SECTION-I

GENERAL ACCOUNT OF THE LEVELS OF ORGANIZATION

A fundamental question that "how life came into existence", still remains thought provoking. Evolutionists have put forward various theories to this effect with arguments in support of each, but this is still enigmatic. In the living world, we come across to look at from simplest particles (the viruses) to highly organized and complex organisms with specialized functions. Nature has defined a sphere of activity for these organismal levels. Present day scientists have categorized all the organisms that are capable of interacting with the other organisms according to their body architecture. Viewing the diversity of life around us twined with complexity attained during the course of evolution, these organisms can be grouped into five basic organizations of life:

Supra-molecular level

Nucleic acids may not modulate the physiology of any organism, but there are such particles which show similar structure and are capable of changing the life of organisms to which they infect. These are the viroids, which virtually consist of single or double stranded nucleic acids (DNA or RNA), without a protein coat and much smaller than viruses. Furthermore, they are chemically resistant to exonucleases and retain their super coil structure. So at organizational level they present themselves as the supra-molecular assemblage. They are usually transmitted by seed or pollen and use higher plants (e.g. potatoes, tomatoes etc.) to reproduce, inserting themselves into the nucleus of a plant cell for replication. Infected plants show distorted growth.

Chromosomal level

Chromosomes are made of proteins and nucleic acid (strictly DNA). The viruses also show similar organization, but the nucleic acid may be either DNA or RNA. Despite of a remote structural and functional relationship, the viruses and chromosomes share the following commonalities:

1. Basic building (biochemical) constituents are similar in both
2. Both can not replicate without the metabolic assistance of the compartment where they are confined to
3. Both show a variety of shapes and types

A virus is a piece of genetic instructions in a protective coat. Virus particles are tiny and can easily pass through the cell membrane. A cell can manufacture and contain as many as a thousand of them before breaking open. They have almost none of the machinery that a cell has, only a smallish quantity of DNA (or RNA) and a protective coat. Viruses are not living things. When they are outside of their host cell, they are just very complex molecular particles that have no metabolism and no way to reproduce. Some of them can even be crystallized, like minerals. In this state they can survive for years, until they are made to contact their particular hosts. Evidence is gaining support that viruses are actually portions of genes of the host or species closely related to the host. It is plausible that after the death of the organism, a fragment of the chromosome might code for protein that can self assemble into a coat and have some infectious potential.

Organelle level

Organelles are small structures within cells that perform dedicated functions. There are a dozen different types of organelles commonly found in eukaryotic cells. The organelles are membrane bound, can perform specialized functions by means of inner membrane systems and, most importantly, the membranes of organelles can act as sites for biochemical reactions. Two of the most important plant cells organelles are chloroplasts and mitochondria, which are semi-autonomous in replication. Both of them have circular DNA, which transcribes RNA and have 70s type ribosome and other protein synthesis paraphernalia. The members of kingdom Monera show the structural organization sufficiently related to the organelles like mitochondria and chloroplasts. In contrast to eukaryotes, the prokaryotes have no definite membrane bound nucleus that contains chromosomes or other specialized structures for metabolic functions, rather all the functions are performed by the intricate cytoplasmic membranous systems. There are quite a few bodies structured for the storage of reserve material, a commonality with pyrenoids of the chloroplast of most eukaryotic algae. Evolutionists believe that certain protoctists, by the phagotrophic mode of nutrition, engulfed the cyanobacteria, which, in due course of evolution, became semi-autonomous and eventually the part of their body as organelles.

Cellular level

Eukaryotic cells are bestowed with all the requisite machinery and compartmentalization of specialized metabolic functions for maintenance of continuity in life. Important cellular structures include organelles, like nucleus, mitochondria, chloroplasts, ribosome and other membrane bound structures. All have their own enzymes systems for metabolism assigned to each compartment. Cytoplasm of these cells is plasmalemma bound and has numerous enzymes lying free in it. Some scientists regard the cytoplasm itself as an organelle. It is, however, noteworthy that normal cells are unable to sustain independently of plant body, unless provided with specific growth supplements and growing environment. This is due to the fact that they are connected to each other symplastically (by plasmodesmata). Unicelled eukaryotic organisms i.e. protoctists have been taken at cellular level of organization due to the fact that they contain all the mechanics, which enable them to thrive independently. A further advancement in unicelled habit is the formation of spore-like structures to overwinter adverse conditions.

Resumption of normal vegetative activities is another characteristic of the organisms. However, the modes of nutrition have to be taken into account while categorizing them at cellular organization level.

Tissue level: In simple words tissue is defined as an aggregation of structurally and functionally related cells. Tissues may be simple or complex depending upon their function and position in the plant body. Examples of some tissues in higher plants include mesophyll, cortex, epidermis etc. Complexity in structure from unicellular habit to multicellular in the course of evolution led to the formation of filamentous forms. The filamentous protoctists or fungi show similar cells in the thallus, which resemble simple tissue system of higher plants. Higher order algae (members of Phaeophyta and Rhodophyta) and bryophytes show a more complex and elaborate tissue systems in the thalli, which is an important evolutionary tendency in these organisms.

Table 1: Organization levels and tools to study the organisms falling under them

Organization level	**Size**	**Visualizing tool**	**Example**
Supramolecular	~10 nm	Electron microscope	Viroids
Chromosomal	~100 nm	Electron microscope	Viruses
Organelle	~1-2 µm	Light microscope	Bacteria, cyanobacteria
Cellular	10-100 µm	Light microscope	Algae, fungi and protozoans
Tissue	1-10 mm	Light/dissecting microscope	Filamentous algae, fungal hyphae

SECTION II
VIRUSES AND BACTERIA

Chapter 1
Viruses

Plant viruses differ greatly from all other plant pathogens not only in size and shape, but also in the simplicity of their chemical composition. The physical structure and methods of infection, multiplication, translocation within the host is also different from bacteria and fungi. Because of their extremely small size and the fact that they are transparent, viruses generally cannot be viewed and detected by the methods used for other pathogens. Cell inclusions containing virus particles, however, are visible by light microscopy.

Definition: Viruses are entities whose genome is a nucleic acid, either DNA or RNA, which reproduce inside living cells and use their synthetic machinery (host ribosomes) to direct the synthesis of specialized particles—the virions, which contain the viral genome and transfer it to other cells.

Viruses differ from other obligate parasites in that i) they contain either DNA or RNA, never both ii) their proteins are synthesized on the host ribosomes and iii) they multiply by independent synthesis of constituents i.e., nucleic acid and proteins.

1.1 Biological status of viruses

With the discovery of viruses line demarcating the living from non-living became hazy. Where to put the viruses? Viruses are nucleoproteins, which are obligate parasites and must enter a host cell to come to life. Are they organisms? Can we call virus a cell? The cell is defined as the smallest unit of life that is capable of independent existence and able to reproduce itself. To carry out its activities, cell needs a space estimated to be 5000Aº in diameter. Most of the viruses range from 100Aº to 2000Aº. Viruses are unable to function independently because they have no enzymes and ribosomes (characteristic of cell) but they have the “know how” the way they put to use for reproduction inside the host cell. So they are neither living ‘organisms’ nor inert chemicals but something between (a macromolecule on the threshold of life).

1.2 Viral architecture

Each virus consists of at least a nucleic acid and a protein. The nucleic acid is 5-40 percent of the virus and protein makes up the remaining 60-95 percent. The lower nucleic acid and the higher protein percentages are found in the elongated viruses, while the spherical viruses contain higher percentages of nucleic acid and lower percentages of proteins. Total weight of the nucleoprotein of different virus particles varies from 4.6 million molecular weight units (broomegrass mosaic virus) to 39 million (TMV) and 73 million (tobacco rattle virus). For most viruses, the weight of the nucleic acid alone ranges only between 1 and 3 million ($1\text{-}3 \times 10^6$) molecular weight units per virus particle. All of the viral nucleic acid sizes are quite small when compared to 0.5×10^9 for mycoplasma, 1×10^9 for spiroplasma and more than 1.5×10^9 for bacteria.

Viral proteins consist of amino acids, whose sequence is dictated by either DNA or RNA. The contents and sequences of amino acids are known for the proteins of several viruses. Thus the protein subunit of TMV consists of 158 amino acids in a constant sequence. In TMV the protein units are arranged in a helix containing slightly above 16 subunits per turn (or 49 subunits per three turns). The central hole of the virus particle down the axis has a diameter of 4 nm, while the maximum diameter of the particle is 18 nm. Each TMV particle consists of approximately 130 helix turns of protein subunits. In the rhabdoviruses the helical nucleoproteins are enveloped in a membrane. In polyhedral plant viruses the protein subunits are tightly packed in arrangements that produce 20 or some multiple of 20 facets and form a shell. Within this shell the nucleic acid is folded or otherwise organized (Fig. 1.1)

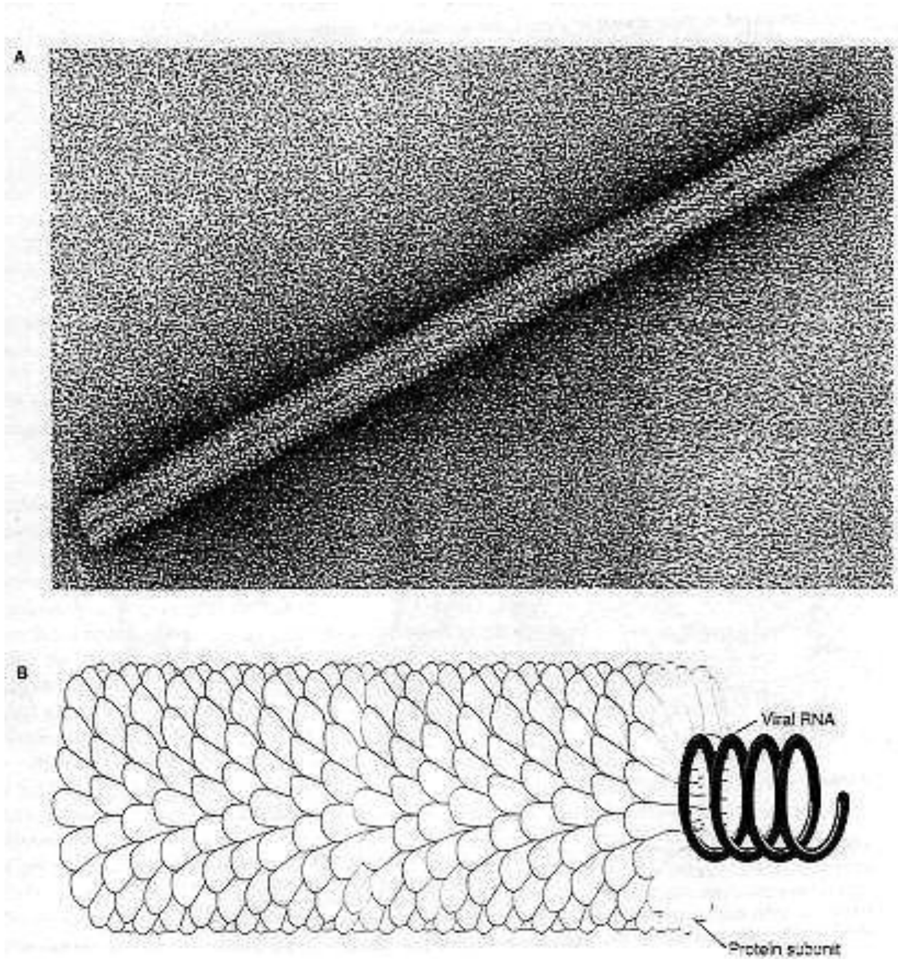

Fig. 1.1: Structure of a typical plant virus

1.3 Composition and structure of viral nucleic acid

The nucleic acid of most plant viruses consists of RNA, but some have been shown to contain DNA. In viral RNA, only one of four bases, adenine, guanine, cytosine and uracil can be attached to each ribose molecule. Most plant viruses (about 540) contain single-stranded RNA, but 40 contain double-stranded RNA, 30 have double stranded DNA, and about 50 contain single stranded DNA.

1.4 Satellite viruses and satellite RNAs

Typical viruses consist of one or more rather large strands of nucleic acid contained in a capsid composed of one or more kinds of protein. These viruses can multiply and cause infection by themselves. Two other types of virus-like pathogens are associated with certain typical viruses. They are called helper viruses, because they depend on the former (original) for multiplication and plant infection. Satellite viruses often reduce the ability of the helper viruses to multiply and cause diseases. They act like parasites of the associated helper virus. The satellites RNA are small, linear or circular RNAs found inside virions of certain multi-component viruses. These are not related, or only partially related, to the RNA of the virus. Satellite RNAs may increase or decrease the severity of viral infections.

1.5 Classification and nomenclature of viruses

The International Committee on Taxonomy of Viruses (ICTV) by the end of 1998 has recognized 85 groups of plant viruses (including satellites and viroids). Previously viruses were named according to symptoms or host plant e.g. Tobacco Mosaic Virus (TMV). With rapidly increasing information on the molecular biology of viruses and their increasing number, virus taxonomy will remain in a state of flux. However, for ease of comparison the genera (with suffix 'virus') and families (with suffix 'viridae') have been arranged according to i) genome type (DNA or RNA), ii) strandedness of nucleic acid (ss or ds), iii) polarity of nucleic acid (+ or – sense), iv) particle morphology and v) number of particle types and of genome segments.

1.5.1 **Alfamovirus** (alfalfa mosaic virus). Family. *Bromoviridae:* Virions with positive sense ssRNA bacilliform but with icosahedral symmetry and of four types. Transmission readily in sap in the nonpersistent manner by aphids and sometimes by seed and pollens. Type species: alfalfa mosaic virus (AMV).

1.5.2 **Badanavirus** (baciliform DNA viruses). Family *Caulimoviridae*: large virions baciliform with parallel sides, rounded ends like those of "rice tungro bacilliform like viruses" and one modal length 9130 nm) although length may range from 60-900 nm. Virions not in inclusion bodies. Transmission not in sap, by mealybugs (cacao swollen shoot virus CSSV), cicadellid leaf hoppers, aphids, or whiteflies in persistent or semipersistent manner, several also seed and pollen transmitted. Type species: banana streak virus (BSV).

1.5.3 **Barnavirus** (bacilifom RNA virus). Family *Barnaviridae:* Viruses of fungi. Virions baciliform, with positive sense ssRNA. One virus restricted to cultivated common mushroom *Agaricus bisporus*. Transmission via mycelium and possibly basidiospores. Role in pathogenesis unknown. Type species: mushroom baciliform virus (MBV).

1.5.4 **Begomovirus** (bean golden mosaic virus). New name for Bigeminivirus. Family *Geminiviridae:* genome of ssDNA in paired-icosahedral virions consists of two segments for most species, one component with four genes and the other with two. It infects dicotyledonous plants and host range is mostly narrow. Some viruses mechanically transmissible, all by whitefly only: *Bemisia tabaci* (and *B. argentifolia*, or "B' or silver leaf biotype of *B. tabaci*). Type species: Okra leaf curl virus (OLCV), Cotton leaf curl virus (CLCuV), Cotton leaf crumple virus (CLCV).

1.5.5 **Caulimovirus** (cauliflower mosaic virus). Family Caulimoviridae: large very stable isometric virions with one molecule of dsDNA in the form of an open circle with single stranded discontinuities. Replication in cytoplasm and sometimes in host nuclei. Virus assemblage probably in large electron-dense viroplasms in cytoplasm. Transmission in sap and by aphids in semipersistent manner. Narrow host ranges. Type species: cauliflower mosaic virus CaMV).

1.5.6 **Closterovirus** (Greek word Kloster=spindle shaped, thread-like). Family Closteroviridae: Virions flexous filamentous with cross-banding contain monopartite positive sense ssRNA. Mechanical transmission difficult. Natural spread by aphids, mealybugs, psyllids or whiteflies. Systemic infetion usually limited to phloem. Host-range narrow. Type species: Citrus tristeza virus (CTV).

1.5.7 **Comovirus** (cowpea mosaic mosaic virus). Family *Comoviridae:* Icosahedral virions with bipartite positive-sense ssRNA. Particles of three types with identical size and including empty shells. Capsids consisting of two proteins, narrow host ranges with usually mottle or mosaic symptoms. Natural transmission by beetles and some in seed. Type species: cowpea mosaic virus (CPMV).

1.5.8 **Cucumovirus** (cucumber mosaic virus). Family *Bromoviridae*: Three types of labile isometric virions of same size and nearly same sedimentation coefficient, each containing a different segment of the ssRNA genome (RNA-1, -2 and –3), the one with smallest segment also containing subgenomic coat-protein mRNA (RNA-4). Satellite RNAs often associated with and modifying symptoms of helper virus. Virus crystals sometimes in vacuoles. Transmission readily in sap, in nature by aphids in nonpersistent manner and often in seed. Wide host ranges. Type species: cucumber mosaic virus (CMV).

1.5.9 **Luteovirus** (luteus = yellow). Family *Luteoviridae*: stable isometric virions, in plants confined to phloem tissue. Virions with positive sense ssRNA. Some viruses contain subgenomic mRNA or satellite RNA. Transmission not by sap, but in persistant manner by phloem feeding aphids. Some members with narrow, others with wide host-ranges. Primarily cause phloem degeneration and necrosis followed by yellowing and premature senescence. Type species; barley yellow dwarf virus (BYDV).

1.5.10 **Nanovirus** (from nanus, dwarf, referring to small size of virion and genome segments) (formerly in Family Circoviridae). Very small icosahedral virion; at least 6 circular ssDNA segments. Transmission not in sap, but most members by aphids in persistent nonpropagative manner. Usually narrow host ranges. Type species; banana bunchy top virus (BBTV).

1.5.11 **Polerovirus** (potato leaf roll virus) recently separated from Luteovirus with newly established family Luteoviridae: Stable isometric virions, in plants confined to phloem tissue. Virions with positive sense ssRNA. Transmission in persistent manner by phloem feeding aphids. Some members narrow others with wide host ranges. Type species; potato leaf roll virus (PLRV).

1.5.12 **Potexvirus** (potato virus X). Stable flexous helical rods with one linear molecule of positive sense ssRNA, axial canal sometimes visible. Readily transmissible in sap through contact and other means. No vectors known. Viruses of a wide range of monocotyledons and dicotyledonous plants species. Host ranges of individual viruses limited. Type species potato virus X (PVX).

1.5.13 **Potyvirus** (potato virus Y). Family Potyviridae. The largest group of plant viruses now recognized. Virions are long flexuous filaments. Characteristic inclusions in cytoplasm containing cylindrical pinwheet structures with lamellae and rolls or scrolls, all composed of virus-coded proteins. Host ranges usually rather narrow, but very wide for a few. Transmission readily in sap, mostly by aphids in the non-persistent manner, and some in seed. Type species; potato virus Y (PVY), bean common mosaic (BCMV), bean yellow mosaic virus (BYMV)chilli veinal mottle virus (ChiVMV).

1.5.14 **Tobamovirus** (tobacco mosaic virus). One type of very stable virion, tubular with axial canal and helical symmetry. Undivided positive sense ssRNA.; subgenomic RNAs also found in virions. Particles often form large crystals in the cytoplasm, amorphous X-bodies also found. Transmission readily in sap and by contact without help of vectors. Some members seed transmitted, though usually not in embryo. Moderate to wide host ranges. Type species tobacco mosaic virus (TMV).

1.6 Dissemination of plant viruses

Unlike most other pathogens, wind or water does not disseminate plant viruses. They are transmitted mechanically through sap or by vegetative propagation, seed, pollen, insects (especially those with sucking mouthparts like aphids, white flies and leafhoppers) mites, nematodes, dodder and fungi. Some of the methods like those by vegetative propagation and by seed are important for transmission from one to the next year's crop but they play no role in the spread of the disease from diseased to healthy plants of the same plant generation. Thus they result only in primary infection and play no role in secondary one. The rate of secondary spread depends upon the size of vector (an animal able to transmit virus) population under favorable conditions in case of vector-transmitted viruses.

For infection of a plant by a virus it must translocate from one cell to another and must multiply in most, if not all, cells into which it moves. Viruses move from one cell or tissue to the other after multiplication through plasmodesmata. Long distance movement of the viruses in the plant takes place through sieve tubes of the phloem.

1.7 Replication of virus nucleic acid

The nucleic acid (RNA) of the virus is first freed from the protein coat. The RNA polymerase enzyme of the host cell, in the presence of the viral RNA acting as a template and of the nucleotide that compose RNA, produces additional RNA. The first new RNA produced is not the viral RNA but a strand that is a mirror image of that RNA and when, as it is formed, is temporarily connected to the viral strand (Fig. 2). Thus, the two form a double-stranded RNA that soon separates to produce the original virus RNA and the mirror image (–) strand, the latter then serving as a template for more virus (+ strand) RNA synthesis.

1.7.1 **The replication of some single-stranded RNA viruses.** In viruses in which the different RNA segments are present within two or more virus particles, all the particles must be present in the same cell for the virus to replicate and for infection to develop. In the single stranded RNA rhabdoviruses the RNA is not infectious because it is the (–) strand. This RNA must be transcribed by a virus–carried enzyme called transcriptase into a (+) strand RNA in the host, and the latter RNA then replicates as above. In the double-stranded RNA isometric viruses, the RNA is segmented within the same virus, is noninfectious and depends for its replication in the host on a transcriptase enzyme also carried within the virus.

1.7.2 **Replication of the double-stranded DNA.** The method of replication seems to be little complex. Briefly upon infection, the viral dsDNA enters the cell nucleus, where it appears to become twisted and supercoiled and forms a minichromosome. The latter is replicated somewhat and is also transcribed into single-stranded RNAs: The smaller RNA is transported to the cytoplasm, where it is translated into virus-coded proteins; the larger RNA is also transported to the same location in the cytoplasm, but there it is used as a template for reverse transcription into a complete virion dsDNA, which is promptly encapsidated with protein subunits to form complete virions. The method of replication of the single-stranded DNA (ssDNA) of plant viruses has not been determined with any degree of certainty. In animal and bacterial ssDNA viruses, however, the ssDNA replicates by forming a rolling circle that produces a multimeric (–) strand, which serves as a template for the production of multimeric (+) strands that are then cleaved to produce unit length (+) strands.

As soon as new viral nucleic acid is produced, some of it is translated, i.e., it induces the host cell to produce the protein molecules that will be the protein subunits and that will form the protein coat of the virus. For virus protein synthesis the part of the viral RNA coding for the viral protein plays the role of messenger RNA. The virus utilizes the amino acids, ribosomes and the transfer RNAs of the host, but it becomes its own blue print (messenger RNA) and the protein formed is for exclusive use by the virus as a coat or other functions (Fig. 1.2).

During virus replication part of its nucleic acid also becomes involved with synthesis of proteins other than the viral protein. Some of these proteins are enzymes, for example replicases, needed for replication of the viral nucleic acid, but the role of most such proteins is still unknown. When the new virus nucleic acid and the virus protein subunits have been produced, the nucleic acid organizes the protein subunits around it, and the two are assembled together to form the complete virus particle, the virion. The first intact virions appear in plant cells approximately 10 hours after inoculation. The virus particles may exist singly or in-groups and may form amorphous or crystalline inclusions with the cell areas (cytoplasm, nucleus) in which they happen to be.

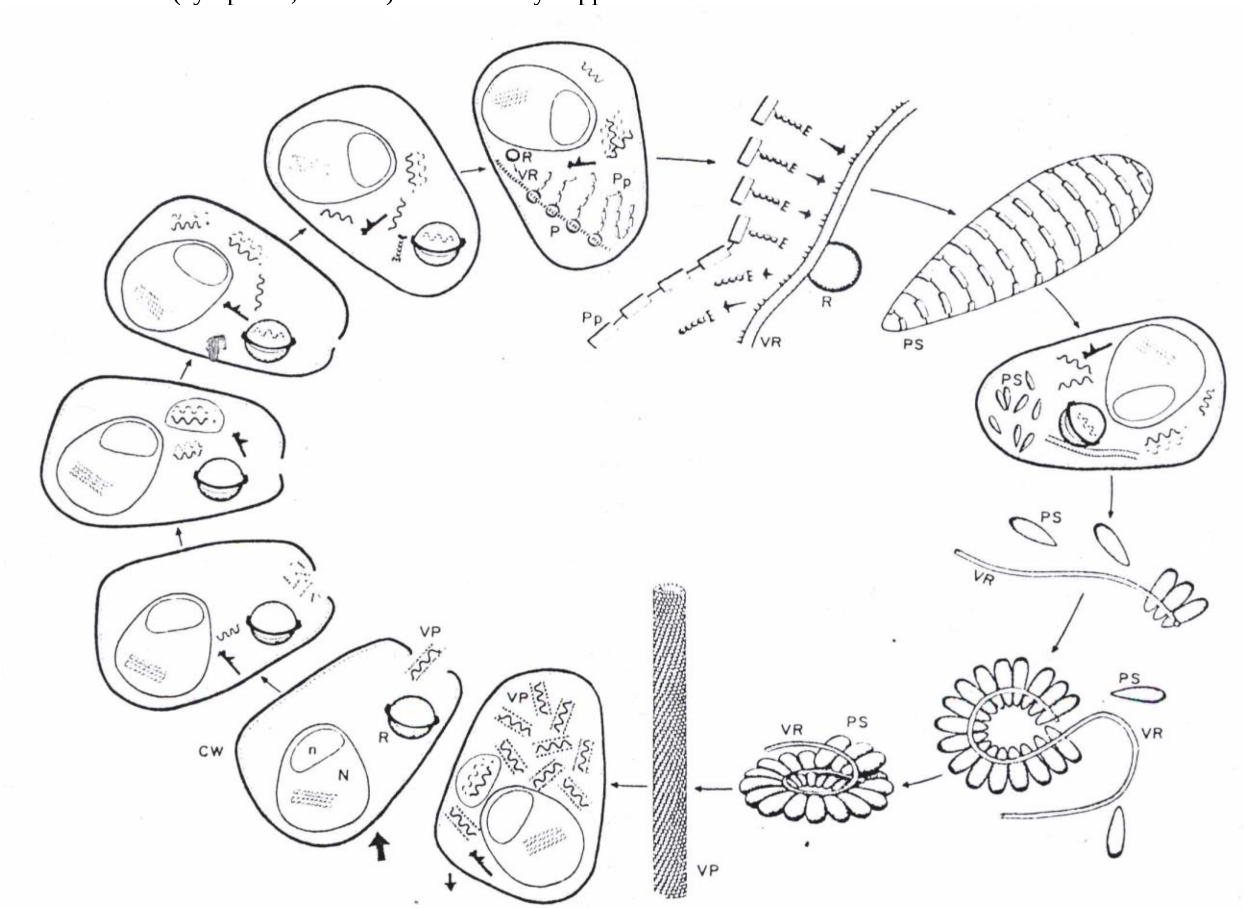

Fig. 1.2: Stages in the replication of viruses. CW (cell wall), R (ribosomes), N (nucleus), n (nucleolus), P (polyribosome), pp (polypeptide, PS (protein subunit), VP (virus particle)

1.8 Symptomatology of virus-infected plants

Several types of symptoms are produced in virus-infected plants. Symptoms may be **internal** as cytological and histological changes and inclusion bodies (which are generally discussed in separate exercises) and **external,** which are generally more striking, obvious and draw the attention of farmers. These symptoms are named and briefly discussed and grouped according to their effect on overall growth of the hosts. Morphological deviations caused by phytopalsma or prokaryotes are discussed separately.

