spore and is made up of two stages the juvenile stage and the leafy gametophyte stage. The germination of spore results in a broadly thallose protonema which develops one upright radial leafy shoot, the 379ntermodal379s .The upright perennial portion of the 379ntermodal379s is differentiated into stem and leaves. The young 379ntermodal379s bears rhizoids with oblique cross walls but these disappear as the 379ntermodal379s matures. Leaves of the 379ntermodal379s are without a midrib. The stems are individually slender and fragile but they gain support by their growth in masses and are thus able to remain erect when growing in cushions above the surface of water.

The mature upright axis of *Sphagnum* has an indefinite power of growth; in deep waters it attains a length of several feet, but, on land, due to the decay of basal parts, the upright stems are more than a few inches long. Branching is usually lateral; from the leaf axils the mode of branching is irregular and eventually results in dense aggregates of cushion-like closely packed sheets.

Near the apex of the main stem, the branches are short, of limited growth and densely crowded to form a compact head or coma. The coma is formed due to

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the fact that the 380ntermodal region between the branch-tufts, near the growing apex, does not as yet elongate, but as new growth appears, the so-called coma tufts, in turn, are displaced downwards. At intervals further down on the stem, there occur other elongated branches, usually in tufts of 3-8 in the axil of every fourth leaf. In aquatic species growing in bogs and pools, all the branches are similar in form and structure and the pendent branches are scarce or absent. But in species which do not grow submerged in water, the branches forming a tuft are of two sorts those which grow upwards towards the apex of the stem from their point of insertion and are known as upright or divergent branches; the others which are elongated, flagelliform and hang downwards are termed as pendent branches.

Apical Growth

Terminal growth of the stem and its branches occurs by a tetrahedral apical cell with three cutting faces. The young segment cut off from each face of the apical cell divides periclinally into an inner cell which forms the axis of the shoot and the outer cell which gives rise to the cortex and a single leaf. Thus each segment eventually produces a single leaf and the subtending portion of the stem. Early in formation, the leaves show a three-ranked arrangement corresponding to the three cutting faces of the apical cell but this arrangement is soon disturbed with the continued growth of the stem. The mature leaves are spirally arranged on the stem with a divergence of two-fifths i.e. each leaf is separated from the one next above it by two-fifths of the circumference of the stem so that from a given leaf if the spiral is followed upwards in the stem after passing five leaves, the sixth leaf will be vertically above and during this course the spiral is followed two times round the stem.

15.5.3 Reproduction

Sexual Reproduction : The sex organs are borne on slightly modified short lateral branches present near the apex of the gametophores. Some species of *Sphagnum* are monoecious, others are dioeciously the antheridia and archegonia in either case are formed on different branches. In a monoecious species, the antheridial branches appear first near the apex of the male shoot but are displaced downwards by the eventual growth of the apex. The leaves on the antheridial branch are closely imbricate and are often more brightly coloured

(yellow, red, brown, purple or even dark green). They are much shorter than the foliage leaves.

15.5.4 The Antheridium : Antheridia are axillary in position on a male branch and are cut off in acropetalous succession.

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Development of the Antheridium : A superficial cell of the stem acts as the antheridial initial and by continuous transverse divisions gives rise to a short filament of cells. With continued growth the terminal cell of the filament acts as an apical cell with two cutting faces. After a young antheridium becomes 12-15 cells in height there are two successive divisions in each of the last 2-5 derivatives from the 'apical cell. The first asymmetrical and diagonal divisions of each cell forms a small jacket initial and a larger sister cell which further divides vertically into another jacket initial and a primary androgonial cell. In this way 2-5 androgonial cells arc encircled by a layer of jacket initials of the young antheridium. It is interesting to note that one of these jacket initials is the old apical cell. The androgonial cell divide and redivide, the last generation of which are the androcytes. Coincident with the division of the androgonial cells, the jacket initials divide to form a one-layered jacket of the antheridium. Longitudinal as well as transverse divisions in the remaining lower cells of the filament which do not take part in the formation of the body of the antheridium result in a long stalk which may be two to four cells broad.

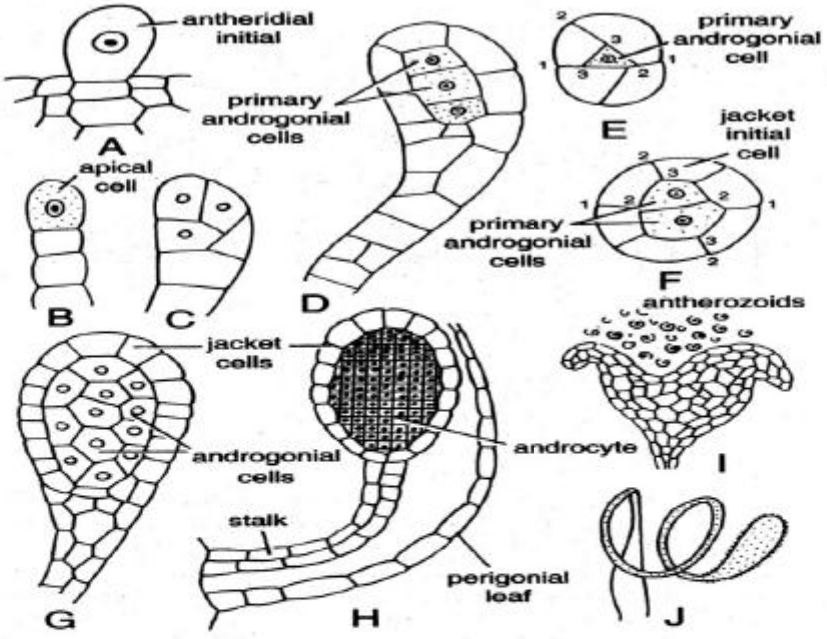


Fig. 15.2 : *Sphagnum* Development of Antheridium

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Structure of the Antheridium: A mature antheridium has a globular body borne on a long stalk of two to four rows of cells. The jacket of the antheridium is single layered and encloses a large number of androcytes each of which gives rise to an antherozoid. The apical cell of the antheridium is also utilized for one of the jacket cells.

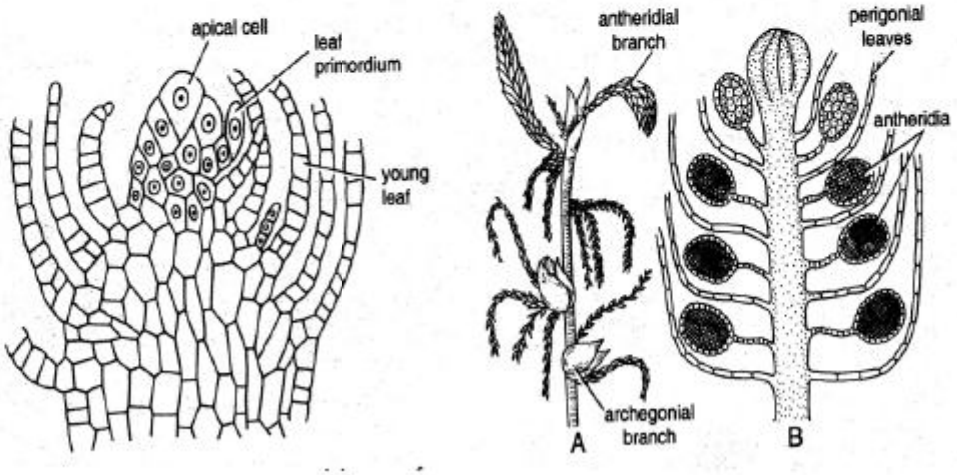


Fig. 15.3 : *Sphagnum* Apical Growth of Thallus and (A) Lateral Branch with Sex Organs (B) Antheridial Branch

15.5.5 The Archegonium: The archegonia are terminal on short, green bud-like archegonial branches. The leaves on these branches are usually much larger than any other leaves on the plant. In anatomical structure, they differ from the branch leaves in having few fibres in the hyaline cells, and from stem-leaves in having abundant chlorophyll in the green cells. These leaves manufacture food material for the developing sporogonium in the early stages of its growth. They also serve as protective organs to the young archegonium and constitute the perichaetium during post-fertilization stages. The number of archegonia borne on an archegonial branch may range from one to five.

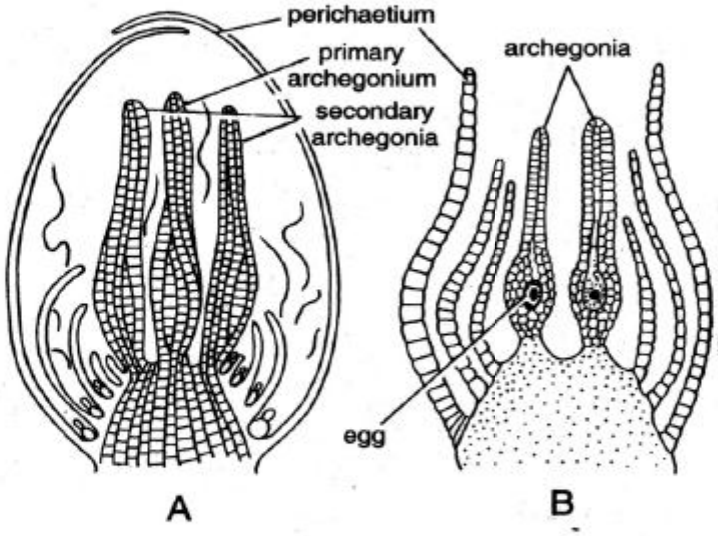


Fig. 15.4 : *Sphagnum* Archegonial branches showing Archegonia

Development of the Archegonium : The archegonial initial, both the primary and secondary archegonia; divides into a filament of few cells. In the primary archegonium, this filament is formed either by successive transverse divisions of the archegonial initial by the activity of the apical cell with two cutting faces. The secondary archegonia do not have any differentiation of the apical cell and divide only by continuous transverse divisions of the terminal cell to form a short filament of few cells only. After the formation of four to six celled filaments, three vertical oblique walls in the terminal cell cut off three peripheral jacket initials surrounding the primary axial cell. The primary axial cell then divides transversely into an outer cover initial and an inner central cell. Transverse division of central cell results into a primary neck canal cell and a primary venter cell much as in other Bryophyta. Eventually the primary neck canal cell forms a row of eight or nine neck canal cells. Late in the development, a transverse division of the primary venter cell results in a venter canal cell and an egg of approximately the same size. The primary cover cell and three jacket initials contribute to the jacket portion of the archegonium. The terminal portion of the neck contributed by the cover initial is not sharply differentiated and the neck merges insensibly with the venter so that there is no clear differentiation between these two parts of the archegonium.

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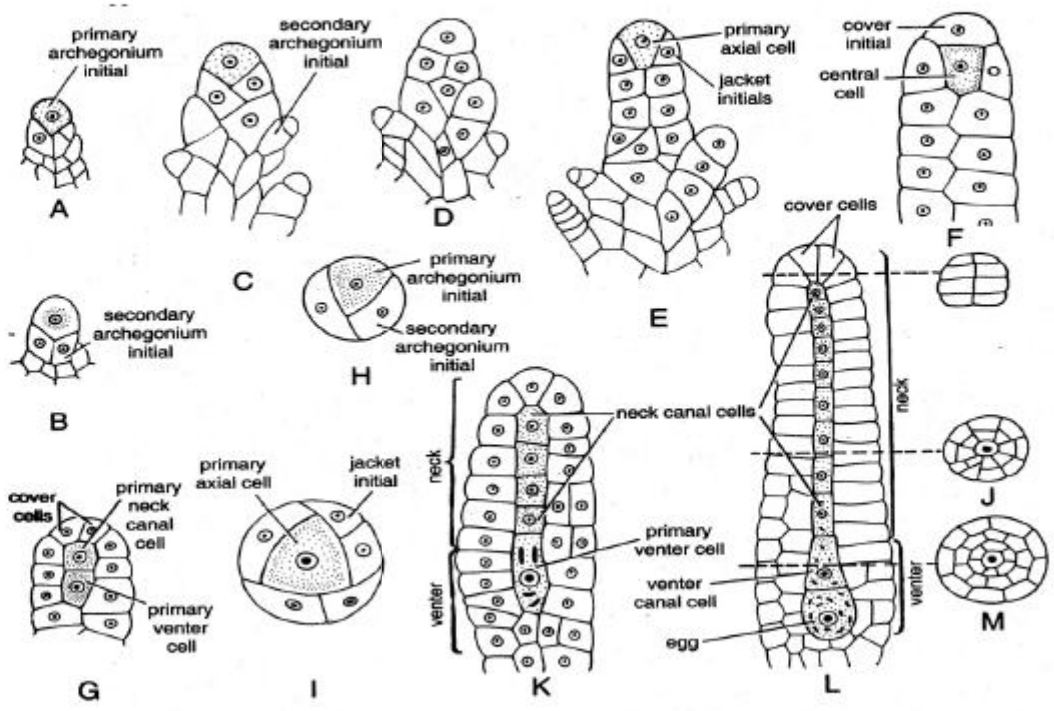