1.8.1 Growth Reduction: Growth reduction is the most prevalent and economically important symptom of virus infection because it reduces yield and quality of produce. It may cause partial or total loss of a crop i.e. **crop failure**. Growth reduction results from **dwarfing** when the plants remain below the normal size of its kind (Barley yellow dwarf virus) and stunting if the growth and development of plant is arrested, as in Peanut dwarf virus. It may cause **reduction in vitality** of the host, which increases its susceptibility and sensitivity to secondary pathogens, and to adverse environmental conditions.

1.8.2 Color variegation. Colour changes of leaves, such as mosaics have been synonymous with virus diseases. **Mosaic** as of tobacco, represents one type of variegation by the appearance of various shades of green and yellow color which are usually irregularly angular but sharply delimited. Diffusely bordered variegation is called Mottling, as in Peanut mottle virus, but there can be various intermediates. If the colored areas are sharply bordered but circular, it is called **flecking** or **spotting**, depending on their size. **Blotching, dotting, drappling, specking, speckling, splotching** and **stippling** are various types of mottling or near synonymous and vary in size, shape and number of patches or boundaries. Systemically infected leaves of woody hosts show beautiful pattern known as **line pattern**, **ring spotting** or **ring-fleckering**. The term **vein mosaic** denotes an irregular mosaic along the veins as in pepper veinal mottle virus. **Vein banding** giving regular mosaic of veins as in potato virus Y, **vein yellowing** when the veins become completely chlorotic (Okra yellow vein virus) and **vein clearing** the veins become transparent as in lemon yellow vein clearing virus. Mosaic in leaves with development of straight parallel yellow or chlorotic lines is called **streaking** (maize streak virus) and **striping** as in barley stripe mosaic. **Flower colour breaking** is the mosaic or variegation of leafy parts of flowers notably the petals e.g. tulip colour breaking virus.

The colour changes may be evenly distributed throughout organs or entire plants. **Chlorosis** occurs when less chlorophyll is produced (cowpea chlorotic mottle virus). In **yellowing**, yellow pigments predominate and increase in concentration (Mung bean yellow mosaic). When the colour disappears totally from affected tissue, it is called **blanching** or **bleaching**. Other pigments may be enhanced after virus infection causing **reddening** (carrot red leaf virus), purpling (cotton anthocyanosis), browning (pea early browning virus), blackening when severe necrosis occurs (Bean black root virus) and **bronzing** which results from superficial necrosis of epidermis over normal tissue. Chlorosis or yellowing restricted to tissue adjoining the veins results in **bright vein yellowing** (okra yellow vein virus).

1.8.3 **Necrosis.** It is rapid local death and is usually accompanied by blackening or browning, often characteristics of local lesions on inoculated leaves. It also results from degeneration of phloem in vascular bundles, called **phloem necrosis**. Similarly, **vein necrosis**, **tip necrosis** or **bud necrosis** occur when these parts rapidly react to virus infections. If necrosis proceeds further, whole plant may die rapidly. Internal necrosis occurs in potato tubers as a result of virus infections; tobacco rattle virus, potato moptop virus from the place of virus entry.

1.8.4 **Malformation:** Apart from dwarfing and stunting, viruses have several other effects on plants. Growth may be locally impeded by chlorosis or completely halted by necrotic tissues. Imbalanced development of plant or parts of plant due to virus infection leads to **malformation**. With persistent viruses, phloem may exert a drastic effect on plant growth by causing accumulation of starch in leaves which become stiff, thickened, leathery and brittle, ultimately causing **leaf rolling** e.g. leaf roll virus. **Leaf narrowing** is the restricted expansion of laminar tissue, because dark green areas along mid rib grow faster than adjacent tissue. Local growth reduction in leaves due to internal torsion forces after necrosis in mesophyll causes leaf curling as in cotton leaf curl virus, and **leaf crinkling** (urdbean crinkle virus) where tensions are induced between necrotic tissues and surrounding expanding tissues. **Rugosity** occurs with retarded growth of veinal tissues (Potato Virus Y) and **rosetting** is the result of impeded internodal expansion at tips as in peanut rosette. Sometimes harmonal disturbances are also associated with malformed or disturbed tissue. New tissue or small outgrowth on leaves especially at veins or stems is called enations as in Pea enation mosaic virus and cotton leaf curl virus. **Tumors** are the large swellings on stems or roots. **Stem pitting** is localized under development and shallow necrosis of certain tissue resulting from failure of cambium tissue. It appears as numerous sparsed elongated pits in tiny furrows and seen when bark is removed (as in citrus tristeza virus). **Stem grooving** occurs under similar conditions of phloem necrosis as big deep, ditches or pits in furrows (apple stem grooving virus. **Etching** is the shallow necrosis or collapse of tissue due to local desiccation of superficial tissue (epidermis) giving an impression of corrosion e.g. tobacco etch virus. Finally **epinsaty** which is rapid growth of infected organ, as petiole and leaf blade, leading to downward bending or curling of entire part as see in peas.

1.8.5 **Water deficiency:** Virus infections can cause water shortage or impede water supply in the plant leading to wilting which is manifested as loss of strength or vigour, drooping and flaccid leaves which ultimately dry. **Withering** is irreversible desiccation of tissue which decays or dies after the tissues have shriveled and shrunk.

1.8.6 **Some misleading symptoms confused with viruses**

- **a.** Certain insect toxaemias producing chlorosis, necrosis, malformation.
- **b.** Silvery components i.e. silver leaf of squash/cucurbits. A phytotoxic effect of feeding by the Biotype B of whitefly (*Bemisia tabaci*), possibly a new species *Bemisia argentifolii*.
- **c.** Vein clearing induced by feeding by leaf hoppers and mites.

d. Genetic abnormalities.
e. Nutritional disorders (deficiency diseases) inducing mottling, chlorosis.
f. Damage by herbicides, 2-4, D causes malformation and Shoe-stringing in cotton.
g. Environmental and pollution effects.

Therefore, diseases and symptoms must be thoroughly distinguished in each case. Symptoms and disorders mentioned above can not be reproduced by inoculation or grafting and plants can be corrected or cured. On the contrary, symptoms induced by viral diseases can be reproduced but can not be corrected.

1.9 Metabolism of virus-infected plants

The mere presence of virus in a plant tissue does not indicate the disturbance in its physiology because some viruses, especially mild strains, continue to live within the plant without any external signs or symptoms of disease. However, severe virus strains infection results in the depletion of chlorophyll, thus a decrease in photosynthesis takes place. Viruses also cause a decrease in the amount of growth-regulating substances (hormones) in the plant, frequently by inducing an increase in the growth-inhibiting substances. A decrease in soluble nitrogen during rapid virus sysnthesis is common in virus infected plants. Many functional systems of plants infected with viruses are affected directly or indirectly. It depends upon the resistance or tolerance level of the host. The effects of virus on nitrogenous compounds on growth regulators and on phenolics have been considered to be the immediate causes of various types of abnormalities in the morphology and physiology of host plant.

Suggested readings

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Chapter 2

Bacteria and Actinomycetes

General account and evolutionary tendencies in Bacteria and Actinomycetes

In the beginning living world was divided into two kingdoms: plants and animals. Antony Van Leeuwenhoek in 1676 discovered the microbial world by his simple microscope, when he observed millions of bacteria streaming in a droplet of water. He exclaimed, “Dear God, what marvels there are in so small a creature”. Some organisms showed the characters of both animals and plants, e.g. *Euglena* (no cell wall, but with a chloroplast) indicating the two kingdoms of living creatures; Plantae and Animalia. But where to put this third living world? German biologist, Haeckel in 1894 proposed a third kingdom, Protista or protoctists (Gr. Protiston = very first), which included those organisms that do not have the development of tissues e.g. algae, fungi, bacteria protozoa etc. Whittaker (1969) proposed a five-kingdom classification of living world (Fig. 2.1).

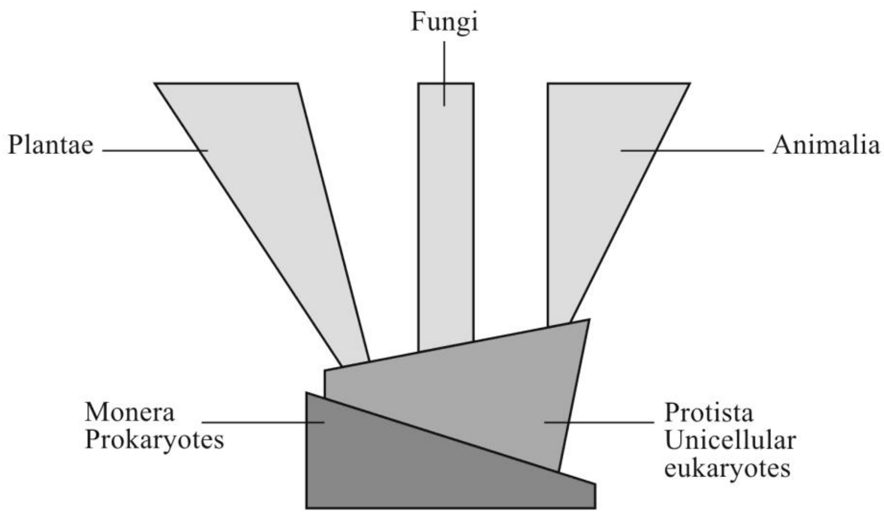

Fig. 2.1. Five kingdom classification of the living organisms.

The kingdom Protista was divided into two large groups: a) lower protists, which lacked a definite nucleus, bacteria, blue green algae and b) higher protests, which had a true membrane bound nucleus and other organelle system to carryout metabolic functions (Table 2.1).

Table 2.1: Difference between prokaryotic and eukaryotic cells

Features	Prokaryotic cell	Eukaryotic cell
Organization	Unicelled or chain of cell forming a filament.	Unicelled to multicellular forming a complex organization
Range of cell size	Between 1-10 micrometer.	Between 10-100 micrometers.
Genetic system	As irregular mass called nucleoid	Confined to chromosomes
Nucleus	Absent	Well-defined
Nuclear membrane	Not there	Present
Mitosis	Does not take place	Takes place
DNA packing	DNA histones absent	DNA histones present
Cytoplasmic organelles	Absent; the functions performed by the membranes	Well defined and fully functional
Ribosomes	70s type	80s type
Outer structures		
Plasmalemma	Present, carries out metabolic functions	Present, but does not perform photosynthesis and respiration
Cell wall	Peptidoglycan i.e. made of proteins and sugars	Made up of cellulose, hemicelluloses etc
Flagella	Absent	When present are made up of 9+2 fibrils of tubular proteins and are powered by ATP

The prokaryotic protists (blue green algae and bacteria) show a considerably narrow range of structural variation than the eukaryotic protists (e.g. fungi). The blue green algae are physiologically uniform, consisting mostly of photoautotrophs while bacteria show extraordinary physiological diversity and consist of photo, chemo, auto or heterotrophs. The major sub-groups of prokaryotic organisms consist of blue green algae, myxobacteria, spirochaetes, eubacteria (true bacteria); the last group contains most of the bacterial plant pathogens. Structure of a typical bacterial cell is given in Fig. 2.2.

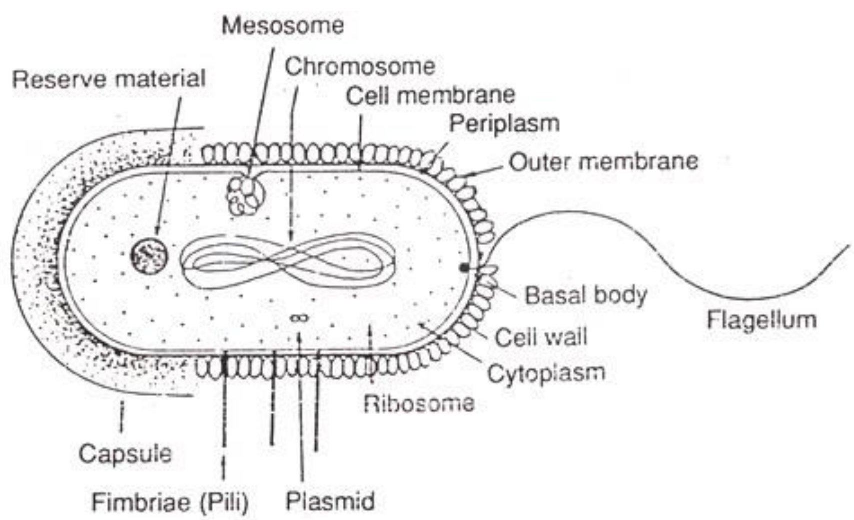

Fig. 2.2. A typical bacterial cell.

Actinomycetes (mycelial eubacteria)

For a long time the actinomycetes were included in fungi, but after the elucidation of their cell structure as prokaryotic they were shifted to bacteria. Compared to fungi, the filaments of Actinomycetes are very thin (1-5 µ). These form asexual reproductive bodies, conidia and sporangiophores and also multiply by fragmentation. Actinomycetes are present in soil and are the most important source of antibiotics. Some also cause important diseases of plants and animals.

2.3 Classification

Phylogenetic taxonomy has not been developed in the kingdom Prokaryotae, because the higher ranks of prokaryotes do not necessarily reflect the phylogenetic background in a strict sense, with the possible exception of Proteobacteria and Archaebacteria. The kingdom Prokaryotae has been divided into four divisions on the basis of the structural and chemical characteristics of cell envelopes (Fig. 2.3)

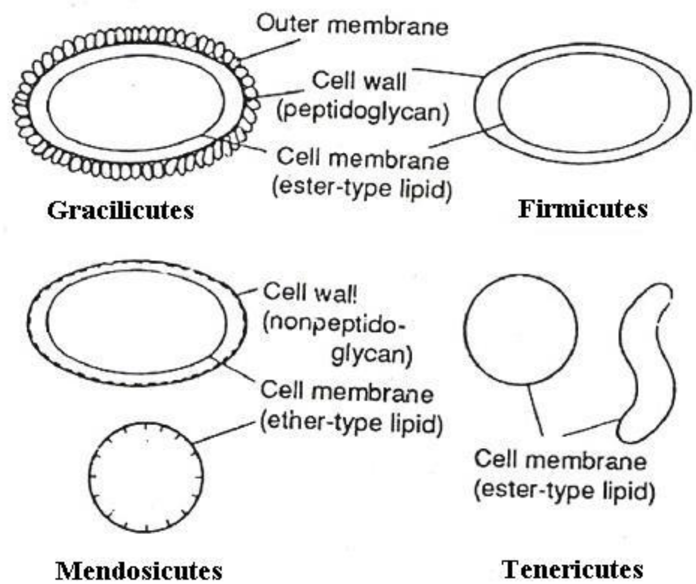

Fig. 2.3. Classification of bacteria based on structural and chemical characteristics of cell envelopes.

2.3.1 **Gracilicutes:** These are gram-negative type cell envelope consisting of an outer membrane, a peptidoglycan layer, and a unit membrane with fatty acid-glycerol ester type lipids. Endospore is not formed. Gracilicutes is divided into the two classes: Proteobacteria and Oxyphotobacteria. Proteobacteria are mostly single celled bacteria containing all gram negative plant pathogenic bacteria.

2.3.2 **Firmicutes.** These are gram positive bacteria consisting of a thick peptidoglycan and unit membrane but without an outer membrane. Cells may or may not show branching. Gram reaction is generally but not always positive. Some produce endospores. Firmicutes is further divided into two classes of Firmibacteria and Thallobacteria. *Bacillus* and *Clostridium* are included in Firmibacteria. Actinomycetes and related bacteria such as *Streptomyces, Clavibacter, Curtobacterium, Arthrobacter, Rhodococcus* and *Nocardia* are included in Thallobacteria or branched bacteria. *Bacillus* is involved in causing tuber rots, rot of seeds and seedlings, and white stripe of wheat. *Clostridium* causes tuber rots, wet wood of elm and popular.

2.3.3 **Tenericutes.** These are the prokaryotes that lack a cell wall. The cells are enclosed by a unit membrane. They are highly pleomorphic and range in size from large to small (0.2 μm) deformable form, which is filterable. Tenericutes include the Class *Mollicutes* in which plant pathogenic mycoplasmalike organisms and Spiroplasma belong. This class has two families i.e. Spiroplasmataceae, containing Spiroplasma, causing corn stunt, and citrus stubborn diseases and Phytoplasmataceae containing *Phytoplasma* (formerly known as mycoplasmalike organisms or MLO), causing numerous yellows, proliferation, and decline diseases in trees and some annuals.

2.3.4 **Mendosicutes**. The prokaryotes that have a cell envelope of no conventional peptidoglycan or lack wall material. Cell walls are made purely of protein macromolecules or heteropolysaccharides. Gram reaction is positive or negative. The unit membrane contains ether-linked polyisoprenoid branched chain lipids. The transfer RNA has unique sequences. *Mendosicutes* includes a class *Archaeobacteria* branched first from a common ancestral progenote in the evolutional process of prokaryotes. No plant pathogenic prokaryotes belong to this division.

2.4 Cell structure

2.4.1 Surface appendages: The bacterial flagellum (120-150 °A) is cylindrical hollow strand made up of protein molecules called flagellin which are structurally similar to the protein of the hair and muscles. Each flagellin molecule is 40 °A in diameter. Several (usually 3-8) longitudinal chains of flagellin molecules run longitudinally twisting around each other to form a wavy helical or rope like structure. A cross section of the flagellum reveals 8 flagellin molecules around a central space. The flagellum consists of three morphological parts: a basal body, the hook and the filament. The basal body is anchored in the plasma membrane; the hook penetrates the wall and the filament is the part that appears in the stained preparations. The cell wall is necessary for the flagellar movement. If the wall is removed the flagellar movement ceases.

2.4.2 Surface adherents: A gelatinous covering around bacterial cell when relatively narrow is called slime and when well defined it is called capsule. Chemically these are polysaccharide of glucose subunits. In *Bacillus anthracis*, it is polypeptide. Depending upon thickness it may be called macrocapsule (>0.2μ) or microcapsule (<0.2μ). The production of capsule and slime is a hereditary mutable character. The capsules protect the pathogenic bacteria from phagocytosis, and also serve as a storage product, which may be consumed when needed. Certain pathogenic bacteria (e.g. *Pseudomonas solanacearum* causing wilt disease of several plants) owe their virulence to the capsule polysaccharide or slime.

2.4.3 Cell wall: A wall made of mucopeptide surrounds bacterial cells, which in some members is surrounded by a polysaccharide in the form of a definite layer called capsule. Mucopeptide forms the major cell wall component (80%) in Gram positive and only a minor component (10-20%) in Gram negative bacteria, rest of the portion comprised of lipoprotein and lipopolysaccharide. It is a polymer comprising of alternating units of NAG (N-acetyl glucosamine) and NAM (N-acetyl muramic acid) joined by β, 1-4 linkages. Murein is a common name given to structural polymers of bacterial walls, which are mucopeptides, mucopolymers, glycopeptides and glycosaminopeptides. Murein is the principal agent for maintaining the shape and strength of the bacterial wall. The bacterial cell walls are multifarious modifications of the basic design of murein architecture.

2.4.4 Cytoplasmic organelles: The bacterial protoplast can be differentiated into a cytoplasmic region, which is rich in ribonucleic acid, and a chromatin region containing the DNA. The genome consists of a single closed ring 1000 μm long. The DNA in feulgen stained preparations is seen concentrated forming a gel like structure but is less dense than the cytoplasm. There is no nuclear membrane and spindles are not formed during cell division.

2.4.5 Ribosomes: They are small particles (100 A in diameter) lying free in the cytoplasm (In eukaryotic cell they lie attached to the endoplasmic reticulum), and they have a sedimentation coefficient of 70s against 80s of eukaryotic ribosomes.

2.4.6 Reserve materials: Under electron microscope the cytoplasm appears granular due to the reserve materials. Some reserve materials lie in a state of fine dispersion in the cytoplasm. The reserve materials can be classified into three categories: **organic polymers** including polysaccharides, lipids etc., **inorganic metaphosphate granules** including volutin granules, which are polymers of phosphate insoluble reserves and **elemental sulfer** present in sulfer oxidizing bacteria serves as energy source.

2.4.7 Special structures: *Bacillus clostridium* forms heat resistant endospores, when chromatin together with some cytoplasm is enclosed by a thin septum. Thus a cell is formed within another cell, the sporangium. This endospore cell is surrounded by a number of layers or envelopes. These are cortex and one or two spore coats. Ultimately the spore is liberated which can withstand extremes of temperatures and chemical effects. At the return of congenial environment the endopsores germinates and produces a vegetative bacterium.

The stalked bacteria like *Caulobactor* have narrow extension of the cell, the wall of the stalk being continuous with the wall of the cell. In *Gallionella* the stalk is impregnated with ferric hydroxide and for this reason these bacteria are referred to as iron bacteria. When a cell divides, the stalk bifurcates; each branch bearing one daughter cell.

2.4.8 Locomotion: Bacteria can move by flagella whose number can also serve as identification character. On the basis of number and arrangement of flagella, bacteria have been divided into different groups: **Monotrichous** forms have a single flagellum at one end of the cell, **Lophotrichous** forms show two or more flagella at one or both ends of the cell, **Amphitrichous** forms have one flagellum at each end and **Peritrichous** forms have a large number of flagella surrounding the cell (Fig. 2.4).

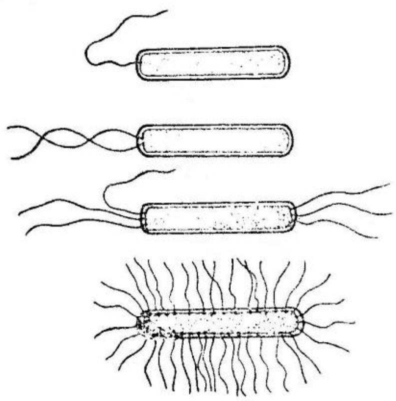

Fig. 2.4. Flagellation in bacteria

2.5 Nutrition in bacteria

Originally biologists recognized two main types of nutrition: **autotrophic**, in which the organisms live on entirely inorganic compounds, and **heterotrophs**, in which all the organic substances serve as the nutrients. Green plants are the typical autotrophs and animals are typical heterotrophs. However, now it is known that a sharp distinction cannot be made between the two types. Even the typical autotrophs like the green plants require specific growth factors, which are organic compounds. Therefore, new nutritional classification has been made. If the need for the growth factor is disregarded, the organisms can be classified on the basis of use of ultimate energy source: light or chemical. Organisms, which use sunlight, are called **phototrophs (photosynthetic)** and those, which use chemical energy, are called **chemotrophs (chemosynthetic).** Another classification can be made on the basis of the source of electron, inorganic or organic compounds. The nutritional types will be named as **organotrophs** or **lithotrophs.** Organotrophs use organic compounds as electron sources while the lithotrophs derive them form inorganic sources, like hydrogen, H_2S ammonia or sulfur. The bacteria show a diverse mode of nutrition as given below:

2.5.1 Photosynthetic autotrophs (photolithotrophs). These are photosynthetic bacteria which use inorganic electron donor H_2, H_2S, NH_3, S etc. (but never water) for fixation of CO_2 to organic compounds, e.g. green sulfur bacteria (Chlorobacteriaceae), purple sulfur bacteria (Thiorhodaceae). Because of the non-utilization of water as electron source, O_2 is never evolved in such photosynthesis.

2.5.2 Photosynthetic heterotrophs (photoorganotrophs). These are also photosynthetic bacteria but the difference is that instead of inorganic substances, organic substrates supply the electrons for reduction of CO_2 in the presence of sunlight, example: non-sulfur bacteria. Thus, here also O_2 is not evolved.

2.5.3 Chemosynthetic autotrophs (chemolithotrophs). No organisms other than bacteria come in this category. They derive energy for growth from the oxidation of inorganic substances. A number of specialized groups of bacteria belong to this category viz., the hydrogen bacteria, colorless sulfur bacteria, nitrifying bacteria, iron bacteria etc. Most of them are autotrophic and use CO_2 as the source of carbon.