Fig. 15.5 : *Sphagnum* Development of Archegonium

Structure of the Arehegonium: A fully developed archegonium has a long stalk, a massive venter and usually a long twisted neck. The venter and lower portion of neck are two or three celled thick whereas the upper part of neck always remains one cell in thickness. The primary cover cell forms the terminal portion of the neck but this is not well demarcated as in archegonia of Hepaticopsida. The axial row of cells consists of an egg, a venter canal cell and 8 to 9 neck canal cells.

15.5.6 Sporophyte

Structure of Mature Sporophyte

The mature sporophyte is differentiated into foot, seta and capsule. The foot is bulbous or cylindrical and haustorial in function. It is composed of parenchymatous cells. The seta is an inconspicuous narrow region between the foot and the capsule. The capsule is an almost spherical structure of dark brown or black color. The wall of the capsule is 3-7 layered. The outermost layer, which has thick walls, firms epidermis. It has many non-function and rudimentary stomata. The cells of the capsule wall are compactly arranged and they contain chloroplasts. The presence of rudimentary stomata and chloroplast

in the capsule wall show photosynthetic ability of the sporophyte of the ancestors of *Sphagnum.*

A circular biconvex disc-shaped lid is present at the apex of the capsule. It is called operculum. The operculum is seperated from rest of the capsule by a circular groove of thin walled cells, known as annulus. At maturity, the operculum breaks off from the annulus and allows dispersal of spores.

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The central part of the capsule is occupied by a cylinder of sterile cells, called columella. The sporogenous tissue forms a dome shaped arch over the columella. The young sporophyte is enclosed within calyptra and perichaetium, but at maturity the axis of the archegonial branch elongates, pushing out the capsule from the protective coverings. This elongated and leafless axis of archegonial branch, present at the base of the sporophyte, is known as pseudopodium. It develops after fertilization. The distal end of the pseudopodium together with the basal part of the calyptra forms a sac like structure, known as vaginula. The foot of the sporophyte is embedded in vaginula.

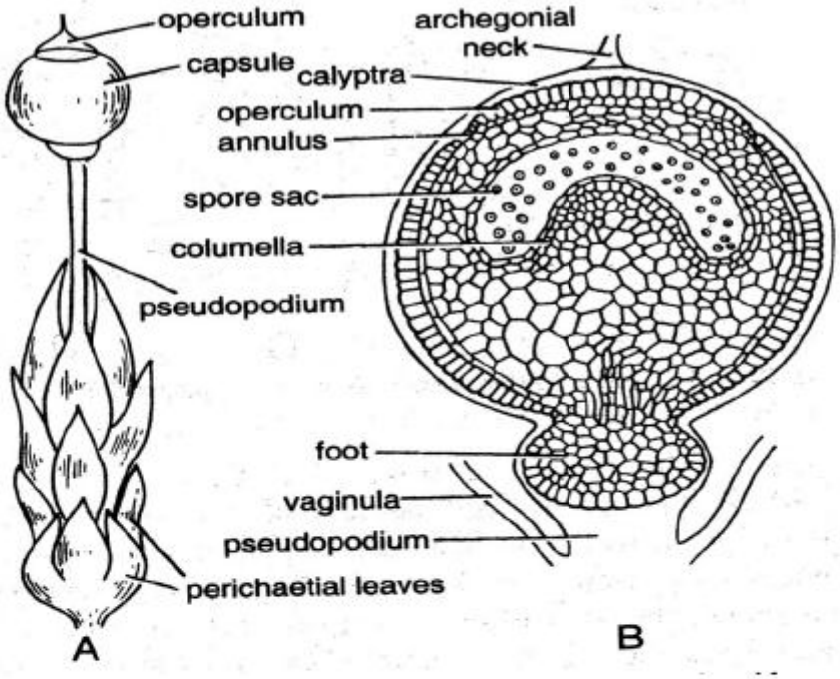


Fig. 15.6 : *Sphagnum* : Vertical Section of Sporophyte

15.6 *Polytrichum*

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The Polytrichales consists of a single family, the Polytrichaceae, which include about 15 genera and 350 species.

Class	:	Bryopsida
Subclass	:	Bryidae
Order	—	Polytrichales
Family	—	Polytrichaceae
Genus	—	*Polytrichum Hedw.*

15.6.1 Occurrence and Distribution

Polytrichum, a large genus of about 100 species is widely distributed throughout the world, chiefly in temperate and trophical countries. Only four species have been reported from India (Bruhl, 1931) namely *P. densifolium, P. xanthopilum, P. juniperinum,* and *P. alpinum*—these are known from very high Himalayan ranges. *Polytrichum commu*ne is cosmopolitan in distribution.

The genus grows on a wide variety of habitats ranging from dry woody peaty, moors, damp soil, and sandy bank to margin of lakes and ponds.

15.6.2 The Mature Gametophyte

External Morphology. The plant body of *Polytrichum* is a gametophore differentiated into two regions: a horizontal, underground so-called rhizome from which arises the slightly branched, aerial leafy shoot which may attain a height of 20 centimeters or more in some species as *P. commune*.

In *P. commune*, there is a transitional middle region between the rhizome and the upper leafy shoot which is brown in colour and three sided.

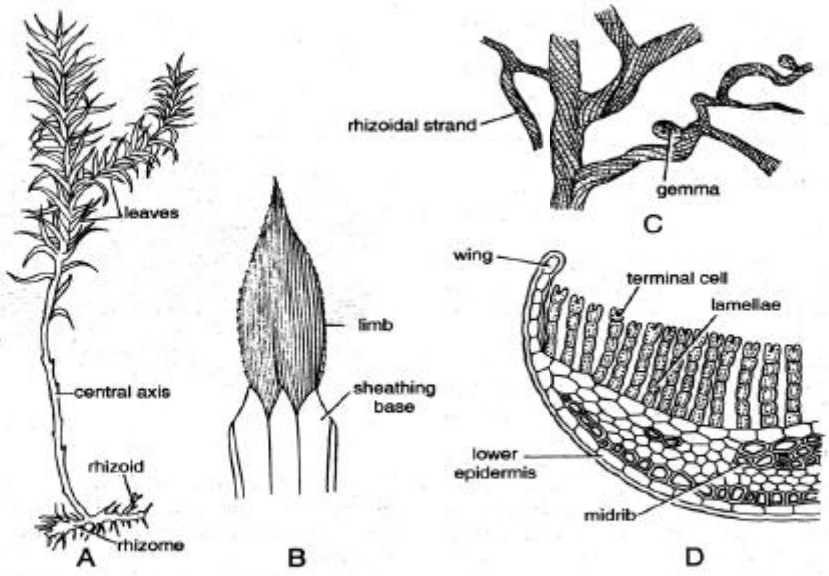


Fig. 15.7 : *Polytrichum* External Features of Gametophyte

15.6.3 Reproduction

Polytrichum is usually dioecious; the antheridia and archegonia arise in clusters at the top of separate gametophores.

15.6.4 The Antheridium : Antheridia are borne in clusters at the apex of the male shoot within an involucre of perigonial leaves (The leaves bearing the antheridia are termed the perigonial leaves). The position of the antheridia in the centre surrounded by the involucre of perigonial leaves looks almost a conspicuous flower-like open cup. The perigonial leaves differ in form and colour from the vegetative leaves occurring lower down on the gametophore. The perigonial leaves are dull red or reddish-brown in colour and each leaf possesses a very broad sheathing base terminating in a short bristle point.

The vegetative growth of the male shoot is not checked by the development of the antheridia as the apex of the stem is not used up in their formation. After producing a large number of antheridia, the apex of the male shoot terminates in a vegetative bud in the middle of the antheridial head and in the following year, the bud forms a fresh shoot which produces antheridia at its apex.

The perigonial or involucral leaves are arranged spirally from the vegetative axis outwards. The antheridia arise in groups at the base of each perigonial leaf in the position of lateral buds.

A mature antheridium consists of a club-shaped body), borne on a short stalk. In the centre of the antheridium are androcytes surrounded by the peripheral one-

layered jacket. Interspersed with the antheridia are the paraphyses. Some of these are simply filamentous; other has the terminal cell of the Filament broadened into a spathulate single celled thick mass of cells.

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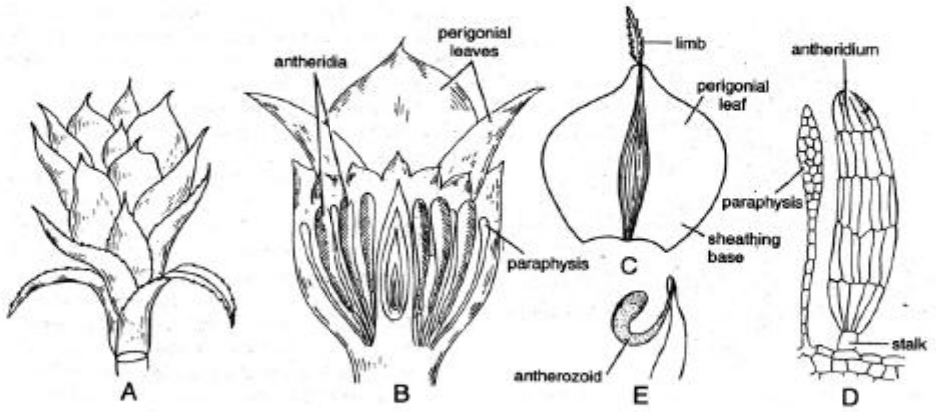


Fig. 15.8 : *Polytrichum:* Male Sex Organs with Antheridia

15.6.5 The Archegonia

The archegonia are borne in clusters at the apex of the leafy stems within an involucre of leaves. The number of archegonia in a cluster may be three (as in *P. commune*) or more. As the apical cell of the shoot itself gets converted into archegonial initial, the further growth of the shoot is checked with the formation of the sporogonium. The structure and development of the archegonium is essentially similar to that found in *Funaria* but the number of neck canal cells is rather large and often variable.