All the energy-yielding reactions of chemolithotrophic bacteria are oxidation-reduction reactions in which the hydrogen or electrons are transferred from one compound to the other. The acceptor of the electrons may be oxygen or another inorganic substance. The energy is trapped in ATP molecules during the transport of hydrogen to the oxygen, as it occurs during respiration of organic compounds.

a. **Hydrogen Bacteria.** These oxidize hydrogen in presence of oxygen e.g., *Hydrogenomonas:* $H_2 + ½ O_2 \rightarrow H_2O$ + energy. The key reaction in the oxidation of hydrogen is splitting of molecules into two hydrogen atoms by the enzyme hydrogenase.

b. **Nitrifying Bacteria.** The oxidation of ammonia into nitrate occurs in two steps, each carried out by a specialized group of bacteria. In the first step ammonia is oxidized into nitrite by species of the genus *Nitrosomonas*. The energy liberated is the sole source of growth of these bacteria. The carbon is obtained from CO_2.

$$NH_3 + 1½ O_2 \rightarrow NO_2^- + H_2O + H^+ + \text{energy}$$

In the second step, the nitrite is converted into nitrate. This is brought about by species of the genus *Nitrobactor*, which use this energy for growth. Here also carbon is derived from CO_2.

$$NO_2 + ½O_2 \rightarrow NO_2^- + \text{energy}$$

c. **Sulfur Bacteria**: They are placed in two categories. i) Those which oxidize the elemental sulfur. For example, *Thiobacillus thio-oxidans* obtains energy from oxidation of elemental sulfur and sulfuric acid is produced. The bacterium thus can survive in the extreme acidic environment.

$$S° + H_2O + 1½ O_2 \rightarrow H_2SO_4 + \text{energy}$$

ii) Some others oxidize H_2S to S. *Beggiatova* uses the energy from oxidation of H_2S for growth, and sulfur is stored as granules in the cell.

$$H_2S + O \rightarrow H_2O + S° + \text{energy}$$

d. **Iron Bacteria:** These bacteria show the most interesting but most simple oxidation. Example: *Ferrobacillus*. The Ferric (Fe^{3+}) is deposited as insoluble ferric hydroxide.

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

2.5.4 **Chemosynthetic heterotrophs (chemoorganotroph).** Energy is obtained from the oxidation-reduction reactions using organic compounds as the oxidizable substrate. Animals, fungi and most bacteria (e.g. *Escherichia coli*) are chemoorganotrophs. These bacteria secrete extracellular enzymes, which degrade complex nutrients, carbohydrates, proteins fats etc. into simple smaller units, which are absorbed and oxidized for the release of energy. If O_2 serves as the ultimate hydrogen acceptor the energy yielding oxidation is called **respiration;** if it is an inorganic substance other than oxygen, it is called **anaerobic respiration**. It is called **fermentation** if an organic substance serves as the hydrogen acceptor.

2.6 Bacterial Metabolism (photosynthesis, fermentation, respiration and N fixation)

Nutritional and metabolic traits of plant pathogenic prokaryotes are extremely complex. For example some plant pathogenic bacteria can saprophytically grow in plant residues and even in soil. In contrast, Mollicutes and xylem and phloem limited bacteria are parasites of both plants and insects and quite difficult to grow on artificial media. Thus knowledge of nutritional requirements and metabolism of plant pathogenic bacteria is essential not only for accomplishing their cultivation in artificial media but also for understanding their host-parasite interactions and behaviors in natural ecosystems.

2.6.1 **Bacterial Fermentation:** Carbohydrates are the most important substrates of bacterial fermentation. At least seven distinct types of fermentation of glucose are known, each having a different end product. Proteins and amino acids are also fermented. Much less is known about these fermentations as compared to glucose fermentation. The bacteria are employed for the industrial production of these products of fermentation.

2.6.2 **Bacterial Respiration:** It is of two types:

a. **Aerobic respiration**. The oxidation of organic compounds by oxygen is called aerobic respiration; CO_2 + H_2O are the end products. The role of bacteria (as scavengers) in disposal of organic debris is of great significance. They are capable of oxidizing any organic compound found in the living world.

b. **Anaerobic respiration.** Species of the genus *Desulfovibrio* oxidize organic compounds anaerobically, using sulfate as the hydrogen acceptor (oxidant). Another important anaerobic respiration involves the use of nitrate as hydrogen acceptor. It is reduced to N_2 or NH_3 by the denitrifying bacteria. It is important to note that the sulfate reducers cannot use oxygen even when available, but the denitrifying bacteria use nitrates only in the absence of oxygen. The denitrifying bacteria restore the nitrogen gas to the atmosphere and thus, are of great importance in maintaining the nitrogen cycle.

2.6.3 **Nitrogen fixation:** Bacteria are important both in fixation and liberation of nitrogen. Nitrogen fixing bacteria live independently in soil or as symbionts in root nodules of plants, especially of legumes. The free-living nitrogen-fixing bacteria are *Clostridium* (anaerobic), *Azobactor* (aerobic) and *Rhodospirillum* (photosynthetic). In addition to bacteria, filamentous heterocystous blue-green algae are also important nitrogen fixers, especially in tropical countries. Nitrogen fixation by fungi, though suspected since long, has not been conclusively proved. The symbiotic bacterium associated with root nodules is *Rhizobium leguminosarum* (earlier called *Bacillus radicicola*). The nitrogen-fixing bacteria (free living or symbiotic) form organic nitrogen compounds from the atmospheric nitrogen, which enrich the soil. The root nodules also ultimately reach the soil and the nitrogen compounds contained in them are made available to soil.

The nitrogenous organic compounds are decomposed to form ammonia, which is oxidized to nitrite, (NO_2^-), nitrate (NO_3), and ions by different nitrifying bacteria. *Nitrosomonas* oxidizes ammonium to nitrate and *Nitrobactor* oxidizes nitrite to nitrate. The oxidation of ammonia is the key step in the nitrogen cycle. These are utilized by higher plants and reused in synthesis of organic nitrogen compounds. The fixed nitrogen however is oxidized to N_2 by denitrifying bacteria, which is returned as N_2 gas to the atmosphere.

2.7 Reproduction:

2.7.1 **Binary fission:** It is simple division of cell into two halves. Each half becomes an independent individual. The process may be repeated once in every 20 or 30 minutes. Within this time the cell usually attains its full growth, matures and is ready to multiply again.

2.7.2 **Sexual reproduction:** Bacteria employ some sexual-like processes for genetic recombination and multiplication. In **transformation** the DNA is absorbed from the external medium. During **conjugation** the recipient female (f^-) receives the DNA from a donor bacterium Hfr, a male with high fertility rate, through cellular contact. In **transduction**, the DNA is acquired through a virus. Thus it is a "phage mediated genetic transfer." The **lysogeny** involves the association of genetic material of a virus with that of the bacterium, so there is a kind of host-guest relationship.

Suggested readings

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SECTION III
PHYCOLOGY

Chapter 3
General Account of Algae

Algae are more commonly called as water mosses or seaweeds. The word "***algae***" has its origin in Latin, wherein this word stands for "**seaweed**". Thus the study of algae is called "***Phycology***" is a Greek word for the study of algae, which is the combination of two words "Phykos" means the seaweeds and "Logos" means to discuss.

The algae constitute an important group of protoctists, which comprises the lowest and simplest group of living organisms. They range in form from unicellular or multicellular, but without any histological differentiation; a characteristic of higher plants. The characteristics on the basis of which algae can be defined are difficult to specify, that's why a number of definitions are available. The most common definition of algae is:

"***Chlorophyll bearing aquatic organisms which are thalloid (lack true tissues), and range in organization from unicellular to multicellular***"

3.1 Difference between algae and higher plants

Broadly we cannot isolate algae from higher plants due to the following reasons; a) cell structure of all algae (except Cyanophyta) is similar in many respects to those of higher plants and b) they contain chlorophyll and largely carryout same kind of photosynthesis. However, there are certain features which distinguish algae from the plants (Table 3.1).

Table 3.1: Distinguishing features of algae from higher plants

Characters	**Algae**	**Other plants**
Thallus	Present	Absent
True tissues	Absent	Present
Sex organs	One celled	Multicelled
Habitat	Aquatic (in most cases)	Wet dry
Main photosynthetic pigments	Chlorophyll a	Chlorophyll a, b
Reproductive cells	Not protected by sterile cells	Well protected by sterile cells.
Motility	Majority are motile	All are non- motile

3.2 Types of algae

The members are prokaryotes (Cyanophyta and Prochlotophyta) and eukaryotes (single celled to muticelled) in organization. There are certain distinguishing features between lower algae (Cyanophyta) and higher algae (rest of the phyla of algae discussed in Chapter 6). Fig. 3.1 depicts the structural differences in prokaryotic and eukaryotic protists or protoctists. Comparative details of these characters is given in Table 2.1

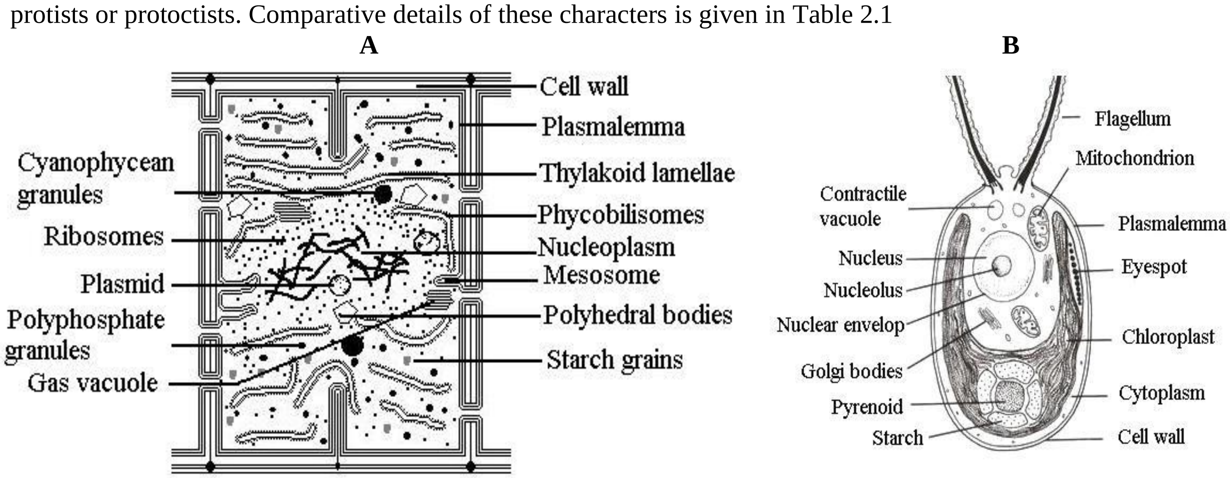

Fig. 3.1: Comparison of cell structural details of prokaryotic (A) and eukaryotic algae (B)

Detailed account of Cyanophyta is given in chapter 6.1. However, a comparative account of various eukaryotic algal phyla has been given in considerable detail below:

<u>GENERAL ACCOUNT OF EUKARYOTIC ALGAE</u>

The eukaryotic algae show wide ranging differences with respect to cellular details, motility, plastids, pigments, reserve material, growth, methods of reproduction, thallus habits, habitats and their distribution. A comparative account of eukaryotic algae is given below:

3.3 Cell structure

3.3.1 Cell wall: It is typically two layered. Inner layer is firm consisting of micro-fibrils and forms skeleton of the wall. Outer layer is gelatinous and amorphous and forms a matrix in which a micro-fibrils component of the inner wall is embedded (Fig. 3.2). Most eukaryotic algae show the chemical composition of cell wall as follows:

Fig. 3.2: Typical structure of eukaryotic algal cell wall

- **a. Inner layer micro-fibrils:** Most algae have cellulose, which is β-1, 4-D-glucose, while in Chlorophyta and Rhodophyta it is mannose beta-1, 4 D-mannose linkage.
- **b. Wall mucilage:** It is different in different algae. For example in Chlorophyta it is residues of D-glucose, L-arabinose, D-xylose, L-xylose, L-rhanmose, D-glucoronic acid. In Phaeophyta it is alginic acid, beta β-1, 4 manuronic acid, fucoidin and α-1, 2, α-3 and α-1, 4-linked L-fucose with SO_4 at 4 carbon atom. In Rhodophyta it is glactans agar, porphyran, and carragenaan β-1, 3- and β-1, 4-linked galactose polymers.

3.3.2 Flagella or undulipodia: Most of eukaryotic algae, except Rhodophyta, possess flagella. The presence of flagella has been used as a criterion of classification in eukaryotic algae. Flagella arise from the axoneme in the basal body, which is attached to the plasma membrane on the periphery (Fig. 3.3). The flagella consist of a central microtubule surrounded by nine doublet microtubules in the axoneme. **Classification of flagella** is based on the size, shape, number and presence of hairs or mastigoneme on their surface (Fig. 3.4).

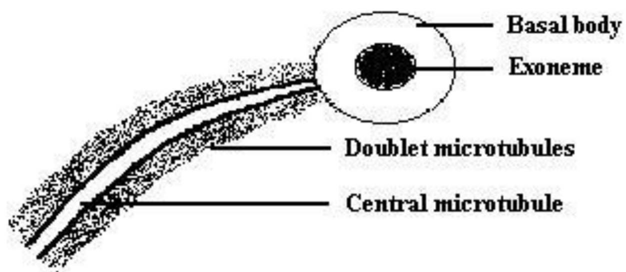

Fig. 3.3: Basic structure and origin of flagella

- **a. Based on size:** Flagella may be isokont, when they are of equal size and heterokont when one is smaller than the other

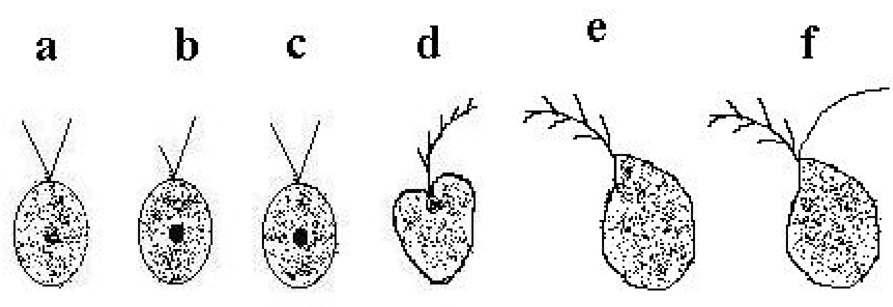

Fig. 3.4: Different types of flagella met in various divisions of eukaryotic algae. Examples based on size are isokont (a), heterokont (b) and based on the presence of mastigoneme are stichonematic (c), pantonematic (d) and one flagellum acronematic (e) and other pantonematic (f)

- **b. External structure and presence of hairs:** Some flagella have no hairs or mastigoneme on their surface and are referred to as **acronematic** or **whiplash.** Such flagella are met in some members of Chlorophyta. There are other flagella that have hairs on their surface and are referred to as **pleuronematic** or **tinsel.** On the basis of presence of hairs the pleuronematic flagella can be further divided into two types; **stichonematic** in which the hairs present on one side of the flagellum e.g. Euglenophyta, and

pentonematic, in which the hairs are present on both the sides of a flagellum e.g. Chrysophyta (some members). One hairy one whiplash flagella are met in other members of Chrysophyta.

3.3.3 Eyespot or stigma: In many motile algae, eyespot is present, which is an animal like organelle. It acts as photoreceptor organ and directs the movement of cells while swimming. Chemically it is composed of highly packed lipid globules. In the Chlorophyta, Chrysophyta, Xenthophyta and Phaeophyta, the eyespot occurs as lipid globule in the chloroplast, while in the Euglenophyta and Dinophyta, it occurs as a group of membrane bound lipid droplets free of the chloroplast.

3.3.4 Cytoplasm: It is reticulate viscous mass bounded externally by plasmalemma. It varies in density and viscosity from cell to cell. Cytoplasm of most algae has the following organelles. **Vacuole** in the cytoplasm is surrounded by tonoplast and is large enough. **Mitochondria** are slender shaped, membrane bound and important for electron transport. **Golgi bodies** are especially evident, present as a body of small vesicle and mainly comparable to animal cells. **Endoplasmic reticulum** (ER) continues from plasmalemma to nuclear membrane and form the skeleton of the cells. Surface of ER has particles called ribosomes, which are 60% RNA and 40% proteins in composition and are involved in proteins synthesis. **Contractile vacuole** is mainly met in fresh water algae. It has a homeostatic function and exports excess of water and other materials out of the cell.

3.3.5 Plastids, pigments and reserve materials

a. Plastids: All eukaryotic algae have plastids, which perform various functions.

i. ***Amyloplast:*** Colorless, contains storage products mainly starch.

ii. ***Chromoplast:*** contains pigments other than green.

iii. ***Chloroplast:*** Of the three, chloroplast is the most important physiologically. It contains green pigment and is capable of photosynthesis. A chloroplast consists of flattened membrane vesicles, called thylakoids. The thylakoids contain chlorophylls and are the sites of photochemical reactions, while the CO_2 is fixed in stroma. In the chloroplast of algae, the grana are absent. The chloroplast contains densely packed protein bodies called **pyrenoids**. They synthesize and store products of photosynthesis e.g. starch in Chlorophyta. Every division of eukaryotic algae has a pyrenoid, except Rhodophyta.

There is a great ***variation in chloroplast structure in algae*** with respect to additional membranes of endoplasmic reticulum (ER) enclosing it.

Membranes of ER	**Algal class**
None	Chlorophyta, Charophyta, Rhodophyta
One	Euglenophyta, Dinophyta
Two	Chrysophyta, Bacillariophyta, Xanthophyta, Phaeophyta

b. Pigments: There are a great variety of pigments, which are also considered as important tools in algal classification (Fig. 3.5). Their detail is as follows:

i. ***Chlorophylls:*** Chlorophyll a, b, c and d are met in different algal classes. Chemically they are lipid derivatives, soluble in methanol, acetone, ethyl alcohol, but insoluble in water. They form the primary photosynthetic pigments in all algae.

ii. ***Carotenoids:*** They may be red, orange, yellow or brown in color. Chemically they are also lipid derivatives and soluble in methanol, benzene or acetone, but insoluble in water. They form the secondary or accessory light absorbing system. Depending upon their chemical properties, they are of two types:

- <u>Carotenes:</u> Oxygen free derivatives; five in number i.e, alpha-carotene, β-carotene, γ-carotene, E-carotene, flavicene and lycopene. Of these β-carotene is widely spread.
- <u>Xanthophylls:</u> Oxygenated derivatives, and are of many different types. Xanthophylls of Chlorophyta resemble higher plants only

Various division of algae differ widely in the distribution of photosynthetic pigments as detailed in Table 3.2.

Table 3.2: comparative account of photosynthetic pigments found in various divisions of eukaryotic algae

Pigments	Euglenophyta	Dinophyta	Chrysophyta	Bacillariophyta	Xanthophyta	Chlorophyta	Charophyta	Phaeophyta	Rhodophyta
Chlorophylls									
A	+	+	+	+	+	+	+	+	+
B	+	-	-	-	-	+	+	-	-
c_1	-	-	+	+	+	-	-	+	-
c_2	-	+	+	+	+	-	-	+	-
d	-	-	-	-	-	-	-	-	+
Carotenoids									
a. Carotenes									
α carotene	-	-	-	+	-	+	+	-	+
β carotene	+	+	+	+	+	+	+	+	+
γ carotene	+	-	-	-	-	-	-	-	-
e carotene	-	-	-	-	-	+	-	-	+
b. Xanthophylls									
Astaxanthin	+	-	-	-	-	-	-	-	-
Antheraxanthin	+	-	-	-	-	-	+	-	+
Diadinoxanthin	+	+	-	+	+	-	-	-	-
Diatoxanthin	-	+	-	+	+	-	-	-	-
Dinoxanthin	-	+	-	-	-	+	-	-	-
Flavicene	-	-	-	-	-	-	-	-	+
Fucoxanthin	-	+	+	+	-	-	-	+	-
Heteroxanthin	-	-	-	-	+	+	-	-	-
Loroxanthin	-	-	-	-	-	-	-	-	+
Lutein	-	-	+	+	-	-	-	-	-
Lycopene	-	-	-	-	-	-	+	-	-
Neoxanthin	+	-	-	-	-	-	+	-	-
Peridinin	-	+	-	-	-	-	-	-	-
Siphonoxanthin	-	-	-	-	-	+	+	-	-
Violaxanthin	-	-	-	-	-	+	+	+	+
Zeaxanthin	-	-	-	-	-	+	+	-	+

+, found; -, not found

iii. ***Phycobilins:*** These are water soluble bluish or red colored pigments found in the Cyanophyta and Rhodophyta respectively on or inside the thylakoid membranes. They are chromoproteins and the chromophore in them is tetrapyrrole or bile pigment the chromophore is tightly bound to the apoprotein by covalent linkage (Fig. 3.5). They are generally classified as phycocyanobilins or phycoerytherobilins based on their light absorption properties:

- **Phycocyanins:** C-phycocyanin and allophycocyanin are found in Cyanophyta, while R-phycocyanin in Rhodophyta
- **Phycoerythrins:** They are also of three types. R-phycoerythrin and B- phycoerythrin are met in Rhodophyta while C- phycoerythrin in Cyanophyta

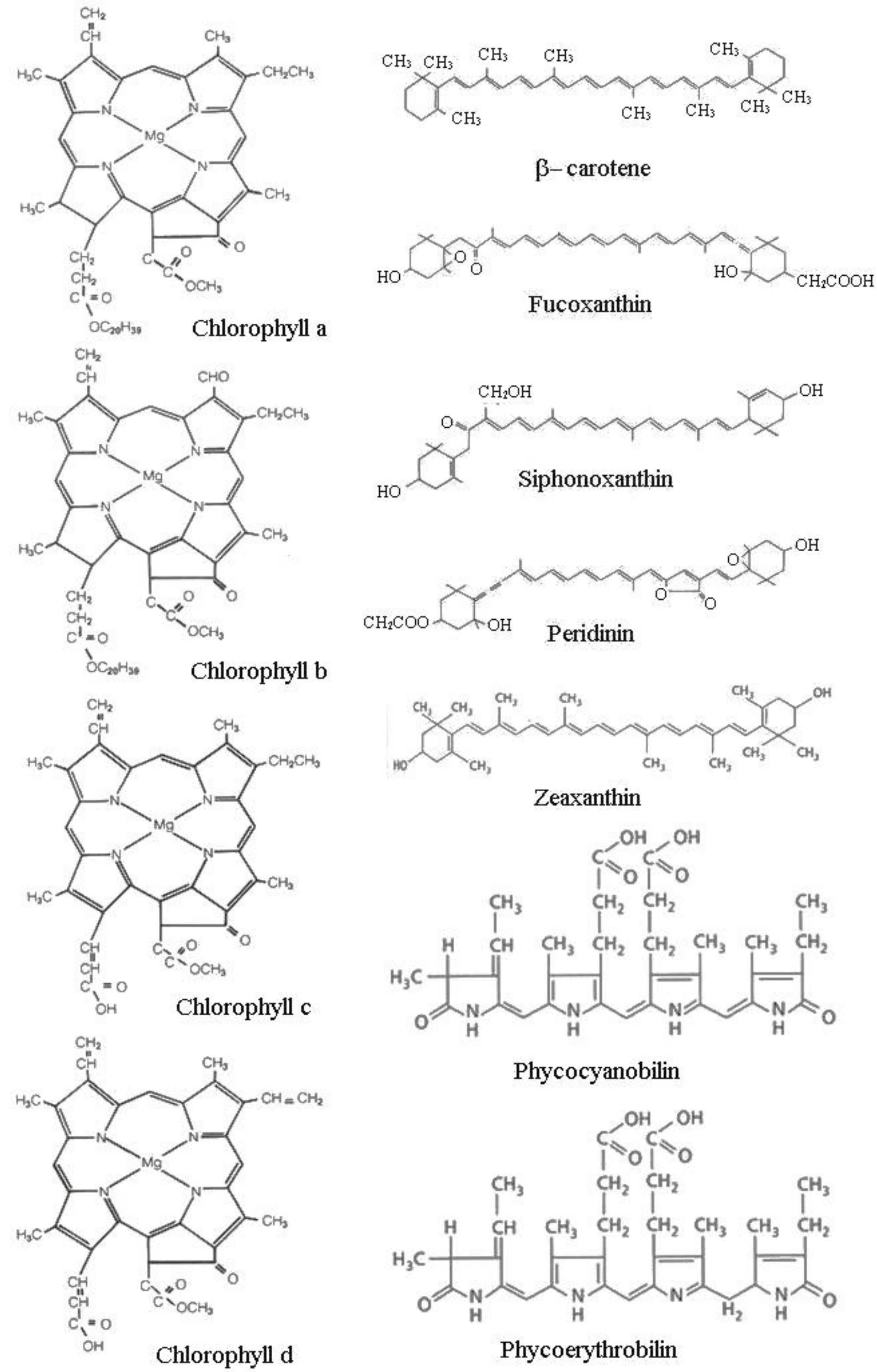

Fig. 3.5. Structural formulae of various photosynthetic pigments found in various classes of algae

c. Storage products

i. There are two types of storage products i.e. low molecular weight or short-term and high molecular weight or long-term products of photosynthesis. There is a considerable variation among algal classes for the accumulation of stored reserves, as given below (Table 3.3):

Table 3.3: Short- and long-term storage products of some classes of eukaryotic algae

Class	**Short-term Carbohydrates**	**Long-term Polysaccharides**	**Others**
Euglenophyta	Sucrose	Paramylon	-
Dinophyta	Glucose, mannitol	Amylose, polyglucan	Oil (rarely)
Chrysophyta	Glucose	Chrysolaminarin	Oil
Bacillariophyta	Glucose	Chrysolaminarin	Oil
Xanthophyta	Glucose, mannitol	Polyglucan	Lipids
Chlorophyta	Glucose, sucrose	Amylose, Fructosan	-
Charophyta	Glucose, sucrose	Amylose	-
Phaeophyta	Glucose, mannitol	Laminarin	-
Rhodophyta	Glucose, xylose, trehalose	Floridean starch	-

3.3.6 Nucleus and nuclear division: Eukaryotic algae show a few differences regarding nuclear division and chromosome morphology.

a. In Dinophyta and Euglenophyta, the chromosomes remain condensed during nuclear division, nuclear membrane persists and chromosomes are attached to it. Nucleolus also remains intact

b. In rest of the algae, the chromosomes are condensed and are visible during prophase and disperse during telophase. The nucleus is small, chromosomes are attached to spindle fibers and nuclear membrane disappears

3.4 Growth

It is an increase in the cell size, thallus or colony of algal cells. In unicellular algae, the growth is by simple cell division. In filamentous, tubular or membranous algae, it is by fragmentation. In colonial algae, the growth is by division of coenobial cells, while in multicellular algae, it is of three types.