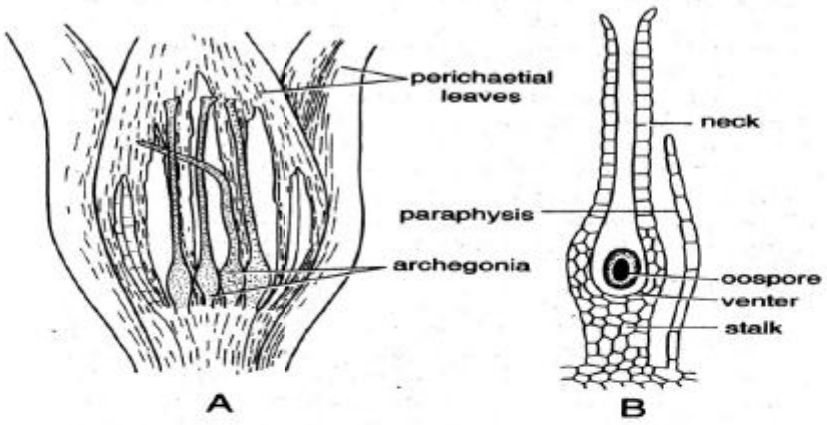


Fig. 15.9 : *Polytrichum:* Female Sex Organ with Archegonia

15.6.6 Sporophyte

The mature sporogonium consists of a foot, a long seta and a capsule. The early developmental stages of the sporogonium are similar to that occurring in *Funaria* except that the foot is embedded deep down into the apex of the archegonial branch and is in close contact with its tissues. The foot is made up of thin-walled parenchymatous cells. Just above the foot is a long slender seta which carries the capsule at its apex. A transverse section of the seta shows a thick-walled superficial layer. Inside this layer is a band of brown, sclerenchymatous cells which merges internally into thin-walled green, parenchymatous cells with intercellular spaces. The axial central strand consists of compactly arranged cells, essentially similar to those in the gametophore axis but usually of much simpler structure.

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At the base of the capsule, the seta enlarges to form the apophysis which is considerably larger than that of *Funaria* and is separated from the sporogenous region. The apophysis has a well defined epidermis with stomata below which is a mass of lax chlorophyllose tissue. The stomata are usually restricted to the groove, they are large, long-pored and raised above the level of the epidermis. Normally two guard cells are present; occasionally a single guard-cell may also be seen. The capsule of *Polytrichum* is usually angular and shows a square outline in cross section. In the region of theca proper (middle portion of capsule) there is a several-layered wall formed of cells containing chloroplast. The outermost layer is the epidermis consisting of cells with thick outer walls. Lying internal to the epidermis is the air space or outer lacuna which is traversed by radially situated assimilatory filaments which connect the epidermis with the outer wall of the spore sac. There is a similar inner lacuna consisting of photosynthetic filaments and connecting the spore sac to the central columella.

The spore sac is surrounded on each side by two layers of thin walled cells both on the outer and inner surface. The archesporium consists of one layer in the young and 4-6 layers of sporogenous cells in the adult sporogonium. All cells of the sporogenous tissue are potential spore mother cells capable of giving rise to spores. The centre is occupied by the columella.

The apex of the capsule consists of an operculum which appears a conical lid with a long beak or rostrum. There is no well marked annulus seen in *Polytrichum* although the usual thickened diaphragm or rim is present in the region of the theca.

The peristome is formed of 32-64 short and stout teeth, composed of bundles of curved crescent-shaped sclerotic cells;

In the mature capsule, the peristome consists of 32 to 64 Pyramidal teeth united below with the capsule wall and above with margin of the epiphragm by their tips. The top of the columella is expanded into a flat disc, the epiphragm which is a transverse band of thin membranous tissue formed of pale compressed cells without intercellular spaces. The diaphragm expands like a drum-head and closes the opening of capsule; it fills the space inside the ring of peristome teeth and attached to their tips.

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Dispersal of Spores: In dry weather, the thin walled cells between the teeth dry up and small openings are formed in the margin of the eniphragm (the opening between the teeth form a ring of pores k7. like those round the top of a poppy capsule) through which the pores are dispersed, a few at a time, by the forces of wind shaking the capsule (censer mechanism).

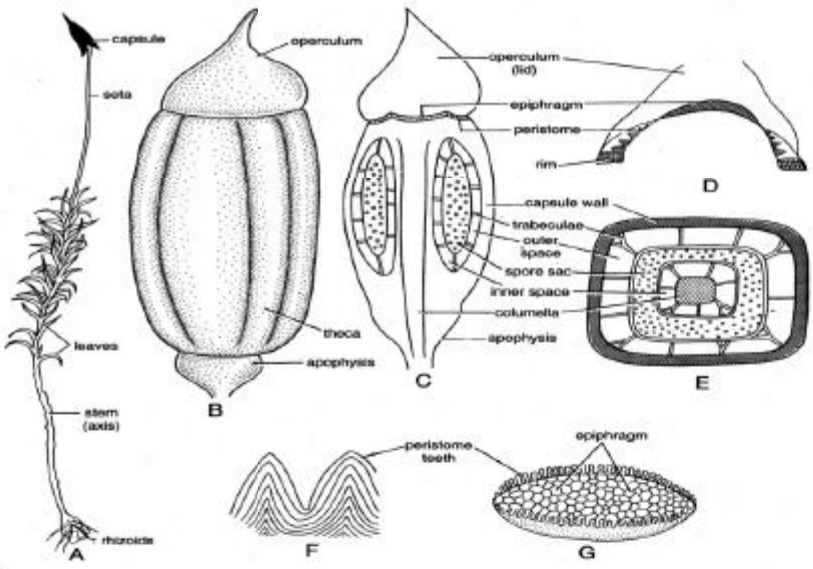


Fig. 15.10 : *Polytrichum* Structure of Sporophyte

The Young Gametophyte

Morphology of the Spores: The spores are small in size, ranging from 0.005 to 0.01 millimeter in diameter. They remain viable for a very long period.

Germination of Spore and Formation of Protonema: The germination of spore has been studied for *P. commune.* The spore is at first yellow but soon

turns green due to the development of chlorophyll. The exospore bursts and the endospore enclosing the protoplast protrudes out as one or more germ tubes. By rapid enlargement the germ tube forms a septate, branched, filamentous protonema as a result of repeated transverse divisions. Growth of the filaments occurs by an apical cell. Some of the filaments grow upwards towards light and become green; others remain colourless and penetrate downwards into the substratum. These latter filaments have oblique cross walls and are of a smaller diameter than the upward filaments. After some time, buds originate near the base of the upright filaments. Eventually, a pyramidal (tetrahedral) apical cell of the future shoot is differentiated which cuts off segment that gives rise to a leafy shoot bearing two kinds of rhizoids at the base. The mature leaves make their appearance only in the third year.