3.4.1 Generalized growth: Any cell in the filament may undergo division (e.g., *Ulva*)

3.4.2 Localized growth: Specific cells divide-three types of growth. The growth is **apical** when it is restricted to extreme tips (e.g. *Cladophora* and *Fucus*), **basal** when restricted to base of the thallus and is rare in occurrence (e.g. *Oedogonium*, *Laminaria*), and **intercalary** when it is from the central cells of the thallus.

3.4.3 Polar growth or polarity: In some algae, the growth of body and deposition of material in the cell wall is under the control of auxin like substances, causing polar growth, a phenomenon called polarity. In algae, the polarity has been observed at anterior end of the cell.

3.5 Nutrition

Although most algae are photosynthetic, other nutritional modes are also reported. Some of them are as follow:

3.5.1 Autotrophic or lithotrophic: These require inorganic compounds and light as energy source for growth

3.5.2 Heterotrophic: They require external organic compounds as source of energy, e.g. glucose, sucrose or fructose. They may be of different types

a. **Phagotrophic or holozoic:** They ingest food particles as a whole and digest them e.g. Volvocales

b. **Osmotrophs:** They absorb water-soluble nutrients through plasma membrane and grow.

c. **Parasitic:** Grow on the enzymes system of living organisms

3.5.3 Auxotrophs: Require a small amount of organic compound for growth, but not as whole energy source. For example several blue-green algae require vitamin B-12 for growth

3.5.4 Mixotrophs: They are photoautrophs during the day and can use organic material for growths during night.

3.5.5 Chemotrophs: They derive energy by metabolizing inorganic compounds

3.5.6 Amphitrophs: These algae grow by adopting more than ways of obtaining energy

3.6 Habits

Several types of habits are met in algae (Fig. 3.6):

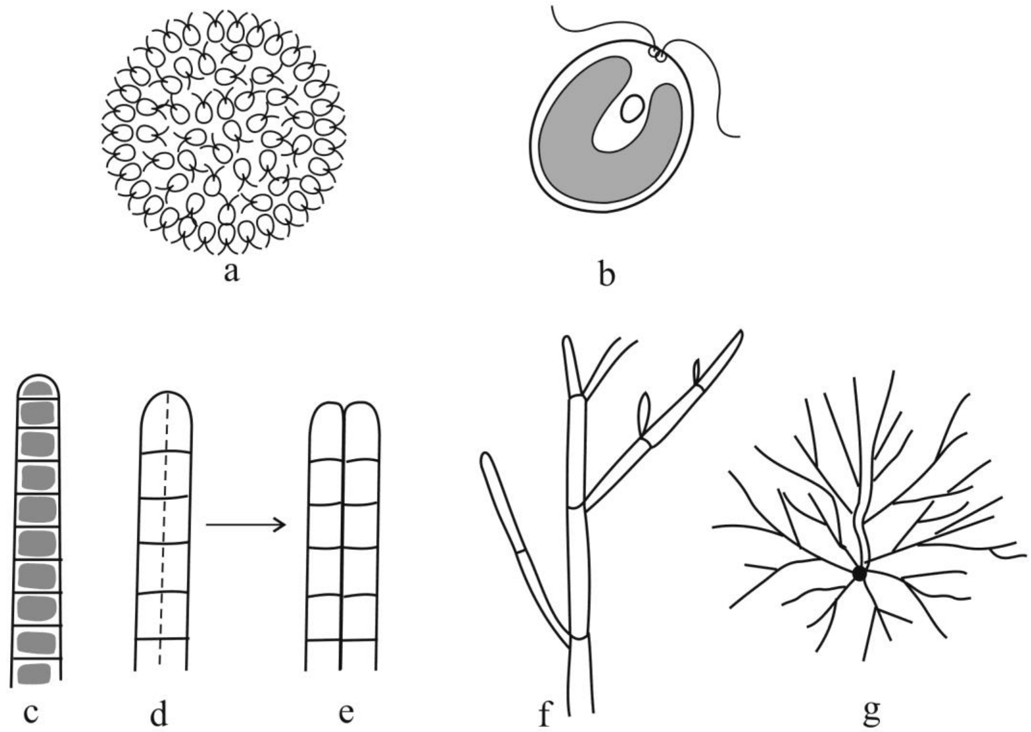

Fig. 3.6. Habits in eukaryotic algae: motile colony (a), motile unicell (b), coccoid (c), simple filamentous (d), foliaceous filament (e, f), branched filament (g) and heterotrichous form (h).

3.6.1 **Motile:** Presence of flagella, mainly unicelled algae show this habit. The cells are more or less spherical, oblong or pear shaped. Members remain motile throughout life. Some flagellates settle on the substrate and exhibit creeping movement, with the protrudation of pseudopodia or rhizopodia. Examples are Chlorophyta, Euglenophyta and Dinophyta. Another motile form is the motile coenobial colonies in green algae.

3.6.2 **Palmelloid:** In this habit, the motility is lost during vegetative phase and occurs only during reproductive phase. In many algae, this habit is permanent with reproductive cells e.g. Chlorophyta and Phaeophyta

3.6.3 **Dendroid:** In palmelloid habit, some colonies produce mucilage at their base, which form basal mucilagenous stalk e.g. Chlorophyta

3.6.4 **Coccoid:** In this many unicells some to rest and withdraw their flagella before the cell division to form new motile cells. During reproductive period, the cells become swarmers. A further step in this evolutionary line resulted in complete loss of motility even in the reproductive cells

3.6.5 **Filamentous habit:** In such habit, the cell division occurs in one plane and the cells formed as a result of division remain attached to each other and form a chain of cells called filaments. The filaments may be of two types

- **a. Uniseriate filaments:** Composed of single row of cells
- **b. Multiseriate filaments:** composed of more than one row of cells. When the cells in the filament divide, in one or more than one plane, there is the formation of parenchymatous thallus.
- **c. Heterotrichous filaments:** In this type the thallus consists of two parts; prostrate, creeping system anchoring the thallus to substratum and a projecting or erect system composed of usually branched filaments.

3.6.6 **Siphonecaous habit:** In this type, the body enlarges with multiplication of organelles but with out septation. This structure is called siphonaceous or coenocytic and nuclei, chloroplasts and other organelles share the same cytoplasm.

3.6.7 **Pseudoparenchymatous:** In this type, filaments are united into a solid structure, which is differentiated into regions that resemble tissue.

3.6.8 **Parenchymatous:** In this type, thalli are organized into true tissues composed of several different types of cells.

3.7 Reproduction

It takes place by various ways in different divisions of algae

3.7.1 **Vegetative reproduction:** This is common to all algae and includes multiplication by cell division or by fragmentation. In this type of reproduction, there is no formation of specialized structures (cells or organs).

3.7.2 **Asexual reproduction:** This comprises of the formation of specialized cells or organs, which give rise to body, without uniting with any other cell. Different kinds of spores involved in asexual reproduction are:

- **a.** **Zoospores:** They are flagellated; contain one, two, four or more flagella for movement. They can be produced either form ordinary vegetative cells or in specialized cells called zoosporangia by zoosporogenesis. The zoospores germinate and form a new individual.
- **b.** **Aplanospores:** They are similar to zoospores; the only difference is that they lack flagella. They perform the same function as zoospores.
- **c.** **Akinetes:** They are spore-like vegetative cells, having variously thick walls and contain abundant food reserves. They can withstand adverse environmental conditions. Under the favorable conditions they give rise to a filament, a branch or whole body after germination.
- **d.** **Hypnospores:** They are thick-walled non-motile spores that undergo a long resting period.
- **e.** **Statospores:** Spores with ornamented wall produced for overwintering.

3.7.3 **Sexual reproduction:** This involves the fusion of gametes to form a zygote. With respect to sexual reproduction, the algae are classified as:

- **a.** **Homothallic or monocious algae:** Male and female gametes are formed on the same thallus.
- **b.** **Heterothallic or dioecious algae:** Male and female gametes are formed on different thalli.
- **c.** **Types of sexual reproduction:** The production of gametes and reproduction is of different types, these are of following types.
    - ***i.*** ***Isogamous:*** This is the most primitive type of sexual reproduction. In this type the morphologically and physiologically similar motile gametes fuse to form a zygote. So it is not possible to call them male or female gametes. Rather they are called as plus (+) or minus (-) gametes.
    - ***ii.*** ***Conjugation:*** Joining together of the contents of two haploid cells from (usually) different filaments
    - ***iii.*** ***Autogamous:*** This involves the fusion of sister nuclei to form a zygote nucleus.
    - ***iv.*** ***Parasexuality:*** In this the transfer of genetic material occurs at anytime
    - ***v.*** ***Anisogamous:*** In this morphologically and physiologically different gametes fuse to form a zygote. Female gamete is large and sluggish or non-motile, while male gamete is small and actively motile.
    - ***vi.*** ***Oogamous:*** This is the most advanced type. In this case there is fusion of a large non-motile egg, with a smaller motile sperm. The eggs are formed within an oogonium, while the sperms are formed in an antheridium. The egg contains well-developed chloroplasts and many reserve materials, while the sperms have less developed chloroplasts and few reserve materials. Sometimes chemotaxis is observed, in which mature egg cell release some chemical substance that attracts sperms towards it. This results in zygote formation.
- **d.** **Fertilization:** After fertilization the egg accumulates food reserved and develops a thick wall around it. The zygote in this form is called as zygospore or oospore, and it can with stand adverse environments. Under favorable conditions, the zygote germinates to give rise to an individual body.
- **e.** **Parthenogenesis:** Sometimes the gametes do not get fused; rather they germinate and form a new plant like parents.

3.8 Life cycles

In life cycle sporophytic generation (diploid) alternates with the gametophytic generation (haploid). Eukaryotic algae show a variety of life cycles depending upon the complexity in the organization of algal divisions. Various life cycles and their detail are given below:

3.8.1 Haplontic: The main body is haploid, giving rise to gametes, which fuse to form diploid zygote. Soon after, zygote develops a thick wall, meiosis takes place and haploid spores are produced , which give rise to haploid vegetative individual (Fig. 3.7)

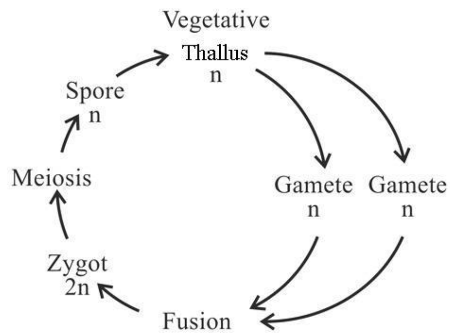

Fig. 3.7. Haplontic life cycle

3.8.2 Diplontic: Main body is diploid, which meiotically produces gametes. Zygot is formed after fusion of the gametes, which gives rise to a diploid vegetative individual (Fig. 3.8)

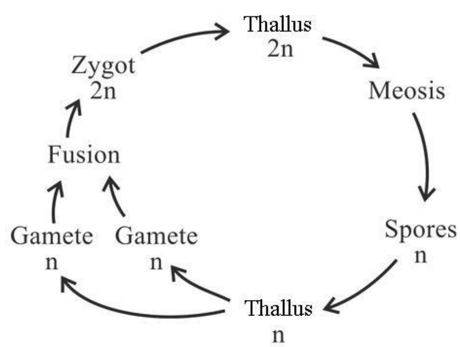

Fig. 3.8. Diplontic life cycle

Isomorphic: Both haploid and diploid phases are similar in external appearance. The haploid thallus produces gametes, while diploid generation after meiosis produces haploid spores, which germinate to form the haploid thallus

Haplodiplontic or Haplobiontic: In this life cycle, both gametophytic and sporophytic phases are equally well presented (Fig. 3.9). It may be isomorphic (gametophyte and sporophyte morphologically similar) or heteromorphic (gametophyte and sporophyte morphologically different) e.g. in *Bartachospermum*.

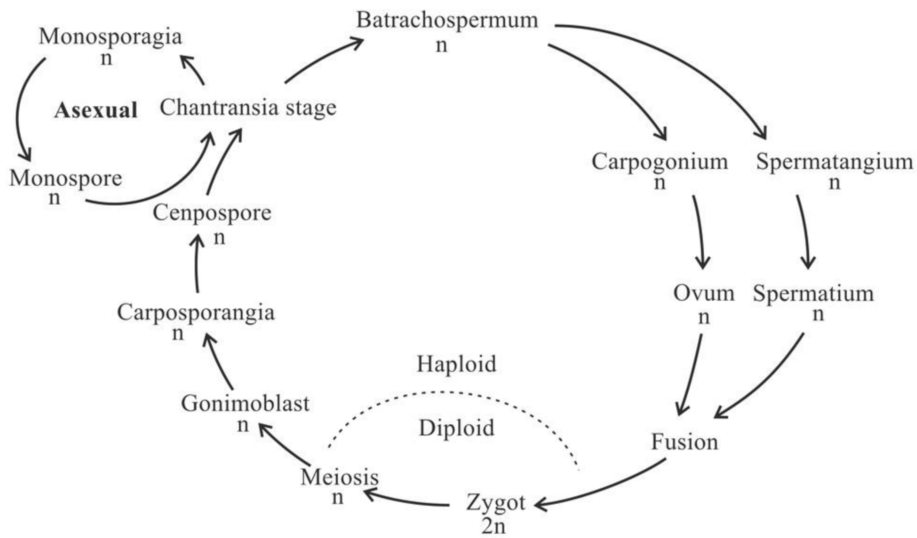

Fig. 3.9: Haplodiplontic (heteromorphic) life cycle of *Batrachospermum*

Diplohaplontic or diplobiontic: Also called as trigenic life cycle. In this one haploid gametophytic phase alternates with two diploid (sporophytic) phases. The sporophytic phase is extended one, e.g. life cycle of polysiphonia (Fig. 3.10).

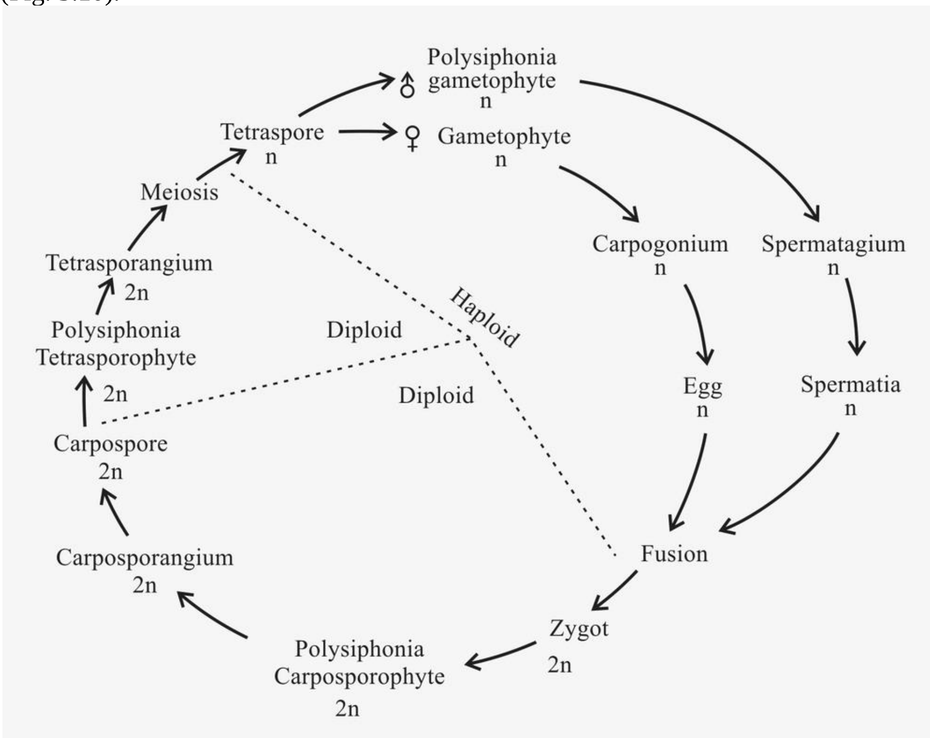

Fig. 3.10. Diplohaplontic life cycle

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Chapter 4
Classification of Algae

From old times the living creatures were placed into two main groups; the plants and animals. The discovery of microscope in 1676 made possible to observe otherwise invisible living creatures, the microbes both in the terrestrial and aquatic environments. With sufficient knowledge of this 'Micro' world, there was a dire urge to classify these organisms.

From the middle of 20th century, many taxonomists noted that certain organisms such as bacteria and fungi differ from plants and animals. To accommodate the bacteria and fungi, third and fourth kingdoms were proposed from time to time, but this was not acceptable to most of the taxonomists. However, in 1960s, drastics changes in the classifications systems were introduced because of the knowledge advanced by using biochemical and electron microscopical techniques. R.H. Whittaker (1969) advanced five kingdom system, which gained a considerable support. The algae were classified accordingly.

4.2 Criteria of algal classification

Algae are perhaps the most widely spread living organisms on this planet, inhabiting a variety of environments and range in size from unicellular to multicellular, and from microscopic to giant kelps. They have a variety of characteristics and are regarded as primary producers performing >90% of photosynthesis. Many phycologists have attempted to classify the algae from old to modern times adopting certain criteria. Following criteria have been adopted in different phycological classification systems (Table 4.1):

4.2.1 Photosynthetic pigments: Their chemical nature and relative abundance
4.2.2 Reserve products: Types of products and their chemistry
4.2.3 Flagellation: Their type, number, insertion and morphology
4.2.4 Nucleus: Presence or absence of true nucleus
4.2.5 Reproduction: Types of reproductive organ and gametes

Table 4.1: Classification of algae described by various phycologists

G.M. Smith (pigments and gross morphology)	**Prescott** (Pigment, flagella, nucleus)	**F.E. Round** (Pigments, gross morphology, nucleus)	**V.J. Chapman** (pigments, flagella, gametes	**R.H. Whittaker** Basic affinities, ultrasstructural biochemical/ details
Cyanophyta i. Myxophyceae	Chlorophyta i. Chlorophyceae ii. Charophyceae	**Prokaryota** Cyanophyta i. Cyanophyceae	**Prokaryota** Cyanophyta i. Cyanophyceae	**Monera** Cyanophyta
Chlorophyta iii. Chlorophyceae iv. Charophyceae	Euglenophyta i. Euglenophyceae	**Eukaryota** Chrysophyta i. Chrysophyceae ii. Bacillario-phyceae i. Xanthophyceae ii. Haptophyceae	**Eukaryota** Rhodophyta i. Rhodophyceae	**Protoctista** Dinoflagellata
Phaeophyta i. Pheaophyceae	Chrysophyta iii. Chrysophyceae iv. Bacillario-phyceae v. Xanthophyceae	Chlorophyta i. Chlorophyceae ii. Oedogoniophy-ceae iii. Brypsidophyceae iv. Conjugatophyceae v. Carophyceae	Chlorophyta i. Chlorophyceae ii. Prasinophy-ceae iii. Charophyceae	Chrysophyta
Rhodophyta i. Rhodophyceae	Pyrrophyta i. Desmophyceae ii. Dinophyceae	Euglenophyta i. Euglenophyceae	Euglenophyta i. Euglenophyceae	Euglenophyta
Euglenophyta ii. Euglenophyceae	Pheaophyta i. Pheapsporae ii. Isogeneratae iii. Heterogeneratae	Pyrrophyta i. Desmophyceae ii. Dinophyceae	Chloromonadophyta i. Chloromonado-phyceae	Cryptophyta

	iv. Cyclosporae			
Pyrrophyta iii. Desmophyceae iv. Dinophyceae	Rhodophyta i. Bangiophycidae ii. Floridophycidae	Cryptophyta i. Cryptophyceae	Xanthophyta i. Xanthophyceae	Xanthophyta
Chrysophyta vi. Chrysophyceae vii. Bacillariophyceae viii. Xanthophyceae	Cryptophyta	Phaeophyta i. Pheaophyceae	Bacillariophyta i. Bacillariophyceae	Eustigmatophyta
	Chloromonadophyta	Rhodophyta i. Rhodophyceae	Chrysophyta i. Chrysophyceae ii. Haptophyceae	Bacillariophyta
	Cyanophyta i. Coccogonae ii. Hormogonae		Phaeophyta i. Pheaophyceae	Pheaophyta
			Pyrrophyta i. Desmohyceae ii. Dinophyceae	Rhodophyta
			Cryptophyta i. Cryptophyceae	Gamophyta
				Chlorophyta

4.3 Algal divisions and their most significant characteristics

With the availability of sophisticated biochemical and electron micrscopical techniques, the algae have been characterized based on their photosynthetic apparatus, type and chemical nature of stored material, nature of cell wall, number, morphology and insertion of flagella and type of habitat where they are found. A comparative account of these characteristics in respect of various algae is given below (Table 4.2).

Table 4.2: Algal divisions and their most significant characteristics

Algal division	**Pigments**	**Reserve material**	**Cell wall characteristics**	**Flagella**
Cyanophyta	Chlorophyll a Phycocyanin Phycoerythrin β carotene Xanthophylls	Cyanophycean granules Polyglucose Polyherdal bodies	α, ε-diamino-pimelic acid Peptidoglycan	Absent
Euglenophyta	Chlorophyll a, b α, β carotene Xanthophylls	Paramylon starch	Absent	1-2 equal, apical
Dinophyta	Chlorophyll a, c Fucoxanthin, Peridinin	Starch, Oil	Cellulosic	Two anterior; one encircles the cell
Chrysophyta	Chlorophyll a, c β -carotene several xanthophylls	Chrysolaminarin Leucosin oil	Cellulosic Silicified	One or more, subapical, heterokont if more than one
Bacillariophyta	Chlorophyll a, c α, β carotene Xanthophylls including diatoxanthin	Chrysolaminarin	Organosilicated Pectic Composed of frustules	One tinsel at male gamete
Xanthophyta	Chlorophyll a, c, β -carotene Xanthophylls in abundance	Glucans, lipids	Cellulosic, Glucoronic acid	One or more, subapical, Stichnematic Heterokont

Chlorophyta	Chlorophyll a, b α, β carotene Several xanthophylls	Starch	Cellulosic, containing xylan and mannans, Calcified in some	1-8, may be equal, whiplash, apical
Charophta	Chlorophyll a, b α, β carotene Several xanthophylls	Starch resembling higher plants	Cellulosic, Glucosepyranoside Calcified in some	Two equal, whilplash
Phaeophyta	Chlorophyll a, c β carotene Xanthophylls including fucoxanthin	Laminarin, Mannitol	Cellulosic Alginic acid Fucoidin	Two equal, laterally inserted, heterokont
Rhodophyta	Chlorophyll a, d R-phycocyanin R-phycoerythrin Xanthophyll	Floridean starch	Cellulose Xylans Galactan	Absent

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Chapter 5
Ecology and Distribution of Algae

Algae are cosmopolitan in distribution, as they are found in aquatic, terrestrial and variety of other habitats. A detailed account of algal distribution based on the various environments is given hereunder.

5.1 Habitats and environments

The algae are mainly confined to the aquatic (both marine and fresh water) environment; the reason why they are called seaweeds. Nevertheless, they are not restricted to one single environment and are distributed everywhere except in sand, desert regions and glaciers. They occur along the banks of canal or on the places where sufficient moisture is available. Sometimes they grow on damp soil, at the surface of snow at high altitudes, bark of trees, forming symbiotic association with fungi (lichens) and on the body of other plants (epiphytic) or animals (epizoic). Based on diverse natures of habitats, occurrence and ecological distribution, the algae have been classified accordingly (Fig. 5.1).

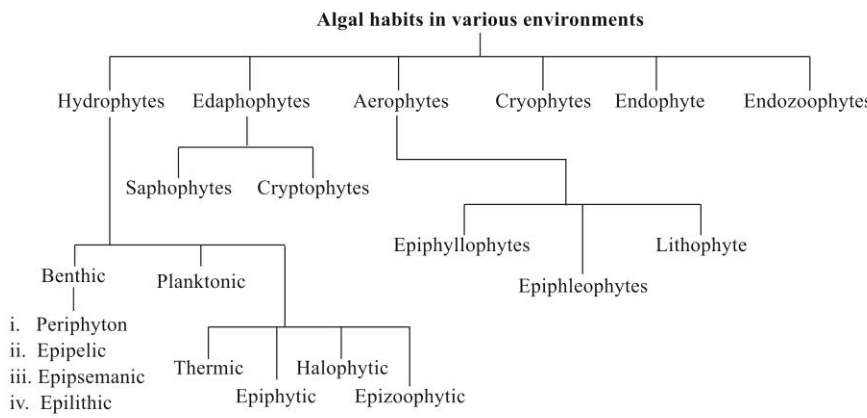

Fig. 5.1. Algal habits based on the environment where they are confined to

5.1.1 Hydrophytes: Aquatic algae are another name given to this class. Algae found as submerged in freshwater or marine environment are grouped as benthic or planktonic based on their attachment to the substratum or as floating habit.

a. Benthic or phytobenthos: They are associated with a submerged substratum, rather than floating on the surface of water. Smaller algae form loose, while larger ones form firm attachment to the substra. The entire thallus may be attached to the substrate, but many species have special structures called holdfast for this purpose. Fresh water benthic forms include *Cladophore*, *Chara*, *Nitella* etc. while marine benthoses are the members of Phaeophyta and Rhodophyta. Based on the nature of substratum for attachment, the algae are further placed into four categories:

- ***i. Periphyton:*** These are the algae which are found attached to the submerged vegetation. They are actually epiphytes and endophytes. When they are attached to the surface of submerged vegetation these are epiphytes, and when these lie within the body of the submerged vegetation are endophytes.
- ***ii. Epipelic:*** These are the algae that are found growing on or in the sediments.
- ***iii. Epilithic:*** These are the algae that grow on the rocks.
- ***iv. Epipsammic:*** These are the algae which are found growing on sand.

b. Planktonic: They comprise of phytoplankton community of a lake or ocean, and float or swim weakly on the surface of water. In order to receive sufficient light for photosynthesis, they remain near the surface of water and show a variety of adaptations for floatation. The fresh water planktonic algae are the members of Cyanophyta, Chlorophyta and Euglenophyta. Marine forms include the members of Cyanophyta, Bacillariophyta and Chlorophyta etc.These planktonic algae are further divided into two types; macroplanktonic and microplanktonic depending on their size. Their size is usually determined by using a fine planktonic net:

- ***i. Macroplanktonic:*** They are large in size and could be caught by a fine plnaktonic net. These algae are greater than 75 µm in size.

ii. ***Microplanktonic:*** These are too small to be caught by a fine planktonic net and are therefore less than 75 µm in size.

5.1.2 **Edaphophytic or terrestrial algae:** They are also referred to as soil algae. They are of great ecological significance as cyanophytes like *Nostoc*, *Anabaena* etc. have atomospheric nitrogen fixing ability and contribute significantly to the soil fertility. Other examples of soil algae are *Vaucheria*, *Botrydium*, *Zygnema*, *Odogonium* and *Osillatoria* etc. The soil algae are further classified as:

a. **Saphophytes:** These are the algae which are found on the surface of soil.

b. **Cryptophytes:** These are the algae which are found deep in the soil. They are present few inches to few feet deep in the soil.

5.1.3 **Aerophytic algae:** These are also known as air algae. They are exposed to high levels of light and must minimize the evaporative water loss. Special resistant stages in their life cycle are important as a survival mechanism under desiccation. They are further placed into 3 categories:

a. **Epiphyllophytes:** These are the algae that grow on the surface of leaves.

b. **Epiphloeophytes:** These are the algae that grow on the bark of the stem.

c. **Lithophytes:** These algae grow on the surface of rocks, which are exposed to air.

5.1.4 **Cryophytic algae:** Also named snow algae, grow in semi-permanent to permanent snow in the alpine or polar mountains and impart attractive colors to them. The optimum growth temperatures for these algae are generally below 10°C. They need to undergo long dormant periods and can show active growth when the snow melts. They have successfully adapted to their harsh environment through the development of a number of adaptive features, which include polyols (sugar alcohols, e.g. glycerin), sugars and lipids (oils), mucilage, motile stages and spore formation. Many snow algae produce a carotenoid, astaxanthin, which shields the cells against light and gives red color. Common examples of the snow algae are:

- *Haematococcus* (Rhodophyte): It gives red color to the mountains in arctic and alpine regions
- *Chlamydomonas* (Chlorophyte): It gives yellow green color to snow in Yellow Stone National Park in America.
- *Raphidonema* (Chlorophyte): It gives green color to some European mountains
- *Cylindrocystis* and *Protoderma* (Phaeophytes): Both these algae give brown colour to snow

5.1.5 **Thermophytic algae:** These are the algae that can grow and sustain in the environments where high temperature prevails. Some algae can tolerate up to 85ºC temperature. These algae have mechanisms for synthesizing specific proteins that do not denature at high temperature. Most thermal algae include the members of blue green algae, a few green algae (Chlorophyta) and some are diatoms (Bacillerophyta). Based on temperature tolerance, the thermophytes are further classified as:

a. **Hypothermae:** They can tolerate the temperature less than 18ºC.

b. **Halirothermae:** They can survive between 18 to 30ºC.

c. **Euthermae:** They are true thermal algae and can tolerate between 30 to 50ºC temperature. Most of the sea weeds fall in this category.

d. **Acrotherame:** They can tolerate the temperature from 50 up to 70ºC.

e. **Hyperthermae:** They can grow in the temperature above 70ºC and up to 85ºC.

5.1.6 **Marine algae:** Certain algae inhabit water with high percentage of salts in the sea and are therefore referred to as marine algae. For example, *Dunaliella*, *Chlamydomonas* and *Ulothrix* are reported to survive in such waters. Marine algae range in size from microscopic individual cells to huge protists more than 100 feet long. Distribution patterns within algal assemblages are dictated by tidal exposure and wave impact, as well as by species interactions such as grazing by invertebrates and competition for space and light. Common marine algae of the high intertidal include Turkish towel, *Mastocarpus papillatus*, and rockweed, *Fucus distichus*. Common in the middle and lower intertidal are sea lettuce, *Ulva* spp.; feather boa kelp, *Egregia menziesii*; dead man's fingers, *Codium fragile*; and the iridescent, rubbery *Iridaea* species. Kelp forests, found in subtidal waters as deep as 100-200 feet, are a unique ecosystem largely restricted to the west coast of the Americas, and best represented in California's coastal waters. Giant Kelp, *Macrocystis pyrifera*, and bull kelp, *Nereocystis luetkeana*, are the largest known brown algae. Their blades are harvested for industrially valuable gels, called alginates. The multi-layered canopy of kelp fronds provides a complex aquatic habitat for thousands of fishes and invertebrates.

5.1.7 **Epiphytes:** Some algae grow or attach themselves on the surface of other plants or animals. In fact they have no nutritional relationships with their hosts; rather they seek attachment support only. For example a few species of *Oedogonium* and *Ulothrix* grow on other larger algae. Some important epiphytic algae and their hosts are: *Coleochaete* on *Chara* and *Nitella*; *Chaetophora* on *Nelumbo*; *Oedogonium* on *Hydrilla*.

Similarly, some algae can grow on the body of animals and are referred to as epizoophytes e.g. *Cladophora* can grow on the body of snail.

5.1.8 Endophytes: Some algal species grow within or between the cells of the host plants are called endophytes, and those of animals are called endozoophytes. For example *Anabena,* a cyanophyte, is present in the mesophyll tissues of *Azolla,* a ptrediophyte, which is commonly present in rice fields. These algae are used for nitrogen fixation. Some algal species present in the roots of *Cycus*, while *Nostoc* grows in the thallus of *Anthocerose,* a bryophyte.

Likewise, some algae live within the body of animals. These algae are beneficial to their hosts in supplying the products of photosynthesis. Some animals like flatworm sometimes become habitual of not living without their algal counterparts. Chlorella has been found to live within the body of different animals including *Paramecium*, *Hydra*, mollusks and some freshwater sponges.

5.2 Occurrence of algae in aquatic environments

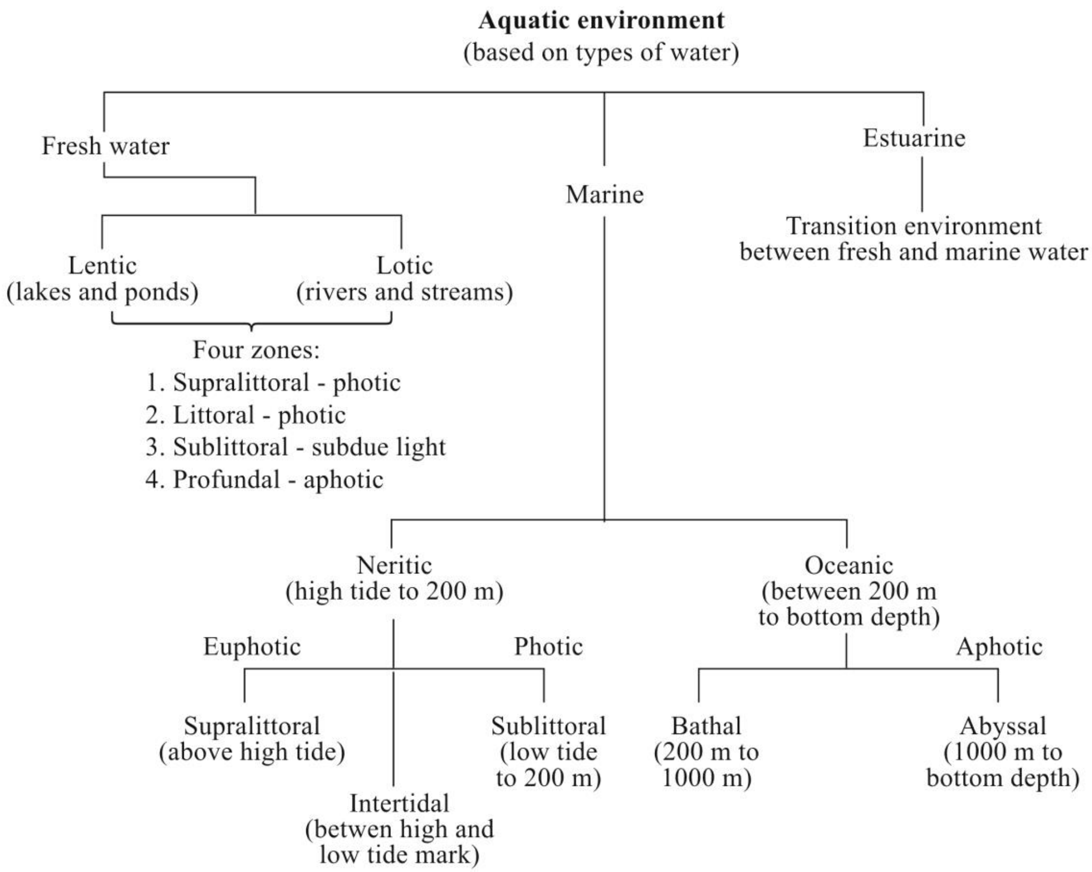

Fig. 5.2: Distribution of algae in various aquatic environments

The algae are mostly confined to the aquatic environment and those inhabiting other than aquatic are few in number. Depending upon the characteristics of water, the aquatic environment is further classified into three kinds i.e. freshwater, marine and estuarine (Fig. 5.2).

5.2.1 Fresh water environment: Two types of communities are present in this environment, where the algae are found.

a. Lentic communities: These communities include lakes and ponds. In both these, the water is in the photic zone and benthic algae may grow up to the bottom. In ponds, since the water is standing, calm or seldom show wave motion, the floating mats of green or blue green algae quite often develop on the surface of water. Examples of mat forming algae include *Spirogyra*, *Pithophora*, *Oedogonium*, *Oscillatoria*, *Lynsbya* etc. In lakes, the benthic algae are confined to shallow areas but within the photic zone. With the passage of time the lakes become enriched with algal flora and some of the algae become attached to the bottom, where light becomes subdue for photosynthesis.

b. **Lotic communities:** They include flowing water i.e. rivers and streams. The flow of water provides a more open system for the growth of algae than lakes and ponds. Streams are shallower than rivers and show slow water flow. The flow in streams is dependent on the seasonal precipitation and melting of snow. In contrast, the rivers are deeper than streams and show much slower flow of water. As the bottom of the rivers has sediments in the form of silt and mud, the algae may not be found here due to non-availability of sufficient light for photosynthesis. In both streams and rivers, the physical factors such as light, temperature and rate of water flow are important in determining the algal growth.

Based on the population of algae and availability of light, water in both the lentic and lotic communities are divided into the following zones (Fig. 5.2):

i. ***Supralittoral zone:*** The word supralittoral mean above the high tides. This zone is above the edges of standing water, and algae are exposed to wave action during windy season. This is highly photic zone because maximum light is available here.

ii. ***Littoral zone:*** This zone extends from the water surface and vertically deep up to six meters. This is the most productive zone as most of the seaweeds are present here. This is because ample amount of light is available for photosynthesis by algae.

iii. ***Sublittoral zone:*** In this zone the photosynthesis performed by algae is usually equal to the respiration and is therefore called the compensation zone. Here the light penetration is subdued for photosynthesis. This zone extends beneath littoral zone up to 200 meter deep. Few algae may be found here.

iv. ***Profendal zone:*** This zone extends beneath the sublittoral zone to the bottom depth. Here no light is available so it is essentially aphotic zone. So no algae are found here

5.2.2 Marine environment: Marine environment is further subdivided into two basic regions based on the availability of light (Fig. 5.3).

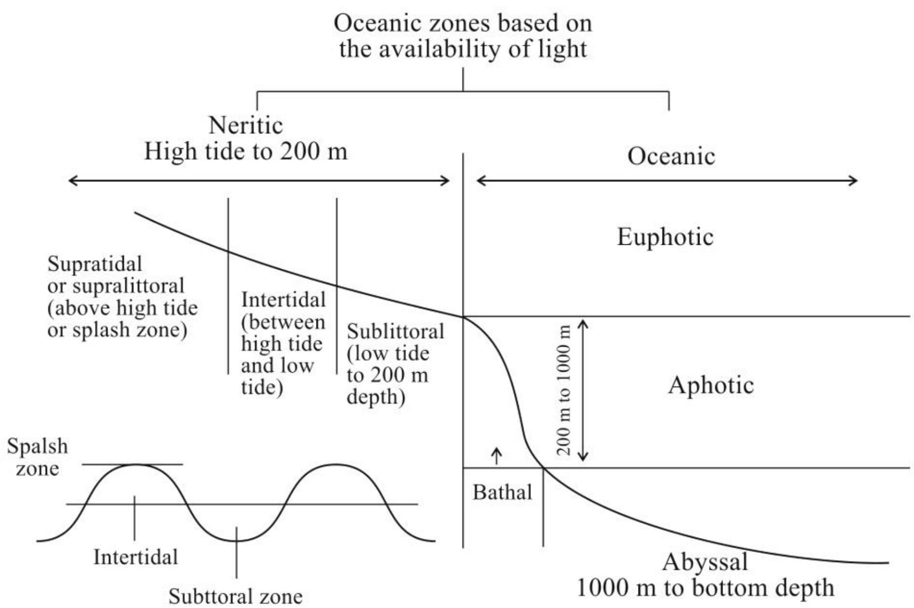

Fig. 5.3. Various zones in the sea depending upon the availability of light

a. **Neritic region:** It starts from high tide mark to 200 meter deep in the sea. It is photic zone and is therefore the center of photosynthetic activities in the sea. It is further divided into three zones:

i. ***Supralittoral zone:*** This is also known as splash zone. This starts above the high tide mark and receives splashes of water from the waves. It is also called euphotic zone. It means excess of light is available for photosynthesis in this zone. The algal flora in this zone includes mostly Cyanophyta (subset in Fig. 5.3)

ii. ***Intertidal zone:*** This zone is between high and low tide mark of strong tides during spring. This is also photic zone. If there are rocks in this zone the algae may be present in abundance. If there is sand in this zone then only few algae may be found.

   iii. ***Sublittoral zone:*** This zone extends from lowest tide mark up to a depth of 200 meters. Subdeu light is present here for photosynthesis. Mainly red and brown algae are found in this zone.

b. Oceanic region: This region starts beneath the neritic region and extends up to the bottom depth of the sea. Oceanic region is essentially aphotic because light can not penetrate below 200 meters depth in water. This region is subdivided into two zones:

   i. ***Bathal zone:*** It extends between 200 to 1000 meters depth of sea. No light is available and seaweeds are seldom found here

   ii. ***Abyssal zone:*** This zone extends beyond 1000 meters up to bottom depth. Essentially no light is available and no algae are found in this zone

5.2.3 Estuarine environment: The word estuarine is derived from "Estuary", which means "semi closed coastal body of water having free connections with open sea". Here fresh water mixes with marine water, so forming transitional environment between fresh and sea water. So the fresh water algae found in this environment have greater tolerance to salinity and temperature fluctuations than fresh water environment. This environment may have few multicellular algae, because of muddy bottoms and variations of temperature and salinity in this environment.

5.3 Factors affecting the distribution of algae

There are three main factors that influence the distribution of algae (Fig. 5.4).

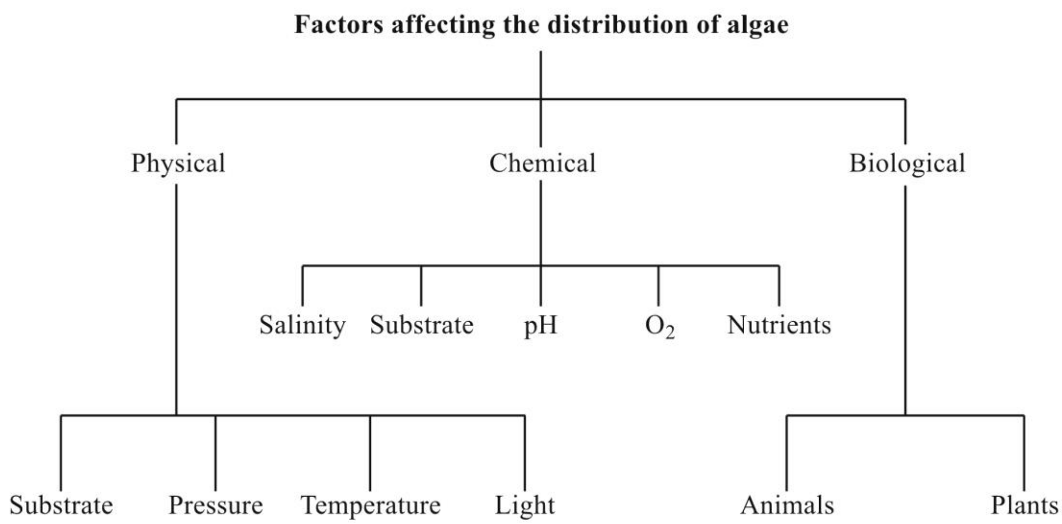

Fig. 5.4. Various factors affecting the distribution of algae

5.3.1 Physical factors: There are four important physical factors:

a. Substrate: Substrate whether solid rock, boulder, pebbles, sand, mud or peat is of basic importance in anchorage and general distribution of algal flora. On the rocky coasts, the angle of slope and the presence of cracks in the rocks may affect the local occurrence of any species. Similarly, the geological nature of rocks may also be important. For example soft rocks or sand may rarely carry any algae.

b. Pressure: This determines the lower limit to which any species will go deep in water. The algae have gas vesicles in them, which present a floatation mechanism and keep the algae near the surface of water. This is brought about by the pressure of gas inside the vesicle or bladder. Shape of the bladder appears to be related to water depth for any algae. The deep dwellers have spherical and shallow ones have pear shaped bladders. During the day due to production of oxygen the pressure in the bladder increases and algae tend to come on the upper surface while during night this pressure decreases and the algae go deep in water.

c. Temperature: This is a modifying factor for algae in the following ways:

   i. ***Seasonal migration:*** It brings about seasonal migration and is therefore a modifying factor. Species may be abundant in the region where temperature is favorable for their growth during any periods of the year.

ii. ***Changes in physiology:*** The rate of photosynthesis and respiration is much dependent upon temperature. Both the processes increase to certain limits of temperature and vice versa.

iii. ***Reproduction:*** Variations in temperature also effects the production of gametes and their fertilization. In Phaeophyta, for example, the formation of gametes and their fertilization is optimum at 2-6ºC and rarely above 16ºC. This, however, depends upon the class of algae and prevailing temperature.

d. **Illumination:** Changes in light affect the algal distribution in many ways. Following are the important characteristics of light in this respect:

i. ***Quality of light:*** Quality or color of light greatly determines the photosynthetic rate in the algae. The hypothesis that "the color of algae (type of pigments present in algae) is complementary to the incident light" is of great significance. Following examples provide explanation for this:

- In Chlorophyta the light absorbing pigments are green (chlorophyll and carotenoids) the absorption and maximum rate of photosynthesis occurs in red and blue regions of the light spectrum. In sea water, red and much of the blue regions are rapidly eliminated. So the chlorophytes found at any depth would be expected to have a very low rate of photosynthesis.
- In brown algae, generally there is increased absorption in the green region due to the presence of fucoxanthin. As this carotenoid, unlike nearly all others, has a very high efficiency (about 100%) of the absorbed energy transfer to photosystem, there is consequently a much increased rate of photosynthesis relative to that in the blue or red region. Consequently, for phaeophytes living at any depth where the light spectrum is predominantly green, photosynthesis is not limited.
- In the Rhodophyta, the phycobiliproteins are of pinkish color and absorb light in green-yellow region. The phycobiliproteins transfer their absorbed energy to the chlorophyll so that light not predominantly absorbed by the chlorophyll is utilized in photosynthesis.

ii. ***Quantity of light:*** With increasing depth of water, the quantity of light available for photosynthesis reduces. Algae living in supralittoral or littoral zones show different photosynthetic responses than those found in sublittoral zone. For example, many of the deep growing algae are fully light saturated at quite low amount of available light ($1/10^{th}$ of full sunlight). The incident light is cut down considerably even at a depth of one meter, while at two meter depth only 25% of the surface light can penetrate. Similarly, the turbidity of water also affects the rate of photosynthesis and the light compensation point.

5.3.2 Chemical factors: Five different chemical factors are important for algae:

a. **Salinity:** Marine environment is highly saline where most of the algae are found. However, sometimes fresh water also becomes saline due to certain factors. Hence the salinity may be a severe factor for algae:

i. In estuarine environment the fresh water runs into the marine water. In these places Rhodophyta and Phaeophyta tend to be replaced by Chlorophyta.

ii. In large bodies of fresh water, due to considerable evaporation, dissolved salts concentrate and cause a state of salinity. In such environments, the intertidal algae show a greater tolerance to changes in salinity than the sublittoral ones. In marine environment the algae are grouped into the following for their response to salinity:

- <u>Sublittoral algae:</u> They are never exposed to air and show relatively less resistance to salinity. They can resist the concentration of 1.4 times greater than seawater.
- <u>Lower littoral-tide algae:</u> They are sometimes exposed to air and are resistant to a concentration 2.2 times higher than seawater.
- <u>Tidal algae:</u> They are often completely exposed to air and can therefore resist a concentration of salts 3 times greater than that of seawater.

b. **Chemical nature of substrate:** The chemical composition of substrate generally has a little effect on the distribution of algae. Only exception is the presence of chalk. The algal flora on chalk cliffs differs distinctly from that of metamorphic and igneous rocks.

c. **pH:** pH is not a factor of great importance. The reason is that pH of seawater ranges from 7.9 to 8.3 and most of the algae can tolerate a pH range of 6.9 to 9.6. Moreover, the pH of pools is rarely more than 9.6.

d. **Oxygen**: The oxygen level in seawater is normally low, but is sufficient for all metabolic processes. In pools during the day, the oxygen level may rise sharply due to photosynthesis by the pool flora.

e. Nutrients: This factor controls the seasonal periodicity of marine and fresh water collections. High nutrient content reflects good vegetation. For example, the pools well supplied with bird droppings commonly show a very rich flora of microscopic algae.

5.3.2 Biological factors: The biological factors include the animal or plant factors.

a. Animal factor: Competition between plants and animals may lead to severe elimination of algae. For example *Patella* (an animal) may drastically affect the establishment of *Fucus* (algae). On salt marshes, the mollusk *Hydrobia ulvae* can cause disastrous effect on the *Ulva* population. Similarly, removal of *Echinus esculentus* from the medium results in increased density of *Laminaria* sp. from 5.1 to 22.7 $meter^{-2}$.

b. Plant factor: Two types of relationships exist between algae and other plants.

i. Host parasite relationships: *Fucus* sporlings (not fully developed spores) seem to depend upon the green algal felts, while the establishment of red alga *Porphyra* sporlings is dependent upon the development of diatoms films.

ii. Host Epiphyte relationships: Certain algal species may be found attached to specific parts of large host plants. When attached to stem are called epicaulic and when present on leaves are called epiphyllic.

5.4 Ecophysiology of algae

Although algae are prone to adverse ecological factors, the changes in the nutritional status of the media, photosynthesis and pollutants are of great ecophysiological significance:

5.4.1 Nutrients: For optimum growth to occur, the seaweeds require the essential nutrients in adequate amounts as do the higher plants. Generally the nutrients uptake and their utilization are influenced by irradiance, temperature, water motion, desiccation and age of the algae. The most growth liming nutrients for algae are the combined source of nitrogen. Of the two, ammonium is more important because its uptake rate is greater than nitrate. This is due to the reason that ammonium can be directly used in the synthesis of amino acids, while the nitrate may be stored in the vacuole and must have to be converted into nitrite, ammonium and amino acids before being incorporated into the proteins. For this purpose, determination of nitrate reductase activity has sometimes been used as index of the ability of the algae to assimilate nitrates. A recent approach is the assessment of expression of genes that encode nitrate reductase components.

Phosphorus can limit the growth of microalgae especially during rapid growth periods. Some algae are capable of supplementing their phosphorus requirements by breaking the phosphorus-containing organic compounds. The phosphorus is released from these compounds extracellularly with the activity of alkaline phosphatase, the production of which is induced by phorphorus deficiency. Accordingly, the assay of alkaline phosphatase has been used as the indicator of the degree of phosphorus limitation experienced by the algae. Other important ion is the bicarbonate which is present in sufficient amount in the seawater. Survey on the assimilation of bicarbonates revealed that six species of Chlorophyta, 12 of Phaeophyta and 6 of Rhodophyta were obligate bicarbonate users. Silica is of absolute requirement for diatoms, Chrysophyta and Xanthophyta. Both fresh and marine water have similar amounts of silica, which is sufficient to support the growth of silica-assimilating algae. However, it sometimes becomes limiting factor, when the diatoms are undergoing active cell division and frustule formation. The silica is recycled in nature with the death and decay of diatomes

Sulfur is required by the algae for the biosynthesis of two sulfur-containing amino acids, cysteine and methionine and sulfur containing lipid in the thylakoid membranes. Uptake of sulfur is an energy dependent process in plants including algae. In marine waters, the sulfate is sufficient and hence it is not a growth limiting factor. However, in fresh water communities, the sulfur reducing bacteria convert sulfate to the H_2S, thus rendering the sulfur as a growth limiting factor in these communities. Some phytoplanktons generate a large amount of dimethylsulfonioproprionate (DMSP) for use in osmoregulation, from its metabolic precursor methionine. The DMSP can be converted to volatile dimethyl sulfide, which is released from the cells and oxidized to DMSO in the atmosphere to form sulfate aerosols. So DMS emission reflects the seasonal pattern of phytoplanktons growth. Studies have revealed that most DMS is released when the algae disintegrate.