15.7 Economic and Ecological Importance of Bryophyta

There are about 2500 species in Bryophytes found almost in all planes of the world. Most of the bryophytes are indirectly useful to man, however they play an important role in the economy of nature and management of ecosystem through being rock builders.

Bryophytes used as medicines

Number of Bryophytes are used as medicines in homeopathy. Chinese medicines include 40 different kinds of Bryophytes that have been used to treat diseases of the cardiovascular system , tonsilits , tympanitis , cystitis and bronchitis and to cure skin disease and burns.

Marchantia polymorpha

This is a liverwort which is used to cure pulmonary tuberculosis (Roigy Mera , 1945) . It is also used for liver treatments. *M. polymorpha* has antitumour properties thus, its extract is used to cure tumor. It is also used as medicine for boil and abscesses.

***Marchantia stellata*:-**

This is also used in tumor ailments. Watt had mentioned the medicinal uses of *Marchantia polymorpha , Fagetellaconcia* , species of Jungermaniales , *Anthoceros and Riccia*. These are used as an external application to cure ringworm. The Chinese and the native Americans have used Bryophytes for example Mnium sp; and Philontis in the form of paste to cure wounds.

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In India the burnt ash of mosses along with little oil and honey is used as an ointment for burns , cuts and wounds in the Himalayan region. The extract of *Rhodobryum giganteum* can increase blood circulation in aorta upto 30% in animals.

The species of *Sphagnum* found in temperate countries is widely used for medicinal purposes. A healing ointment prepared by *Sphagnum* leaves mixed with grease is used in the treatment of cuts and wounds. The decoction prepared by boiling dried *Sphagnum* in water , is used in the treatment of acute haemorrhage.This decoction is used to cure diseases of eyes. The lakes where *Sphagnum* grows are called as Sphagnum bogs. These are well known to produce peat in acidic water. The bog water is antiseptic and has astringent properties.

Antibiotics from Bryophytes

The Bryophytes are delicate land plants and are devoid of thick cuticle and bark therefore they have biochemically active compounds which perform defense mechanism to protect them from enemies like fungi, bacteria and insects. Some liverworts are known to have lunularic acid for example in the extracts of *Reboulia and Pallavicinia* . It shows antimicrobial properties. Due to antimicrobial activity liverworts are not susceptible to fungal disease. Lunularic acid inhibits the growth of pathogenic fungi *Botrytis cinerea*, *Rhizoctonia solani* and *Pythium* spp. whereas petroleum ether extracts of *Barbula* and *Timmiella* species were found to be active against both gram negative and gram positive bacteria.

A number of unsaturated lipids , fatty acids , esters flavonoids , tripenoids and phenols have been reported from Bryophytes. Hayes reported that aqueous extract of *Conocephalum conicum* has antibiotic activity. It is found to contain Norpiguisone .

Bryophytes *Polytrichum* and Sphagnum exhibit strong antibacterial properties against *Gaffkeya tetragena* and *Staphylococcus aureus*.

Bryophytes as an indicator of Environmental Conditions

Bryophytes are good indicators of environmental conditions. Mosses can be used as an indicator of calcium and nutrient content in water. Some Bryophytes can grow only in narrow and specific pH range and therefore their presence can be treated as an indicator of soil pH. Merceya and Michicofera elongate are

indicator of the presence of copper rich soil. Such plants are used as indicator plants for copper rich soil.

Mosses do not possess a protective epidermis and thick cuticle to protect themselves , therefore they are good indicators of acid rain. In polluted areas , standard transplantation of certain mosses has been found to be quite useful for monitoring the intensity and trend of air pollution.

NOTES

Bryophytes as an experimental material in Lab

Bryophytes , both liverworts and mosses are utilized as an important tool for research in lab. It is used as a test material in a number of branches of botany such as ecology, experimental morphology , toxicology , genetics , physiology , reproduction biology , biochemistry and pharmacognosy. During green house experimental plants like tomato , pepper , cucumber and wheat treated with liverwort extract were found to be less infected with fungus infection by *Phytophthora infestans* than unrelated plants.

Bryophytes Prevent Soil Erosion

Mosses like *Pogonatum , Nardia and Blasia* play a key role as inhibitors of soil erosion, Moss like as *Dicranum* and *Rhodobryum* prevent soil erosion on the slopes of hills. Besides, they provide excellent bed for seed germination.

Bryophytes used as Food Material

Bryophytes are directly used as food material by those animals that are useful to man. *Polytrichum and Bryum* are used to make capsular food as a main diet of the chicks, Besides some birds like field fare , song thrush and black bird use mosses as a regular food. Reindeer depends on *Polytrichum and Hylocomium alaskamum* for food.

Use of Bryophytes as fuel

Liverworts and mosses have long been tried and utilized as a fuel in developed countries like West Germany, Sweden, Finland, Poland and Soviet Union. *Sphagnum* peat is suitable for production of low and intermediate BTU gas as well as hydrogen , ethylene , natural gas , methanol and gasoline.

Peat moss is most suitable for the production of methane. Peat is likely to become an important future source of fuel for production of heat and electricity besides methane as its heating value is superior to that of wood because of low sulphur content.

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Rock Builders

Mosses like *Bryum and Hynum* grow in water bodies rich in calcium and bicarbonate in association with aquatic plants perform a key role in rock builders. The bicarbonic ions are converted into the insoluble calcium carbonate by the plants which get precipated and hardened forming calcareous rocks like deposition. These rock deposits can be used as building material.

Soil Formation and Preparation of Substratum Layer for Vegetation

Bryophytes play an important role in soil formation. They germinate and grow in the cracks of the rock. After their death and decay, they add organic matter to almost sterile soil to make them fertile. Thus, they prepare suitable substratum with accumulation of organic matter for other plants to grow. Thus Bryophytes are pioneer plants for lithosphere i.e. succession on rocks.