5.4.2 Photosynthesis and photo-oxidative damage: Algae are the primary producers in the natural ecosystems for many animals in a variety of habitats, accounting for >90% of the photosynthesis on earth. So the sustained rate of photosynthesis is of great significance in these organisms. Algae range from multicellular forms like kelps to microscopic, single-celled organisms. Although they are not as complex as land plants, photosynthesis takes place in the similar way. Light is absorbed by chlorophyll, although various accessory pigments give them a wide variety of colors, located inside chloroplasts. All algae produce oxygen, and many are autotrophic. However, some are heterotrophic, relying on materials produced by other organisms. Photosynthetic bacteria do not have chloroplasts; instead photosynthesis takes place directly within the cell. The cyanobacteria contain chlorophyll and oxygen, in the same way as chloroplasts do. In fact chloroplasts are now considered to have developed from them. The other photosynthetic bacteria have a variety of different pigments, called bacteriochlorophylls, and do not produce oxygen.

Eukaryotic algae are important photosynthetic organisms and highly responsive to changes in their environment, especially differences in incident light. In unfavorable conditions, algae and plants often absorb more light energy than they are capable of using for photosynthesis. This excessive light can cause photo-oxidative damage (bleaching) and loss of photosynthetic efficiency. Photosynthetic organisms have evolved multiple mechanisms to dissipate excessive light. In all photosynthetic organisms, xanthophylls have an essential role in protection from oxidative damage. *Chlamydomonas* xanthophyll mutants have been exploited to analyze photoprotective processes related to singlet oxygen production in the photosystem II light-harvesting antenna.

A major process involved in controlling photosynthesis in excessive light is the downregulation of photosystem II activity by pH- and xanthophyll-dependent dissipation of excess absorbed light energy as heat, measured as nonphotochemical quenching of chlorophyll fluorescence (NPQ). An insight into the molecular mechanism of NPQ by isolating *npq* mutants of *Arabidopsis thaliana* and characterization of a subset of these mutants has contributed to our knowledge of the role of xanthophyll pigments in NPQ. Other npq mutants identify components besides the xanthophylls that are critical for NPQ, and the resources of the *Arabidopsis* genome project are being used to facilitate the isolation of the genes affected in these mutants and their application to algae.

5.4.3 Pollution: In water bodies, extra fertilizer means extra algae and aquatic plant growth. Too much algae harm water quality and makes boating, fishing and swimming unpleasant. As algae decay they use up oxygen in the water that fish and other wildlife need. The elements phosphorus and nitrogen are necessary for plant growth, and are plentiful in untreated waste water. Added to lakes and streams, they cause nuisance by excessive growth of aquatic weeds, as well as "blooms" of algae (microscopic protoctists). This can cause several problems. Algae and weeds die and become biodegradable material. If this water is processed as drinking water source, algae can clog filters and impart unpleasant tastes and odors to the finished water. Blue-green algae and some species of diatoms quite often cause taste and odor problems in water. In addition, algal blooms can interfere with coagulation, be persistent in the distribution system, and modify the pH, color and turbidity of the source water. With time and experience operators can identify a biological problem caused by algae and treat accordingly.

Eutrophication is a pollution problem that causes runaway algae growth and throws entire ecosystems in whack. In different parts of the world, it is getting worse and continues to escalate. This includes an overload of nutrients, notably nitrogen, that are crucial in small quantities and deadly in large ones. Nitrogen washes into the estuary off fertilized lawns and farms, pours out of sewage discharge pipes and falls in rain that is laced with power-plant emissions. Then it fuels runaway growth of certain plants.

Massive algae blooms cloud the water, and sometimes coat the surface with a thick, smelly slime. They blot out the sun, stressing sea grass beds and the creatures that depend on them. Other large algae grow in the bottom, choking the sea grass from below. When the algae die, it sucks oxygen out of the water. Eutrophication is the culprit behind brown tides, a type of phytoplankton bloom that is harmful to sea life and has become commonplace in the estuary in the past 20 years. Eutrophication may also have caused the rapid rise of the sea nettle, a stinging jellyfish that lives off phytoplankton and has appeared in increasingly large numbers in Barnegat Bay in recent years.

Suggested readings

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Chapter 6
Detailed Account of Various Phyla of Algae

6.1 Cyanophyta
(Blue Green Algae)

Cyanophyta are prokaryotic algae due to the presence of photosynthetic apparatus. They perform photosynthesis by means of characteristic pigments which give blue green color to the members. Blue green algae are ubiquitous in distribution. When terrestrial, they generally grow near water, but have the ability to tolerate considerable desiccation for long periods by the formation of akinetes. Some species live in hot springs and others in banks of snow. When aquatic, the gas vacuole allows cyanophytic cells to survive in two distinctly different environments. When gas vacuoles are missing or empty, they sink in the water column to the bottom and sometimes even attach to the substratum. Such bottom-dwelling cyanophytes are termed benthic. Species with functional gas vacuoles are often pelagic or planktonic and allows these forms to maintain a favorable position in the water column. Planktonic cyanophytes are often unicellular and very small in cell size. These vacuoles facilitate buoyancy in the absence of flagella. It is estimated that 20% of the photosynthetic production in the ocean is accomplished by planktonic cyanobacteria.

6.1.1 Classification: The division cyanophyta has been placed into a single class Cyanophyceae and two subclasses i.e. Chroocophyceae and Nostocophyceae. Both have the following characteristics and taxonomic details:

- **A. CHROOCOPHYCEAE:** Subclass coccogony comprises of Cyanophytic algae which are coccoid in habit. The subclass has 3 orders.
  - **a. Chroococcales:** Members are coccoid and reproduces by binary fission.
  - **b. Chamaesiphonales:** Members are coccoid that reproduced by releasing exospores, the exospores are thick walled and are reproduced from the protoplast of the cell. The organisms release the exospores but do not get disintegrated. The spores may not be resistant to heat or dessication.
  - **c. Pleurocapsales:** The members have coccoid habit and reproduced by forming endospores. The endospores are thin walled and reproduced within the parent organism. The parent cell disintegrates after the production of endospores.
- **B. NOSTOCOPHYCEAE:** This subclass includes forms which are filamentous in habit. The filaments contain as many as dozens of cells, which break off, glide away and begins new growth. These fragmentated filaments are called hormogonia. The subclass has two orders:
  - **a. Nostocales:** The filaments either do not branch or show false branching. A branch is not formed by a single growing cell but is formed by a row of different cells
  - **b. Stigonematales:** The members of this order exhibit true branching. A single cell may have two sites of growth on it form where the filaments originate

  The division Cyanophyta has 18 families and 29 genera.

6.1.2 Cell structure (for detailed cell structure see Fig. 3.1).

- **a. Cell wall:** The cell wall is a four-layered structure (Fig. 6.1.1). An apparently soft inner layer faces the cell membrane. The second layer is the rigid layer composed of murein. Murein is a peptidoglycan: peptides attached to a polysaccharide made of alternating N-acetylglucosamine and N-acetylmuramic acid. Soft two outer layers are made of lipopolysaccharides.

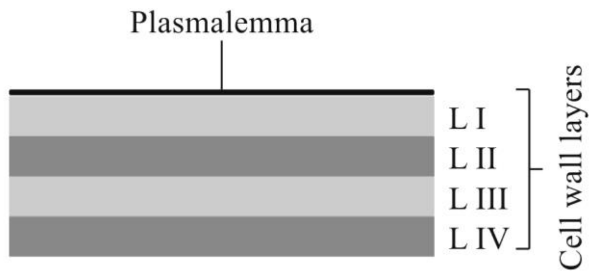

Fig. 6.1.1: Four layered wall structure of cyanophcean cells

b. Sheath of cell wall: Majority of Cyanophyta have a fibrillar mucilaginous sheath outside the cell wall. The sheath has three layers; outer, inner and middle. The outer and inner layers are composed of long fibers and middle layer is composed of disorganized fibrils, In Nostoc, the sheath fibrils are reticulate, while in Anabaena, the fibrils are oriented parallel to each other and perpendicular to the cell surface. (Fig. 6.1.2)

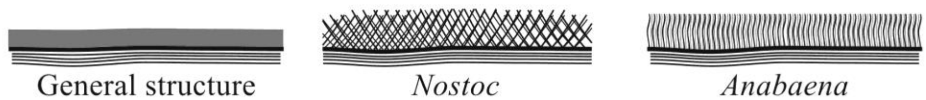

Fig. 6.1.2. Structure of the cell wall sheath in cyanophytes

c. Cell membrane: This is not fundamentally much different from those of eukaryotes. It appears as a three-layered structure under the electron microscope. The outer and inner layers are made of extrinsic and hydrophilic extensions of intrinsic proteins. Middle layer is a phospholipid or glycosylglyceride bilayer traversed by the hydrophobic portions of intrinsic membrane proteins.

The cell membrane invaginates to create a space between the cell membrane and the cell wall called as the "**Mesosomes**". The mesosomes are of great evolutionary importance. These areas of the cell membrane are rich in proteins and involved in electron transfers. During evolution, these proteins developed a mechanism to pump protons (H^+) into the space between the membrane and wall. The gradient of H^+ could then be collapsed back toward the cytosol by passing them through a membrane-bound ATP synthase. This permitted the evolution of the electron transport system required for the light reactions of photosynthesis (photophosphorylation) and later for aerobic respiration (oxidative phosphorylation).

d. Photosynthetic apparatus and pigments: Early in the evolution of blue green algae, the invaginations of the cell membrane formed thylakoid membranes, which are packed in layers around the cell just inside the cell wall. The thylakoid membranes have the electron transport system needed for the light reactions of photosynthesis. This includes the important reaction center, primary pigment, chlorophyll a and accessory pigments including zeaxanthin, B-carotene, echinenone, canthaxanthin, and myxoxanthophyll that are attached to its membrane-bound proteins. These pigments harvest light of a broader range of wavelengths. Attached to the cytosolic face of the thylakoids are particles called as phycobilisomes. They serve as a light-energy antenna for photosynthesis. The phycobilisomes contain phycobiliproteins that consist of a cluster of pigments including phycocyanin (blue) and phycoerythrin (red). Phycobilisomes funnel light energy to photosystem II for the splitting of water and generation of oxygen, which is an evolutionary characteristic of cyanophytes.

e. Color of cyanophytes: The relative abundance of phycobilin pigments explains the color of cyanobacteria. Microscopically, the phycocyanin (blue) pigment in combination with the chlorophyll-a and the accessory pigments lead to a bluish-green color–hence the common name blue-green algae. Moreover, different species of cyanobacteria have differing ratios of phyocyanin and phycoerythrin that gives variegated color to the members. Certain cyanophytes give thermal springs and geyser pools some beautiful color patterns from red to purple and the complete visible spectrum of colors. Terrestrial blooms produce a gooey slime that is blackish in color. However, the ratio of phycocyanin and phycoerythrin can be environmentally altered. Cyanobacteria grown in green light typically develop more phycoerythrin and become red and those grown in red light become bluish-green. This reciprocal change in color has been named chromatic adaptation.

f. **Cytoplasmic inclusions:** Following are some of the important cell structures other than those given above.

   i. ***Nucleoplasm:*** It is the central region of the cyanophycean and cell is less colorful than the peripheral outer region because there are no thylakoids. This region contains the genetic material and, therefore, referred to as nucleoid or nucleoplasm, but should not be confused with a true nucleus. There is no nuclear envelope and no true nucleus in any blue green algae; all species are strictly prokaryotic. In addition, it has all the protein synthesis machinery and other structures for the functions of the cell. This region features the naked (no histone proteins) circular DNA genome. Upon exposure to chromosome stains, stained bodies appear in this region of the cell. These have been interpreted as chromosomes. Indeed cyanophytes are host to a range of small, circular DNA molecules called plasmids.

   ii. ***Ribosomes:*** The transcription and translation in Cyanophyta is identical to that in other Eubacteria. The translation process is accomplished by the assistance of abundant 70S ribosomes in the centroplasm. These are smaller than their counterparts in the eukaryotic cytoplasm, but are typical of all prokaryotes, mitochondria and chloroplasts. They provide an essential piece of the evidence for the endosymbiont theory of eukaryotic evolution.

   iii. ***Storage products:*** As a result of translation by the ribosomes and other cellular metabolism, some structures to store the products are formed. Of these **polyhedral bodies** mainly include the carbon fixation enzyme, Rubisco, which is produced in sufficient abundance. These are usually found closer to the chromatoplasm. **Cyanophycean granules** are another interesting protein that accumulates in abundance to form a visible granular structure. These granules are large enough (500 nm) to be observed sometimes with light microscopy. This protein is a polymer composed of just two amino acids: arginine and asparagine. These granules are considered to be an adaptation for accumulating and sequestering nitrogen for future use. This explains why these organisms can often grow nicely in areas with nitrogen-depleted waters. **Polyphosphate granules** are other products that accumulates to form granules is highly polymerized phosphate $H_2O_2PO\text{-}[PHO_2\text{-}]_n\text{-}PO_2H_2$, carried out by ribosome-translated enzymes, represents a storage material for phosphates. These granules are considered an adaptation for accumulating and sequestering phosphate for future use. Again, this explains why cyanobacteria can often grow nicely in areas with phosphate-depleted waters. **Lipid droplets** are usually found in the chromatoplasm and perhaps the lipids are produced by processes catalyzed by reactions in the cytosol between the thylakoids. The enzymes for lipid synthesis are translated by ribosomes nearer the chromatoplasm.

   iv. ***Gas vesicles:*** A most-interesting translation product is the protein layer that surrounds gas vesicles. These structures are not membrane-bound, but instead consist of laterally-connected cylindrical tubes of protein that are permeable to gas but not to water. As dissolved gas accumulates in the cytosol, some of it equilibrates inside the tubes and collects as a bubble of free gas. Not surprisingly, the change in refractive index of the accumulating bubble makes gas vacuoles quite visible in the light microscope. They appear as gray bodies in the central region. Gas vacuoles are involved with cell buoyancy. As gas accumulates, the cell moves up in the water column and sinks down when the gas is used. A reverse situation may occur with cyanophycean starch grains as ballast. These two systems for buoyancy may cooperate to allow the cell to position optimally in the water column for its photosynthesis or nutrient uptake processes.

6.1.3 Thallus structure: Two types of thalli are found in Cyanophyta

a. **Non-filamentous thalli:** Non-filamentous forms include either palmelloid or coccoid colonies. In a colony, the cells may be arranged in a definite fashion e.g. *Gleocapsa* or may be irregularly arranged e.g. *Microcystis* (Fig. 6.1.3).

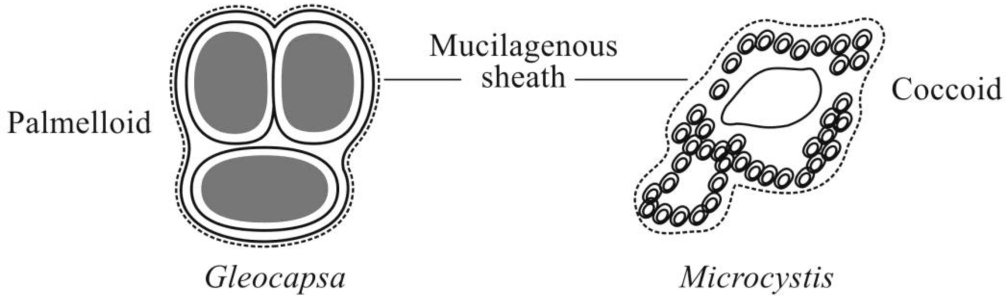

Fig. 6.1.3. Non-filamentous habits in cyanophytes

b. Filamentous thalli: Simplest filamentous form is the **trichome** of *Oscillatoria*, where each filament consists of a long series of cells placed end to end. A trichome is a filament without a mucilaginous sheath. A **filament** is an individual trichome enclosed by a mucilaginous sheath. The filaments may show branching, which is of two types. In ***Pseudobranching*** the branch does not arise from the filament rather it is branch-like arrangement of cells. In ***True branching*** the branch emerging from any filament and results in the formation of any other filament after fragmentation. Branching of filaments is the most complex thallus in cyanophyta. The branching is of two types: **uniseriate** i.e. a branch composed of single row of cells and **multiseriate** i.e. a branch composed of more than one row of cells (Fig. 6.1.4).

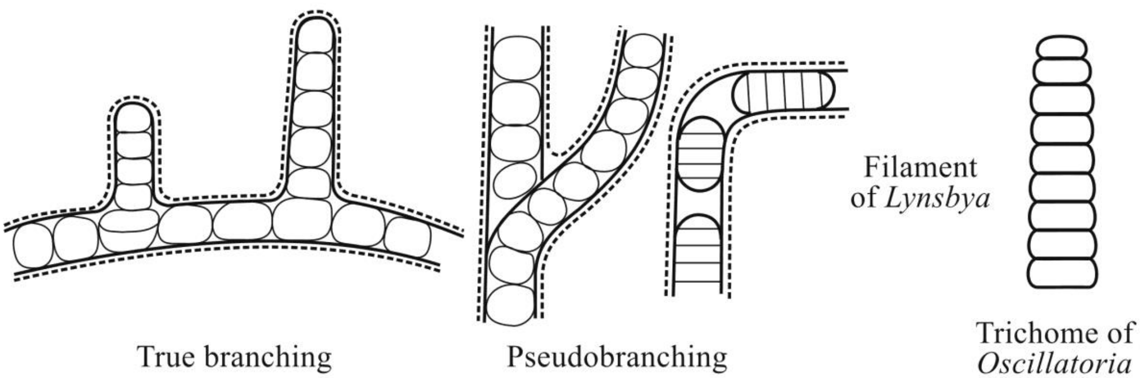

Fig. 6.1.4. Filamentous habits in cyanophytes

6.1.4 Reproduction: Reproduction in Cyanophytes takes place mainly by vegetative means or production of asexual spores, but there is hardly any evidence of sexual reproduction. A detailed account of reproduction is given underneath:

a. Vegetative propagation: This is by the binary fission, fragmentation and hormogones:

i. Binary fission: Most unicellular cyanophytes divide in this way. In binary fission the cell divides into two equal parts by formation of a septum from periphery to the central region, thus dividing the cell into two. Nuclear material divides simultaneously. Each part develops into a new individual

ii. Fragmentation: The colonial, non-filamentous or trichomatous algae divide by breaking into smaller fragments. Each fragment divides repeatedly and full new colony is formed e.g. *Microcystis*. The trichomes of certain forms also fragment to form a new trichome

iii. Hormogones: These are the short pieces of trichomes or filaments that become detached from the parent thalli, glide away, divide repeatedly and eventually form new thalli. The formation of hormogones is only reported in the members of orders Nostocales and Sigonematales

b. Asexual reproduction: This involves the production of asexual spores:

- ***i. Endospores:*** These are formed by the internal division of the protoplast. The vegetative cell called sporangium increases in size and protoplast undergoes division to form endospores. Initially the endospores lack cell wall but by and large the cell wall developes. After germination they form a new individual
- ***ii. Exospores:*** These are formed from one portion of the sporangium by transverse division. On liberation, they are surrounded by a membrane and later on develop a thick wall. After germination they form a new individual
- ***iii. Nannospores:*** These are formed by very fast division of the parent cell. They remain smaller than other cells or spores. They germinate *in situ* to form new colonies
- ***iv. Akinetes:*** In several filamentous blue green algae, certain vegetative cells accumulate food, enlarge in size, turn yellow or dark brown in color and develop thick walls–called akinetes. Akinetes can withstand adverse environmental conditions. They contain cyanophycean granules and other protoplasmic structures remain intact. Under favorable conditions, they loose thick wall, germinate and form a new thallus
- ***v. Heterocysts:*** These are specialized cells which are larger than the normal vegetative cells and appear empty under light microscope. The heterocysts may be terminal or intercalary in a filament. They are formed from the vegetative cells by dissolution of storage granules, the deposition of multilayered envelop outside the cell wall, the breakdown of thylakoids and formation of new membranous structures. The frequency of heterocysts is affected by the concentration of molybdenum and combined nitrogen in the medium. They have no capability to divide but to germinate. They have a limited period of activity and life. They lack PSII, phycobiliproteins and show higher respiratory rate than other vegetative cells and depend upon adjacent cells for energy.

  The heterocysts perform different functions. As they contain nitrogenase, in addition to many other enzymes, they have the ability to fix atmospheric nitrogen. The lack of PSII in heterocysts is important in the sustained activity of nitrogenase. Other important function of heterocysts is that they also act as reproductive structures since they contain genetic material. During germination, the contents of heterocysts divide into two, which further divide to produce four cells. These cells are called germlings. The inner cellulosic wall layers serve as energy source during germling formation. Later, the wall ruptures and releases the germlings, which grow into a new filament.

c. Parasexual reproduction: No gametes are formed in cyanophytes, but there are reports of genetic recombination. This was established by growing *Anacystis* on the streptomycin and polymixin-B antibiotics. Normally both these drugs cause the death of cells. However, such mutants were isolated, which were resistant to both the drugs when grown in the media which contained streptomycine and polymixin-B separately. When these mutants were grown in the medium containing both the antibiotics, these mutants indicated resistance to both the drugs. This provided the proof of genetic recombination in cyanobactyeria.

Suggested readings

1. Bold, H. and Wynne, M.J. 1978. Introduction to the Algae: Structure and Reproduction. Prentice-Hall, Inc. Englewood Cliffs, New Jersey
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6.2 Euglenophyta
(Green, Wall-Less Algae)

Euglenoids show both plants and animals like characteristics. They lack cell wall (an animal like character) and possess green-grass chloroplast (a plant like character). However, some forms are devoid of chloroplasts and are therefore colourless. They occur mostly in freshwater habitats and few forms are marine in distribution. The members are motile and possess two flagella.

6.2.1 Classification: Division Euglenophyta comprises of single class Euglenophyceae, three orders Eutreptiales, Euglenales and Heteronematales, each with a single family Eutreptiateae, Euglenaceae and Heteronemataceae respectively. There are eight genera and more than 800 species. Euglena and Eutreptia are among the well known genera.

- **a. Eutreptiales:** The members are regarded as oldest and have two emergent flagella; one is anterior and the other is posterior. No special ingestion organelles are found. Members are mainly marine in distribution.
- **b. Euglenales:** There are two anterior flagella. Members are freshwater in distribution and have no special ingestion organelles.
- **c. Heteronematales:** Two emergent heterokont flagella; the longer is forwardly and shorter one is backwardly directed. Members have special ingestion organelles.

6.2.2 Cell structure: In euglenoids, the size and shape of the cell varies considerably. They may have fixed shape, or it may vary with swimming depending upon the species (Fig 6.2.1a).

- **a. Outer coverings:** The euglenoids are devoid of cell wall. The outermost covering is plasmlemma. Next to plasmalemma is a layer called pellicle or periplast, which is unique among eukaryotes. Chemically the pellicle is mainly proteinaceous (80%) but also contains lipids (12%) and carbohydrates (8%). A cross-section through the cell shows that the pellicle is organized as a series of ridges and grooves that make it stiff (Fig. 6.2.1b). Such a pattern of pellicle gives shape to the cell. Some euglenoids have many helically arranged proteinaceous strips that give flexibility to the pellicle and allow the organism to exhibit a wriggling motion known as metaboly or euglenoid movement. Such movement takes place when the cells are not moving by flagella. Others have pellicles with few longitudinally arranged strips. These members are usually rigid and do not show metaboly.

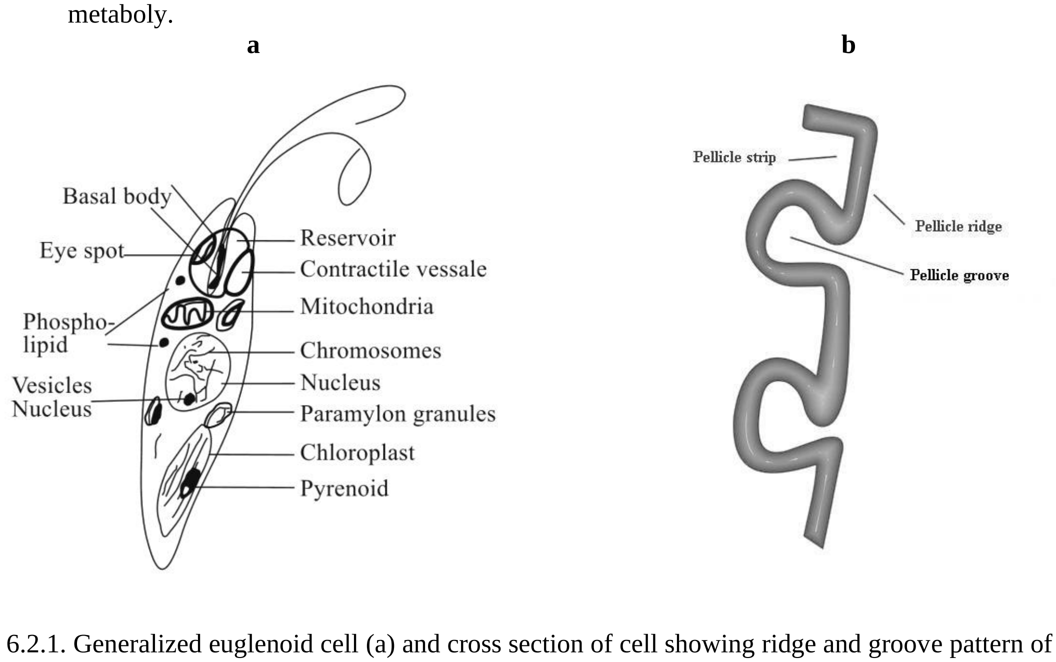

Fig. 6.2.1. Generalized euglenoid cell (a) and cross section of cell showing ridge and groove pattern of outer cell covering (b)

b. Locomotory organs: Euglenophytes are essentially biflagellate. The flagella emerge from the anterior end of the cell. The flagella consist of a narrow tubular portion, the canal and a spherical portion the reservoir. The canal is rigid and reservoir is flexible, due to which movement by flagella occurs. Most euglenoids, including highly phototropic genera such as *Euglena*, have an emergent long flagellum and the other being highly reduced, giving the appearence of a uniflagellate cell. The species in which two flagella emerge, both are quite often dissimilar in structure as well as function.

The basic arrangement of the flagellar apparatus consists of two functional basal bodies, each of which gives rise to a flagellum. The flagella and their basal bodies are either dorsal or ventral depending upon their position within the cell. From basal bodies three unequal microtubular roots originate and proceed anteriorly below the reservoir membrane. Two of these roots are anchored to basal bodies and are designated as ventral or dorsal flagellar roots. A third, called intermediate, flagellar root is located between the basal bodies and is anchored to the ventral basal body.

It is interesting to note that the flagellar apparatus development takes place in a semi-conservative manner. At the onset of mitosis, two additional basal bodies appear which do not yet have flagella associated with them. During cytokinesis the parental basal bodies migrate with their respective new basal bodies into the new daughter cells. Immediately following cytokinesis, the flagellar apparatus is in its simplest form in which two functional basal bodies give rise to three microtubular roots. After cytokinesis each daughter cell contains one parental basal body and a new basal body (a semi-conservative process). In the new daughter cells the striated connective fibers are reassembled between the two basal bodies forcing them to rotate and assume proper position and orientation. Newly produced basal bodies give rise to the dorsal flagella, which by definition are immature, and require another full cell cycle to attain maturity.

c. **Chloroplasts, pigments and stored materials:** The number of chloroplasts present in photosynthetic euglenoids varies greatly; however, lens-shaped chloroplasts are common. The photosynthetic membranes (thylakoids) within the plastids are stacked in groups of three. The grana stacks, typical of higher plant chloroplasts are not present. Euglenoids are believed to have acquired their chloroplasts by the ingestion and subsequent endosymbiosis of a green algal cell. The chloroplast is surrounded by two membranes. The outermost membrane is believed to represent the plasma membrane of the original host cell which engulfed the green alga. Each chloroplast has 3% DNA, which replicates during light periods.

Like the members of Chlorophyta and higher plants, the plastids of euglenoids contain chlorophylls a and b only as primary photosynthetic pigments. Accessory pigments are β-carotene and xanthphylls. Various xanthophylls include antheroxanthin, diadinoxanthin, neoxanthin and astaxanthin. Pyrenoids of various types are present, which are the centers of paramylon or paramylum synthesis. Paramylon is a β-1, 3-glucose polymer and forms a long term stored product. It occurs outside the chloroplast in the cytoplasm. Like chrysolaminarin, it is not stained by iodine due to unbranched nature of the compound.

d. **Other cytoplasmic structures:** Eye spot is a light perceiving organ, and it lies at about the level of flagellar reservoir. It helps the cell to precise the direction of movement. Euglenoids are positively phototactic to low light intensity and negatively phototactic to bright light or darkness. Beneath the reservoir, there is a contractile vacuole, which is osmoregulatory in function and expels excess water out of the cell. It fills and empties at regular intervals of 15 to 60 seconds. It empties into the reservoir from where the water is carried out of the cell through the canal.

Mitochondria are typical algae type. Numerous mitochondrial profiles are found throughout the euglenoid cell. Each mitochondrion is surrounded by two membranes. The inner membrane is folded into the matrix and forms the cristae. Colorless euglenoids have more mitochondria than equivalent sized green euglenoids. Cell has a complex network of an extensive endomembrane system. The endoplasmic reticulum (ER) originates from the nuclear envelope, extends throughout the cytoplasm, and forms a large network at the periphery of the cell under the pellicle strips. The ER also serves as the major source of membrane for the Golgi apparatus. Members of Euglenophyta have one prominent nucleus. It contains one nucleolus and chromosomes.

6.2.3 **Modes of nutrition:** Most of the euglenoids are photosynthetic, but some forms, despite having chlorophyll a and b, are not fully photoautotrophic and require some vitamins, carbon or nitrogen sources as supplements (photoauxotrophic). Phagotrophy is a well known nutritional mode, as the euglenoids are all descended from phagotrophic ancestors and a feeding apparatus can be found in virtually all euglenoid species. In some cases this feeding apparatus is greatly reduced and consists of a pocket originating at the anterior end of the cell adjacent to the flagellar opening. The pocket is supported by interconnecting microtubules that run along its length. The feeding apparatus can be grouped into four types depending upon the type of materials ingested and the species:

a. **Type-I:** This feeding apparatus has the least structural complexity and is vestigial in structure. It is restricted to some bacteriotrophic euglenoids e.g. *Petalomonas cantuscygni* and many photosynthetic euglenoids such as *Euglena gracilis*.

b. **Type-II:** This is relatively more complex feeding apparatus consisting of a cytosome. Cytosome is supported by two rods extending into the cytoplasm and a series of plicate folds called vanes. Both the vanes and rods remain appressed to each other. As in the case of Type-I, this feeding apparatus is typically associated with bacteriotrophic taxa such as *Ploeotia costata*.

c. **Type-III:** This feeding apparatus consists of a cytosome surrounded by vanes and supported by two rods which are composed primarily of microtubules. Contrary to the Type-II, in Type-III apparatus the vanes do not remain appressed to the rods. The number and arrangement of microtubules in the rods varies among genera. One good example is that of *Perenema trichoporum.* Organisms with this feeding apparatus are capable of engulfing eukaryotic prey.

d. **Type-IV:** This feeding apparatus is siphon type and found only in the bacteriotroph form *Entosiphon sulcatum*. It is similar to Type-III, having supporting rods composed of closely packed microtubules and four centrally located vanes surrounding the cytosome. However, near the base of the feeding apparatus, one of the rods splits giving rise to three rods which extend nearly whole length of the cell. Also, unlike Type-III, Type-IV feeding apparatus usually works while cell is in motion.

6.2.4 Reproduction: It is by different means:

a. Asexual reproduction: It takes place by cyst formation and mitotic division

i. Cyst formation: Certain genera of euglenoids have the capacity to encyst so as to withstand unfavourable conditions. During encysting, the cell rounds off and secrete a thick sheath of mucilage that enables it to survive for months until the germination.

ii. Mitosis: Members of Euglenophyta multiply by mitotic division. This may initiate even when the cell is moving in water. The nuclear division (karyokinesis) is followed by cell division (cytokinesis)

- <u>Nuclear division:</u> At the onset of mitosis, the nucleolus begins to elongate and stretches across the equatorial plane of the nucleus. Nucleus migrates from centre to the anterior position (Fig. 6.2.2). The nuclear envelope and the nucleolus remain intact throughout the mitotic process. At prophase, the chromosomes are longitudinally arranged and remain condensed throughout. No spindle is formed. At metaphase, microtubules appear within the nucleus, often near the nuclear envelope. Thay become arranged among the chromosomes, but the chromosomes are not attached to them. At anaphase, the nuclear envelope elongates along the division axis, the nucleolus divides and the daughter chromatids separate and disperse into two daughter nuclei. Ploidy number is maintained by the duplication of the chromosomes.

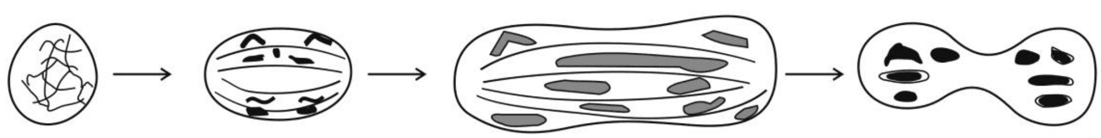

Fig. 6.2.2. Nuclear division in euglenoids

- <u>Cell division:</u> It begins after the nuclear division. The flagella are lost. Two daughter canals are formed and there is an inpushing at the anterior of the cell between the two daughter canals. The cleavage line progresses helically backward between the daughter reservoir and nuclei. Partitioning of organelles is usually equal, so that the two daughter cells are identical in size and content. The mitochondria are many during cell division, which are also equally distributed. Chloroplasts have DNA, which replicates for the formation of new chloroplasts (Fig. 6.2.3).

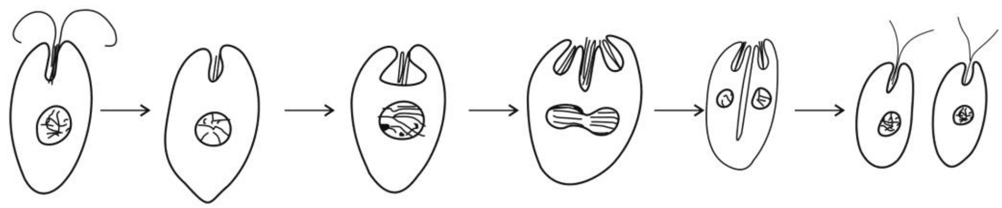

Fig. 6.2.3. Cell division in euglenoids

b. **Sexual reproduction:** It is highly doubtful. Some older reports show that there is the fusion of sister nuclei (autogamy), which forms a zygote nucleus.

Suggested readings

1. Graham, L.E. and Wilcox, L.W. 2000. Algae. Prentice-Hall, Upper Saddle River, New Jersy
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6.3 Dinophyta
(Dinoflagellates)

The Dinophyta are probably a very ancient group that diverged from other eukaryotic organisms before the evolution of typical eukaryotic chromatin but after the evolution of repeated DNA sequences. Dinoflagellates are typically unicellular, free-swimming, biflagellate organisms that constitute an important component of fresh, brackish and marine water. Members may be planktonic or benthic. There are, however, a number of non-motile forms including amoeboid, coccoid, palmelloid and filamentous types. About 50% forms have photosynthesis, while others are saprophytic or holozoic.

6.3.1 Classification: The division comprises of a large number of species of many shapes and sizes. Two groups of dinoflagellates have been distinguished on the basis of insertion of flagella. The Dinokonts have two anterior flagella; one flagellum may be coiled over the surface of the cell. The Desmokonts on the other hand have laterally inserted flagella; one of which is ribbon-like and encircles the cell in a groove and the other flagellum extends back. Systematically, there is one class Dinophyceae with following six orders:

- **a. Prorocentrales:** The members have cell walls divided into two halves. Cells show no girdle. Members are biflagellates and undulipodia are borne at the apex of the cell.
- **b. Dinophysales:** Cell wall is vertically divided into two halves. Cells show elaborate theca with extensions.
- **c. Peridiniales:** The cells are motile bearing two flagella. The epicone and hypocone are separated by a well defined girdle.
- **d. Dinocapsales:** Members are usually non-motile; motility is only temporary if present. Most of the members show palmeloid habit.
- **e. Dinococcales:** Members are unicelled and lack flagella. Vegetative cell division is absent. Reproduction takes place by the formation of zoospores.
- **f. Dinotrichales:** Members are filamentous and show no motility at vegetative stage.

There are 130 genera in this group of unicellular microorganism, with about 2000 living species.

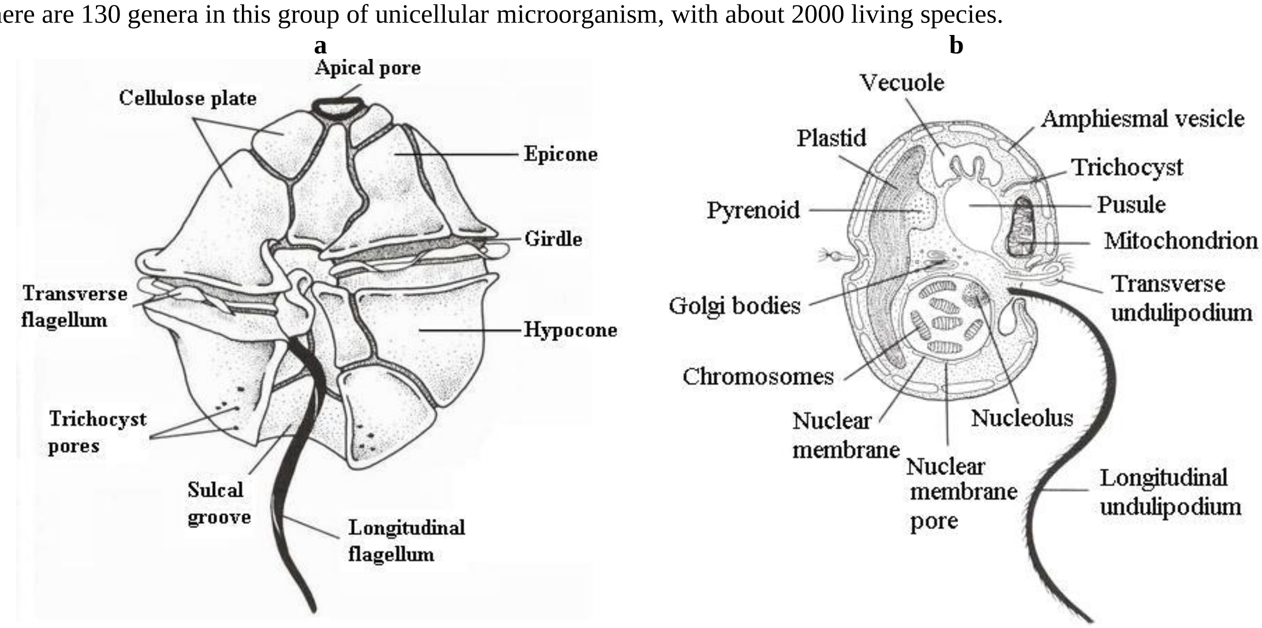

Fig. 6.3.1. External view (a) and internal cell structure (b) of a typical dinophyte

6.3.2 Cell structure: Cell wall may be armored (thecate) or naked and it is the most distinctive feature in the armored dinoflagellates (Fig. 6.3.1a). In armored forms the outer membrane has vesicles containing cellulose plates, which are arranged in characteristic patterns. Members are biflagellate having very fine hairs on flagella. Desmokonts have two anterior flagella; one may be coiled over the surface of the cell. The dinokonts, on the other hand, have laterally inserted flagella, one is in the girdle groove or sulcus and the other extends backwards. Eyespots are very complex, perhaps most complex in any unicell. Some are membrane bound and others are not; some are found attached to chloroplast while others are free. Projectiles known as trichocysts and cnidocysts are found in a number of species and probably have a protective or evasive function.

The mitochondria have tubular cristae. Nucleus is one of the most distinctive features of dinoflagellates. As in Euglenophyta, in Dinophyta too the chromosomes remain condensed at the interphase stage of the cell cycle. The cell divides longitudinally and nuclear membrane persists during mitosis. Some species of dinoflagellates have non-condensed chromosomes at some stage in their life cycle. The chromosomes have histones but atypical of eukaryotes.

6.3.3 Plastids, pigments and reserve materials: About half the species can photosynthesize while remainders are heterotrophs. In photosynthetic species, chloroplast is surrounded by an envelope of three parallel membranes, but unlike other algae, membranes are not associated with a nuclear membrane or endoplasmic reticulum. Thylakoids are usually three to a band. Some genera have pyrenoids in the chloroplast. Main photosynthetic pigments are chlorophylls a and c_2; β-carotene, diadinoxanthin and peridinin are the major accessory pigments. Food reserves are starch and polyglucans and rarely oil.

6.3.4 Bioluminscence: It is the emission of light by a living organism. The dinoflagellates emit bluish white light at approximately 480 nm. Bioluminscence is relatively weak during day and strong during night. Luciferin is responsible for this phenomenon, which is similar in structure to chlorophyll. This pigment is oxidized with the help of enzyme luciferase and light is emitted. Both luciferin and luciferase are found on the membrane bounded particles sometimes associated with the external surface of mitochondria. It is believed that bioluminscence helps the cells in defense against predators.

6.3.5 Symbiosis: Dinophytes make symbiotic relationships with flatworm, marine anemones, reef corals or mollusks; coral reefs being the important hosts. Some forms display endosymbiotic association with diatoms. The dinophytes exert up to 60% of animal diet from photosynthesis as glycerol. If the dinophytes are grown without their host, no photosynthates are excreted. In addition to autotrophic, parasitic dinophytes also show associations with other organisms e.g. in the intestines of pelagic copepods.

6.3.6 Reproduction

a. Asexual: Asexual reproduction takes place by fission or mitosis. In armored forms, cell covering or theca are shed and cells become non-motile. Cell division occurs by simple mitosis, but the nuclear membrane remains intact during cytokinesis.

b. Sexual: It is usually isogamous, but anisogamy is also known. It is induced by limited nitrogen supply or changes in temperature. Most isogamous forms have gametes smaller than the vegetative cells. Vegetative cells divide by meiosis (e.g. in *Noctiluca*) to form up to 2000 uniflagellate isogametes. Pairs of gametes fuse and the zygote, after undergoing a resting period, develops directly into a vegetative cell. There is a eukaryotic nucleus in the vegetative cells, but typically dinophycean (bigger size) nucleus in the gametes. The zygote requires a period of dormancy, which ranges few hours to several months and turn into hypnozygot. Zygote may undergo long resting period under unfavorable conditions.

6.3.7 Life cycle: All members appear to have zygotic life cycle. Life cycle is predominantly haplontic with the only diploid stage being the zygote.

Suggested readings

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6.4 Chrysophyta
(Golden Yellow Algae)

The Chrysophyta form a large and complex group of algae whose plastids contain golden yellow pigments. Cells are heterokont that have one reduced whiplash and the other long tinsel flagella. Most of the species are fresh water and few marine. The member's forms coccoid and filamentous habit. A characteristics feature of the class is the formation of statospores or cysts or statocysts.

6.4.1 Classification: The Chrysophyta has one family Chrysophyceae and four orders.

- **a. Ochromonadales:** Members possess two flagella that arise from the depression in the anterior portion of the cell.
- **b. Chromulinales:** The members are heterokont with a large anterior acronematic and a short posterior whiplash flagella.
- **c. Pedinellales:** Members are uniflagellate; the flagellum is anteriorly located and is wavelike in appearance.
- **d. Dictyochales:** The cell wall shows external silicified extension. The members are motile by means of single well-developed flagellum.

6.4.2. Cell structure: Normally the cell wall is cellulosic and pectic in nature but in some silico-flagellates. The wall is frequently impregnated with silica and mainly uneven in thickness. There are usually 2 flagella; one long-tinsel and the other short-whiplash. The hairs of the tinsel flagellum are fibrous in nature. The whiplash flagellum has a swelling at the base which has an electron dense area called photoreceptor. Eyespot is present inside the chloroplast it consist of lipid globules, which are mainly located between the inner chloroplast membrane and first thallakoid membrane. The eyespot is phototactic in nature (Fig. 6.4.1).

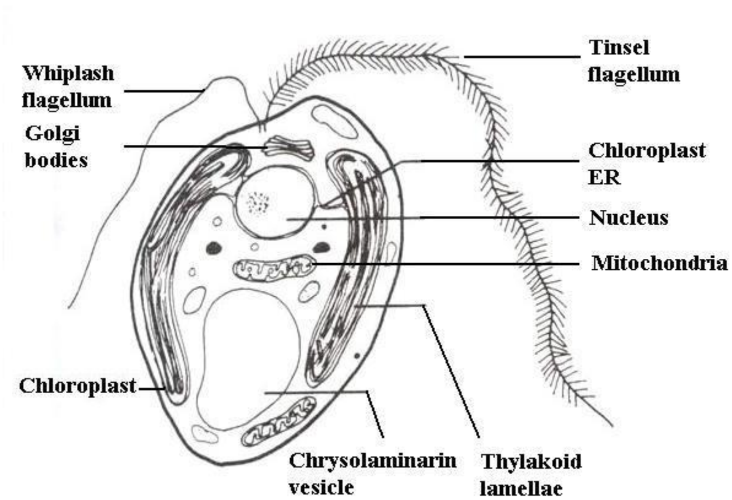

Fig. 6.4.1. Cellular details of a typical chrysophycean cell

6.4.3 Chloroplast pigments and stored materials: The chloroplasts are parietal and usually one or two in numbers. Two membranes of chloroplast endoplasmic reticulum surround them and the outer membrane is usually continuous outside the nuclear envelop. The thallakoid usually form a group of three lamellae. Pyrenoids are found in the chloroplast, which form granular area between the thallakoid lamellae.

The chrysophytes are seen golden yellow due to the presence of pigments giving this color. The light absorbing pigments are chlorophyll a, c_1 and c_2. Carotenes include β-carotene, while the xanthophylls are fucoxanthin and lutein.

Stored material is mostly chrysolamenarin starch and leucosin oil; the former is stored in a large vesicle within the cytoplasm. Similarly leucosin is present in oil vesicles. Both these vesicles may function as a digestive vesicle, breaking down the stored materials when required for the building blocks for cellular metabolism.

6.4.4 Other cellular structures: Chrysophytes are uninucleate. Nucleus is often pear shaped and lies close to the chloroplast with the outer membrane of endoplasmic reticulum enclosing it. There is usually a single large Golgibody forming a stack of vesicles, which lies in the anterior part often in close association with the nucleus. Next to Golgi apparatus, there is a contractile vacuole with a complex system of vesicles. Lipid bodies are seen throughout the cytoplasm, which increase in size and numbers as the cell ages. Mitochondria perform the function of electron transport.

6.4.5 Nutrition: Although most chrysophytes are photosynthetic, some members shows holozoic pattern of nutrition. They ingest the food particles, which supplement the food source for the organism by providing vitamins; particularly vitamin B-12 and some other growth substances. The phagocytosis may be selective in nature.

6.4.6 Thallus organization: Most members are unicelled but there are colonial representative as well. Very few are filamentous and rhizoidal tendency is present in these forms.

6.4.7 Reproduction: Most common method of reproduction in chrysophytes is asexual. Sexual reproduction is rare and of isogameous type, if present. Among the asexual means of reproduction, the formation of swarmers has been reported, which are heterokont zoospores. They germinate to develop into the colonies. Alternate method is the division of cells in a colony to form two or more colonies containing hundreds or thousands of cells. The daughter colonies simply swim away from each other to establish at a new site.

One most prominent feature of this class is the production of statospores or statocysts to overwinter and survive desiccations (Fig. 6.4.2). They account for the asexual reproduction in this class. Statospores are mostly spherical, ellipsoidal or ovate in shape. The outer surface of the statospores may be smooth or ornamented with warts and spines. This character is species specific.

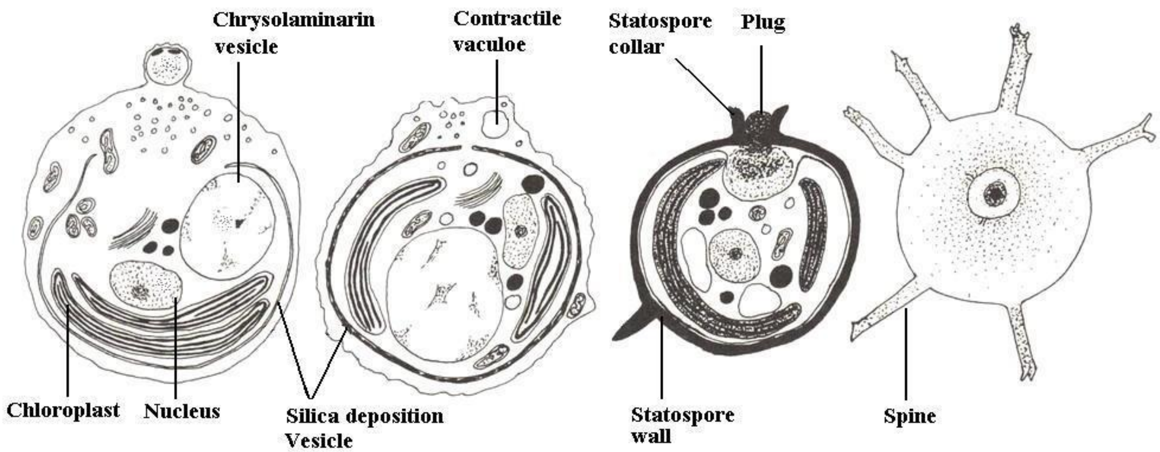

Fig. 6.4.2. Statospore formation in chrysophytes

During statospores formation the cell membrane becomes entirely silicified and complete sphere of silica is formed. At the top of the statospores, there is a pore often surrounded by a tapering conical collar. On the inside of the sphere of silica, chloroplast, nucleus, chrysolamenarin vesicles and golgybodies are segregated, while mitochondria, ribosomes and contractile vacuole lie outside. At the next stage a plug is formed by the cytoplasm in the pore area and outer wall becomes thick. With the formation of plug the connection is lost between the outside and inside of the statospore. The formation of inner membrane functions as plasmalemma. When favorable conditions prevail the statospores geminates with the dissolution of plug. Protoplast comes out of the statospores by amoeboid motion forming flagella as it moves out.

Suggested readings

1. Lee, R.E. 1999. Phycology. Third edition. Cambridge University Press, Cambridge
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6.5 Bacillariophyta
(Diatoms)

Bacillariophyta are popularly known as diatoms. They are ubiquitous in distribution (found in all types of habitats). They may occur as plankton (periphyton), often forming brownish green films on the substrate where they occur. The cells are surrounded by ridge of separate box like cell wall called frustule, which is made of silica. Diatomaceous earth (dirt with diatom "shells") is mined and used as polishes (toothpaste), abrasives, filter components and insecticides.

6.5.1 Classification: Division Bacillariophyta has a single class Bacillariophyceae and two orders:

- **a. Biddulphiales or Centrales**: Also called as centric diatoms. This order consists of four families and seven genera. Members have radial symmetry.
- **b. Pennales or Bacillariales**: Also called as pennate diatoms. The order consists of seven families and eleven genera. Members have bilateral symmetry.