Use of Bryophytes in Horticulture

Bryophytes provide good absorbing material hence are of great use in horticulture. They improve soil quality, moisture content and increase mineral nutrients in the field if added to dry soil. They may be added to pots to hold moisture and mineral contents. They are extensively used for various purposes by the horticulturists.

Use of peat moss in Waste Water Treatment

The peat is highly absorbent and permeable physically. It is known to absorb toxic metals, therefore, Sphagnum is used as an effective filtering and absorption agent for the treatment of waste water and effluent of factories with acid and toxic discharge consisting of heavy metals particularly Ag, Pb, Cu, Hg, Fe, Sb and organic substances like detergents, dyes , microorganisms and soils.

Ecological significance

In the tropical rainforest, 'moss balls' form in the higher elevations. Here they can absorb great quantities of rain and release water slowly into the atmosphere or ground. They also, along with the moisture, release quantities of ions i.e. Ca+. These balls support numbers of invertebrates and smaller organisms. Bascially these layers have created a second 'ground' or terra high in the tropical canopy a world recently discovered with walkways and ladders that span the canopy.

In wetlands such as boglands and swamps- bryophytes absorb great quantities of water and release organic acids which decrease decomposition rates. This

accumulation of biomass over thousands of years forms ecosystems such as the Okeefenokee Swamp, the bogs we find throughout Canada, Northern US and across the oceans.

15.8 Summary

NOTES

Sphagnum, the only genus of Sphagnales and the most primitive one of the Bryopsida, is of special interest as it shows some striking points of resemblance to the Anthocerotales and probably links these with the more highly developed mosses.

A cosmopolitan genus, *Sphagnum* or peat Moss, as it is commonly called, is essentially an aquatic plant growing around the margins of small lakes and ponds or in depressions where water collects. *Sphagnum* is perennial and inhabits acidic waters where along with other plant remains it constitutes peat which has many economic uses.

The gametophyte generation commences with the spore, and consists of a juvenile protonemal phase and a leafy gametophyte phase. The spores germinate to form at first a short filament which soon expands into a, thallose protonema with a two-sided apical cell like that in the gametophyte of some of the anacrogynous Jungermanniales or Anthocerotales. The protonema is a one-celled thick structure anchored to the substratum by numerous rhizoids which are septate. Thallose protonemata also our in *Andreaea* as in *Sphagnum* both considered to be primitive types.

Sphagnum may be monoecious or dioecious; the sex organs are present on short lateral branches near the apex of the gametophore. The antheridia are axillary in position and acropetally arranged. The mature antheridium has a globular form. and in general appearance and position recalls that of Porella. The development of spermatozoids resembles that of the Hepaticopsida; they have two flagella attached anteriorly. Dehiscence of the antheridium is by splitting of the apex of the jacket into a number of lobes which turn backwards, The position, origin and development of the archegogium is much like that of the acrogynous jungermanniales. The primary archegonium is formed from the apical cell of the branch as in Acrogynae and the secondary ones may develop from the last-formed lateral segments of the apical cell. The early development of the archegonium is exactly like that in the Hepaticopsida, the first oblique division in the terminal cell resulting in an axial cell surrounded by three peripheral

ones. The canal cells are usually 8 or 9 and there is no clear differentiation between the neck and the venter.

NOTES

The zygote of only the primary archegonium develops into the sporophyte. Although diverging strongly in the form and structure of the gametophyte, the sporogonium of *Sphagnum* conforms both in form and development to those of Anthocerotales. Alone among the mosses, the embryo of *Sphagnum* divides by successive transverse walls like a liverwort, there is no continued apical growth; the further enlargement, after the first division, is intercalary in the segments already laid down. The young embryo is a 6-12 celled filament, the upper 3-4 cells of which develop into the capsule, the rest forming the foot and the seta. In the capsule, there is the differentiation of a peripheral amphthecium and a central endotlhecium: The endothecium develops into a bulky mass of columella with rounded apex. The amphithecium divides periclinally to give off internally a single layer of archesporium which appears as a continuous dome closely investing the columella exactly as in *Anthoceros*. The outer layer of the amphithecium forms a many-layered capsule wall. The capsule has abundant chlorophyll and a definite epidermis is differentiated having rudimentary stomata. The archesporium is composed of four cell layers thus resembling *Notothylas* rather than Anthoceros. Unlike both Hepaticopsida and Anthocerotopsida, all the sporogenous cells of the *Sphagnum* produce spore-tetrads. There are no elaters formed.

The globular capsule is connected with the foot by a very short neck-like seta but as a substitute, the axis of the archegonial shoot of the parent gametophyte becomes much elongated and carries the capsule beyond the perichaetial leaves. When mature, the capsule opens by a definite operculum or lid. At this stage, the foot is considerably enlarged as a haustorium and the whole sporogonium is borne upwards on an elongated pseudopodium

The gametophyte of *Polytrichum* has reached the highest degree of development known among the Bryophytes. The plant body in these genera consists of a horizontal, under-ground, so called rhizome from which arises a branched aerial leafy shoot which in *P. commune* attains sometimes a length of 20 centimeters. The rhizome and the transitional region have brown or colourless leaves arranged in three vertical rows with, a divergence of 1/3; those on the aerial shoot are large, spirally arranged and with a divergence of 3/8. The rhizome bears numerous rhizoids which are often twisted together into cable-like strands.

Water is absorbed through lumen of the rhizoids and also through the wick-like strands by capillary action.

The axis of the leafy shoot of *Polytrichum,* representing the entire order, has a decidedly complex structure. Within the firm epidermis is the hypodermal sclerenchyma of thick walled, dark coloured elements. The cortex is differentiated into an outer and inner cortical region. There is conspicuous central cylinder composed of two tissue elements; narrow dark coloured sclerenchymatous fibres or the leptom mantle and very much larger thin-walled cells destitute of protoplasmic contents—the hydrome a tissue concerned with the conduction of water and analogous to xylem of vascular plants. Traversing the cortex, are slender strands of elongated cells, the leaf traces which are structurally like the central cylinder but with the water conducting cells less conspicuous. The leaf traces finally unite with the central cylinder in a manner quite like that found in the stems of many vascular plants. Inside the inner cortex and surrounding the central cylinder is the rudimentary pericycle.

NOTES

The sex organs of the family conform with those of the Bryidae. *Polytrichum* is mostly dioecious, the antheridia and the archegonia arise in clusters at the apex. The male plants are often very conspicuous, the leaves surrounding the antheridial cluster being broad and membranous in texture. The mature antheridium is club-shaped and borne on a short stalk. The division of the spermatozoids is much like that of the jungerameniales.

The mature sporogonium consists of a foot, a long seta, and the capsule but the foot is buried deep down into the apex of the archegonial branch. The seta enlarges to form the apophysis much larger than that of *Funaria* and separated from the sporogenous region by a groove.

The early separation of the amphithecium and the endothecium is much like that in the other mosses, but in *Polytrichum* for a long-time, cell activity is restricted to amphithecium and only after it has become 3-4 layers of cells does division occur in the large primary cells of the endothecium. The first division, as in Bryidae, separates the columella from the sporogenous region but it is only at a later period that the actual archesporium is developed in the capsule, and the divisions in the endothecium are much less regular than they are in other Bryidae.

As the capsule enlarges, large lacunae are formed as in the Bryidae, but those occur in both the amphithecium and the endothecium. The archesporium is the

outermost layer of endothecium essentially as in Bryidae but instead of its remaining only a single-layer of cells, it consists of 4-6 layers thus recalling the conditions in *Sphagnum*.

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As in *Funaria*, the two innermost layers, of the epidermis form the outer spore sac and the outer lacunae is developed between the spore sac and the next layer of the amphithecium much as in *Funaria.* The second lacunae develops between the inner spore sac and the columella. The stomata are restricted to grooves separating the apophysis from the sporogenous portion of the capsule. In the development of peristome, *Polytrichum* differ considerably from Bryidae. In these genera, the peristome consists of bundles of thickened fibrous cells arranged in crescent form, the ends of the crescent pointing upwards and joining the ends of the adjacent bundles. In. the mature capsule, the peristome consists of 32-64 short pyramidal teeth surrounding the margin of the theca. The tips of the teeth are connected to a thin circular membrane, the epiphragm which stretches like the head of a drum over the opening of the capsule. In dry weather, the thin-walled cells of the epiphragm between the peristomic teeth dry which leave small openings for the dispersal of spores. As the swift wind shakes the capsule, few spores are dispersed through the pores, at a time. The very large and brown calyptra completely encloses the capsule and persists as a hairy cap; thus the name hairy moss is some-times given to *Polytrichum*.

15.9 Glossary

- **Capsule:** The part of the sporogonium containing the spores.
- **Dorsiventral:** An organ having distinct dorsal and ventral surfaces which usually show difference in structure.
- **Egg:** A female gamete.
- **Elaters:** Cells or part of cells forming hygroscopic spirally twisted structures helping to disperse the spores. In many Hepaticopsida-spirally thickened sterile cells in the capsule.
- **Embryo:** Young plant developed within the archegonium of cryptogams, or inside the seed in the phanerogames, after sexual or parthenogenetic reproduction from an ovum.
- **Exine:** The outer layer of the cell wall of spore.
- **Exotic:** Non-native.

- **Foot:** A specialized organ of attachment and temporary nutrition of the embryo sporophyte of bryophytes and pteridophytes which absorbs food from the gametophyte.
- **Heterospory:** The condition of producing two kinds of spores differing in size, i.e., the smaller microspores and the larger megaspores, the former producing the male and the latter the female plants.
- **Hypobasal:** Forming the lower part of the embryo.
- **Involucre:** A protective envelop enclosing the reproductive organs.
- **Phylogeny:** The ancestral or evolutionary history of the group to which an organism belongs.
- **Protonema:** The early filamentous stage produced on germination of the sexual spore in some bryophytes.
- **Neck Canal:** entry canal through neck to egg in base of archegonium.
- **Peristome:** in mosses, fringe of teeth around opening of capsule (spore container); involved in spore dispersal (peri = around;stoma = mouth, opening)
- **Sporogenesis:** process of giving rise to spores, starting with meiosis in plants
- **Sporophyte:** diploid (2n) meiospore-bearing generation; initiated by fertilization of egg and ends with meiosis (Gr. spora =seed, phyton = plant)
- **Sporophyte generation:** diploid (2n) generation in plants that begins with zygote and ends with meiosis that produces 1n spores; dominant generation in all plants but bryophytes
- **Venter:** swollen basal portion of archegonium, containing egg
- **Venter canal cell:** cell at base of neck of archegonium; disintegrates before fertilization
- **Ventral:** lower or under surface
- **Zygote:** product of fusion of two gametes; fertilized egg before it has undergone mitosis or meiosis.

NOTES

15.10 Self-Learning Exercise

Section -A (Very Short Answer Type Questions)

1. Give two examples of sphagnales.

NOTES

2. Write about the structure of gametophyte in *Sphagnum.*

3. Describe sporophyte of *Sphagnum.*

4. Explain the development of antheridia and archegonia in *Sphagnum* with the help of labeled diagram.

Section -B (Short Answer Type Questions)

5. Describe sexual reproduction in *Sphagnum.*

6. Describe sporophyte of *Sphagnum* with the help of labeled diagram

7. Explain sexual reproduction in *Sphagnum* with the help of labeled diagrams.

8. Give detail account of archegonial development in *Sphagnum.*

9. Describe sexual reproduction of *Polytrichum.*

Section -C (Long Answer Type Questions)

10. Give detail account of life cycle of *Sphagnum.*

11. Describe sexual reproduction in *Polytrichum.*

12. Explain the development of male and female gametophyte in *Polytrichum* with the help of labeled diagram.

13. Describe life cycle of *Polytrichum* with the help of suitable diagrams.

14. Write detail account of sexual reproduction in *Sphagnum.*

15.11 References and further readings

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