There are more than 10,000 living species of these beautiful protoctists; all are single cells or form simple filaments or colonies.

6.5.2 Details of cell structure

a. Cell wall: Cell wall or frustules is a special characteristic feature of Bacillariophytes (Fig. 6.5.1). It consists of two parts or valves. The upper valve is called epitheca or epivalve and the lower one is called hypotheca and hypovalve. Both the valves are connected to each other by a connection band or girdle band. Each valve is composed of pectic and organic materials impregnated with silica. Diatoms require silica for growth. They are so good on silica that they can reduce its concentration to less than that can be detectable by chemical techniques. The formation of thecae or frustules is intracellular and its amorphous material occurs inside the vesicle enclosed by the membrane called as the silicalemma.

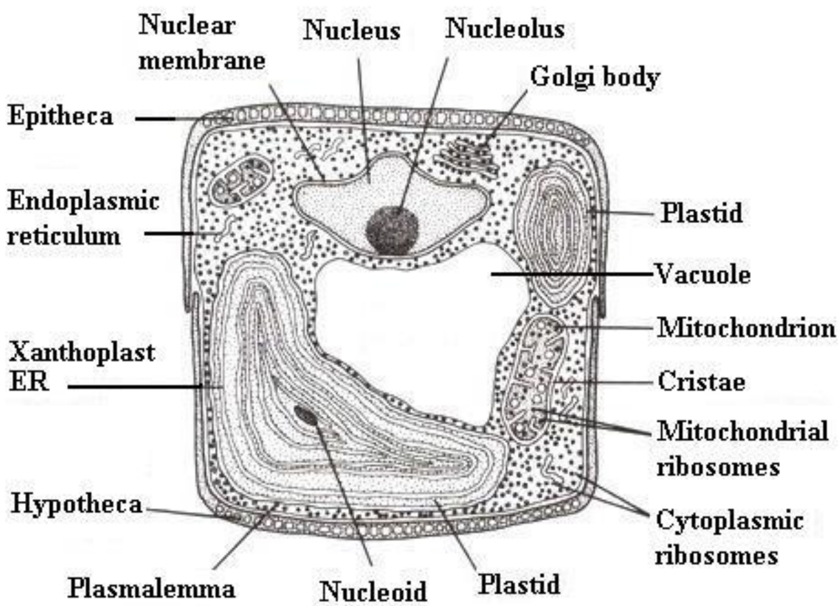

Fig. 6.5.1. Generalized structure of a bacillariophyte

Morphology of frustules or valves: The valves show a sculpturing pattern, which has been used as a criterion to classify the diatoms. There are 4 different patterns for the frustules:

- ***i. Punctae***: Show the fine pores in the cell wall arranged in regular rows.
- ***ii. Aerolae***: Cavity-like progressions and depressions found in the valves.
- ***iii. Canaliculae***: Tubular canals running through the valve surface.
- ***iv. Costae***: Presence of thick ring like regions on the valve surface.

b. Plastids, pigments and reserve materials: The photosynthetic apparatus is chloroplast, enclosed by a double membrane of endoplasmic reticulum. Some people call the chloroplast of diatoms as xanthoplast. The thallakoid are arranged three to a band. In most chloroplasts there is a pyrenoid occupying the central position. The photosynthetic pigments are chlorophyll a, c_1 and c_2. Principal carotenoids are β-carotene, fucoxanthin, diatoxanthin, diadinoxanthin and lutein. Fucoxanthin is the most efficient xanthophyll in energy transfer and forms the part of PSII. The diatoms look golden brown due to the presence of these pigments. There are two main stored materials in diatoms. Chrysolamanarin is stored in the chrysolamanarian vesicles and oil in the oil bodies.

c. **Other cellular details:** Cell membrane encloses the protoplast. The cytoplasm is quite dense containing a vacuole in the center. Cells contain a single nucleus, which has nucleoplasm containing chromosomes and nucleolus. The nucleus is enclosed by a well-defined nuclear membrane. There are many endoplasmic reticulum membranes in the cytoplasm. Golgi bodies play an important role during cell division and valve formation. There are many ribosomes both in cytoplasm and on the crystae of mitochondria.

d. **Locomotion:** The diatoms are devoid of flagella or other locomotory organs at vegetative stage. The centric diatoms are unable to move at all, while pinnate diatoms show gliding movement by means of a series of jerks, but at times it is creeping and steady as well.

6.5.3 Thallus organization

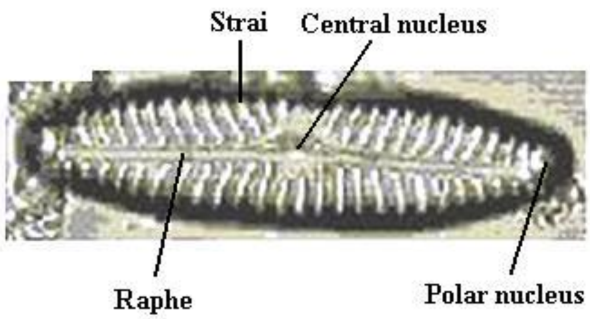

Fig. 6.5.2. Thallus of a unicelled diatome cell

The diatom body is unicellular sometimes colonial diatoms are found in almost every aquatic environment. The body under light microscope is seen as containing a longitudinal slot between the valves called raphe (Fig. 6.5.2). Raphe is divided into 2 parts by a central nodule. At the end the raphe terminates into swollen part called the polar nodule. This structure represents pore or loculi in the theca and these pores resemble like honeycomb.

6.5.4 **Reproduction:** The bacillariophytes reproduce both by asexual and sexual means

a. **Asexual reproduction:** It takes place by means of cell divisions and valves formation in the following steps:

i. Prior to cell division the cell elongates pushing epitheca away from hypotheca.

ii. An invagination of plasmalemma takes place. The Golgi bodies produced translucent vesicles which collect near the plasmamembrane. These vesicles fuse to form silicalemma.

iii. The nuclear division is followed by it. The vesicles other than silicalemma gradually expand and attain the shape of a valve. The inner membrane of silicalemma becomes inner membrane of daughter cells while the old plasma membrane disappears.

iv. Two cells are separated after the complete deposition of silica in the valves. The two daughter cells are always dissimilar in size. The smaller cells will grow to attain the normal size.

v. ***Attainment of normal cell size:*** This takes place by 2 ways; by the production of resting spores and resting cells:

- <u>Production of resting spores:</u> After the cell division, some diatoms develop walls around them and become resting spores. Their cytoplasm shrinks and plasma membrane draws away form the frustule. They settle in the bottom of the lacks and germinate when the favorable conditions prevail. During germination the resting spores produce a number of cytoplasmic strands, which radiate in all directions. The chloroplast and other cell content are gradually released. The cells are much enlarged in size than prior to resting spore formation.
- <u>Resting cells:</u> During harsh conditions the diatoms sink and form resting cells. These cells have same morphology but the difference is that they do not develop a protective layer like the resting spores. A vegetative cell takes about four weeks to develop into a resting cell. During their formation a single large vacuole is converted into many small ones. Mitochondria are few and many lipid bodies are formed. They can survive for two months in such environments. At that time their respiratory rate is

approximately 20% of the normal cells, and the photosynthetic capacity is also very low. Under favorable conditions they resume activity, grow and live like a normal individual.

b. **Sexual reproduction:** In both the orders, sexual reproduction is highly diversified. It ranges form isogamy to anisogamy and oogamy. In some members autogamy is also present. Whatever the method of sexual reproduction, the formation of **auxospore** is characteristic feature specific to the diatoms.

Auxospore is not a spore in *senso stricto*, as it can not resist adverse conditions. Actually the auxospore is shell-less diatom formed when the protoplast is released from the rigid cells. After that it enlarges and secretes initially an organic wall and then a silica wall. During their formation, the protoplast retracts slightly from the wall and produces the hypovalve and an epivalve of daughter cells. Both the pennate and centric diatoms show differences in auxospore formation.

a. **Auxospore formation in Pennales:** In Pennales various methods of sexual reproduction are present, which are mainly by the formation of conjugated cells in common mucilage.

i. ***Formation of single auxospore by conjugating cells*****:** During single auxospore formation, both the conjugating cells lie close to each other and are enclosed in mucilage. In each cell the meiosis takes place and four haploid nuclei are produced; three of which degenerate. One gamete comes out of each cell, and both become enclosed into mucilage and fuse to form a zygote. The zygote later on elongates and forms an auxospore (Fig. 6.5.3).

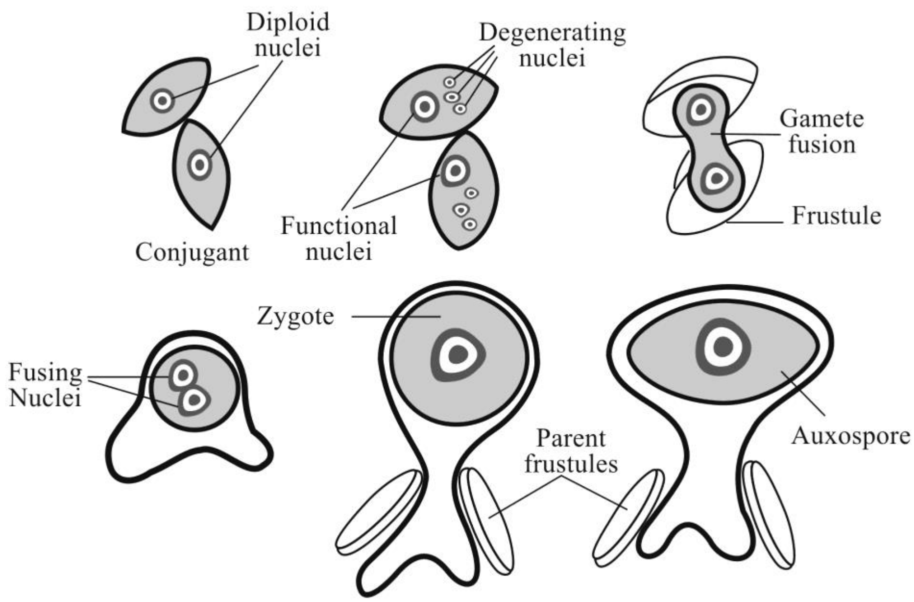

Fig. 6.5.3. Formation of single auxospore by two conjugating cells

ii. ***Formation of two auxospores by conjugating cells*****:** Two conjugating cells come close and become enclosed into common mucilage. The nucleus in each cell divides meiotically producing four haploid nuclei. Two of these nuclei in each cell degenerate and each cell forms two functional gametes. The fusion takes place between gametes from different cells. Both the zygotes after fusion leave the cell wall elongate and form the auxospore (Fig. 6.5.4).

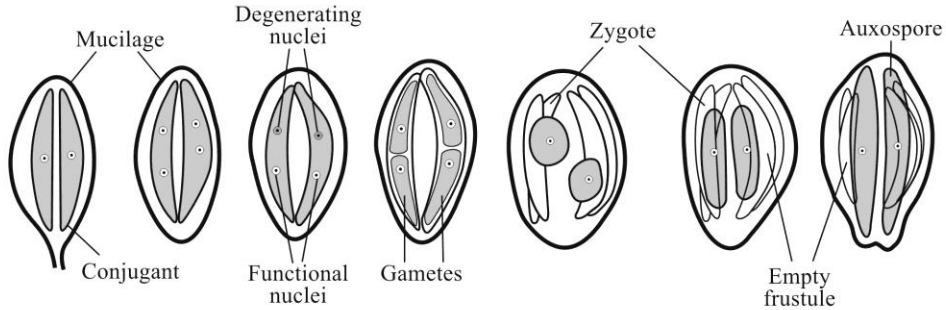

Fig. 6.5.4. Formation of two auxospore by two conjugating cells

iii. ***Auxospore formation by parthenogenesis*****:** In this no conjugation cells are formed or meiosis takes place. Nuclei of two paired cells undergo mitotic division after forming mucilage around them. One of the two diploids nuclei degenerates. The cell containing one nucleus comes out of the cell wall and develops into an auxospore (Fig. 6.5.5).

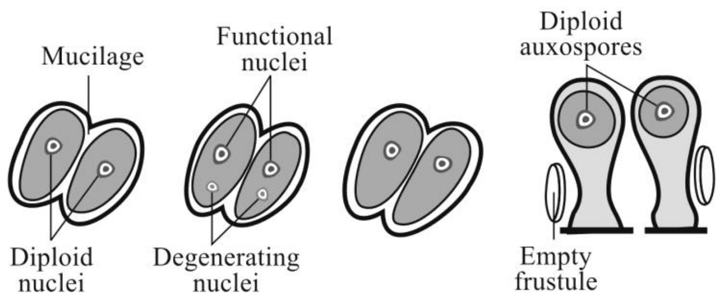

Fig. 6.5.5. Formation of auxospores by parthenogenesis

iv. ***Auxospore formation by authogamy*****:** In this the diploid nucleus divides meiotically to form four nuclei in each of the paired cells. Two of the lower nuclei degenerate. After that the protoplast divides into two containing one functional and the other degenerating nuclei. Two gametes formed in each cell now transfer their nucleus to each other. The zygote will leaves the fruslus and develop into an auxospore (Fig. 6.5.6).

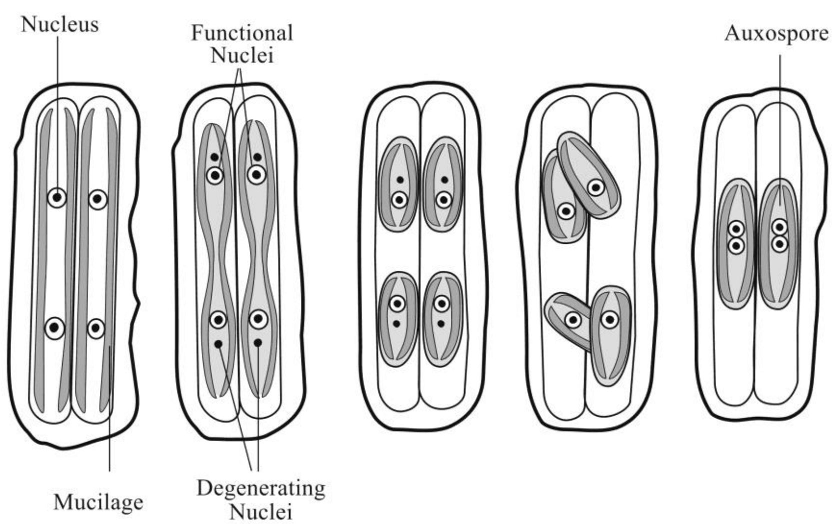

Fig. 6.5.6. Formation of auxospore by autogamy

b. **Auxospore formation in Centrales:** This takes place by two means:

i. ***Formation of auxospores by autogamy*:** During their formation both the valves push apart slightly, nucleus divides meiotically to form four nuclei. Two of the nuclei degenerate and the remaining two fused with each other to form diploid nuclei. Later the protoplast with diploid nuclei is liberated and functions as an auxospore (Fig. 6.5.7).

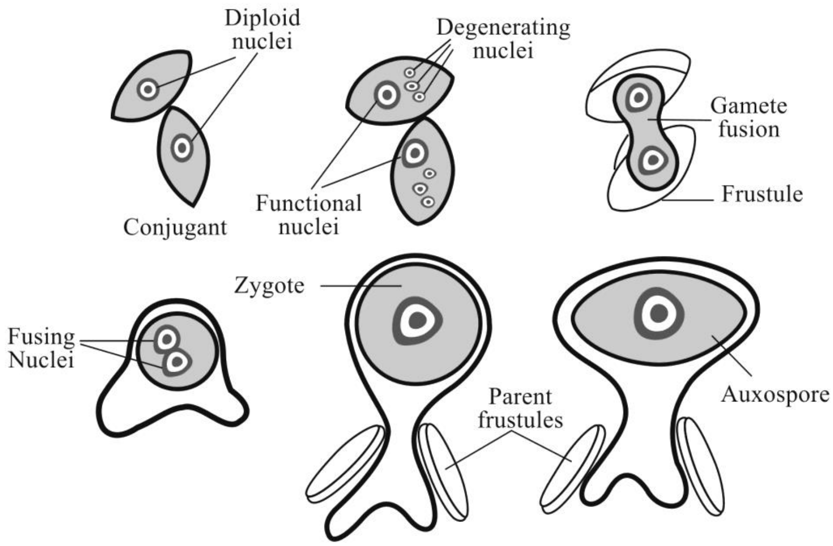

Fig. 6.5.7. Formation of single auxospore by two conjugating cells in centric diatoms

ii. ***Auxospore formation by oogamy:*** The protoplast with the cell wall divides and re-divides by meiosis and ultimately forming 4 to 128 small haploid nuclei in the protoplasts. The first division is meiotic and rests of the divisions are mitotic. The haploid nuclei fuse with each other to form numbers of diploid auxospore.

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1. Graham, L.E. and Wilcox, L.W. 2000. Algae. Prentice-Hall, Upper Saddle River, New Jersy
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6.6 Xanthophyta
(Yellow-Green Algae)

Xanthophyta are mainly fresh water in distribution and only few forms are marine. They have two heterokont flagella; one is longer than the other. They look yellow green in color due to the presence of characteristics pigments. They are comparatively less studied but are characterized on the basis of pigments, flagellation and reserve materials.

6.6.1 Classification: Division Xanthophyta is classified into one class Xanthophyceae, which has following five orders:

a. **Heterochloridales:** Members are flagellated or show amoeboid movement of the vegetative cells.
b. **Heterogloeales:** Members show palmelloid habit form colonies of no definite shape. Vegetative cells can transform from immobile to motile ones.
c. **Mischococcales:** Members are non-filamentous with immobile vegetative cells that can transform to motile. They can produce zoospores by differentiation of a mother cell.
d. **Trigonematales:** Thallus in the members is non-coenocytic filamentous.
e. **Vaucheriales:** Members are filamentous. The filaments are coenocytic and show multinucleate condition.

First four orders have one family each, but Vaucheriales has two families and two genera.

a. Cell structure: Xanthophytes typically have pectin-rich cellulosic walls with few exceptions. For example in *Vaucharia*, 90% of wall material is cellulose and the rest is glucose and uronic acid. Many members have cells composed of two over-lapping halves, which fit together just like a petridish. This can be observed with electron microscope after treatment of cell with concentrated solution of potassium hydroxide. Cells are biflagellate; one flagellum is large tinsel which is anteriorly or forwardly directed and the other is small whiplash and is posteriorly or backwardly directed. Eyespot is present inside the chloroplast and is phototactic (Fig. 6.6.1).

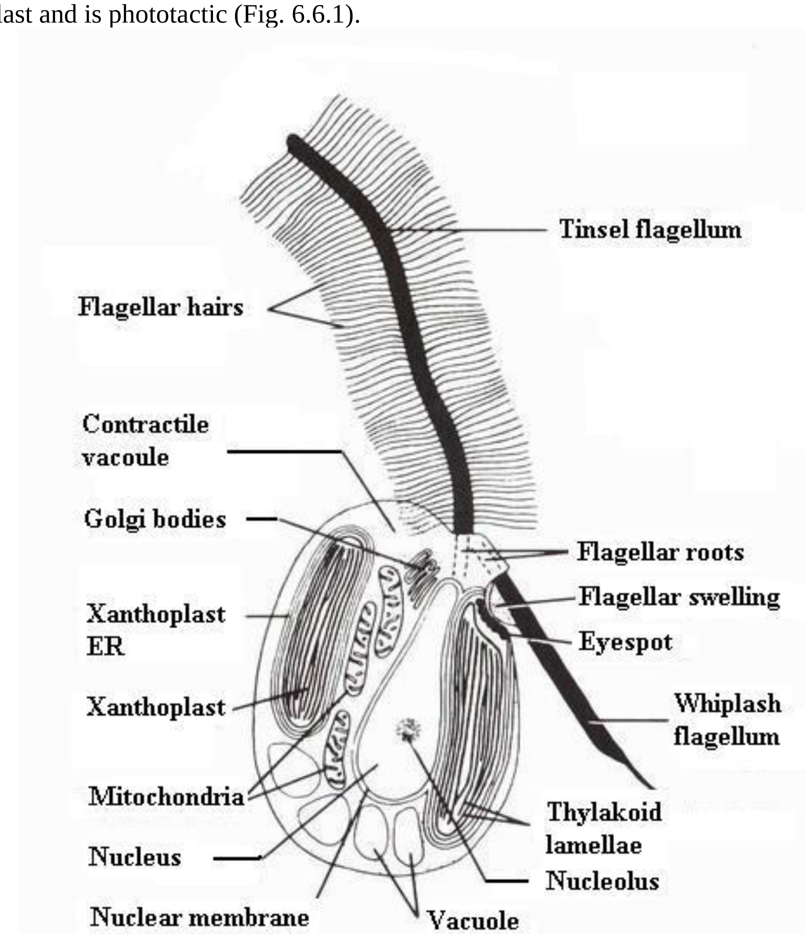

Fig. 6.6.1. Typical xanthophycean cell structure

b. **Chloroplast, pigments and reserve products:** Two membranes of the chloroplast endoplasmic reticulum surround the chloroplast. Outer endoplasmic reticulum membrane of chloroplast is often continues with the nuclear envelope. Thallakoids of the chloroplast are usually grouped into the bands of three and many genera have pyrenoids where the stored products are synthesized. Some people regard the chloroplast of xenthophytes as xanthoplast.

Pigments of the xanthophytes comprise of chlorophyll a, c_1 and c_2. Several xanthophylls are found including diatoxanthin and heteroxanthin. By virtue of the above pigments the xanthophytes appear yellow-green in color. Mannitol and glucose accumulate during photosynthesis in the plastids. Principal storage products: are beta 1,3 linked glucans similar to paramylon. In some forms lipids are principal storage product. However, starch typically of green algae is absent.

c. **Thallus organization:** Xanthophytes may be unicellular to colonial or filamentous in habit. Majority of forms are coccoid, but there may be rhizoidal, siphonaceous, palmaloide forms. In some forms there may be branched or unbranched filaments.

d. **Reproduction**

i. ***Asexual reproduction:*** It takes place by the formation of a variety of asexual spores.

- <u>Zoospores:</u> Under favorable conditions, the cell protoplast undergoes repeated division forming a multinucleate condition and fragmentation. Each of protoplasmic fragments develops into a zoospore. Zoospores are biflagellate with one tinsel and other whiplash flagella. Upon releasing the zoospores germinate and form a new individual
- <u>Aplanospore:</u> During unfavorable conditions protoplasm divides into several bits which may be uninucleate or multinucleate. Each bit gets transformed into an aplanospore. Aplanospores are non-motile, thin walled, rounded and capable of developing into a new individual.
- <u>Hynospore:</u> They are similar to aplanospore; the only difference is that they are thick walled. Under favorable conditions they germinate to give rise to a new organism.
- <u>Statospores:</u> Statospores or cyst formation is common in rhizoidal forms. During their formation the protoplast migrates to the rhizoidal region where it becomes rounded and thick walled. The statospores may directly germinate to form a vegetative body.

ii. ***Sexual reproduction:*** Few reports exist about sexual reproduction in xanthophytes. It has only been reported in three genera; *Botryodium*, *Trichonema* and *Vaucharia*. In the former two genera, the sexual reproduction is of isogamous type, whereas in the latter, it is oogamous. Adult generation is diploid which after meiosis forms male and female gametes. However, in *Vaucharia*, there is production of antheridia and oogonia as the reproductive structures.

Suggested readings

1. Graham, L.E. and Wilcox, L.W. 2000. Algae. Prentice-Hall, Upper Saddle River, New Jersy
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6.7 Chlorophyta
(Green Algae)

Chlorophyta are eukaryotic algae and comprise of one of the largest group. They are distributed in fresh, marine and terrestrial environments, but majority are marine. Unicellular forms are motile. The body ranges from unicellular, colonial (coenobial and non-coenobial), filamentous, membranous or tubular. Certain filamentous forms have lost some or all of their cross walls, thus forming a multinucleate protoplast. Some members contribute to lichen formation. Reproduction is both sexual and asexual. There are more than 7000 species from the above orders.

6.7.1 Classification: The classification of green algae varies greatly with the classifier. In general, the chlorophyta has a single class Chlorophyceae and nine orders with the characteristics as given against each:

- **a. Chloroccocales:** Forms are unicellular to colonial and non-motile. They occur as planktonic or terrestrial algae. Vegetative reproduction is absent.
- **b. Volvocales:** The forms are unicellular and colonial and remain motile throughout their life cycle. Mainly fresh water in distribution.
- **c. Ulotrichales:** Body consists of simple unbranched filamentous thallus. Most forms have single parietal band shaped chloroplast with several pyrenoids. Many forms are fresh water or estuarine in distribution. Cells are uninucleate.
- **d. Oedogoniales:** Body is unbranched and filamentous. During cell division, a peculiar cap cell is formed. Sexual reproduction is advanced oogamous type. The oogonia are much broader than normal vegetative cells. Members are exclusively fresh water in distribution.
- **e. Chaetophorales:** Algal body is composed of profusely branched heterotrichous filaments. Apical cell of the filament is sharply pointed. Forms are largely fresh water in distribution.
- **f. Cladophorales:** Algal consists of branched filaments. The cells in the filament are cylindrical. Each cell is multinucleate with a reticulate chloroplast. Most forms occur in fresh water.
- **g. Siphonales:** The body is filamentous and coenocytic i.e. thousands of nuclei share the same cytoplasm. Siphonoxanthin is present as a carotenoid. Most forms are marine and others are fresh water in distribution.
- **h. Tetrasporales:** The body consists of non-filamentous non-motile colonies. Both sexual and asexual reproduction is present. Members are mainly fresh water in distribution.
- **i. Zygnematales:** Body of members is mainly unicellular and a few froms are filamentous. Cells are uninucleate and have very prominent chloroplasts with pyrenoids. Forms are absolutely fresh water in distribution.

6.7.2 Cell structure

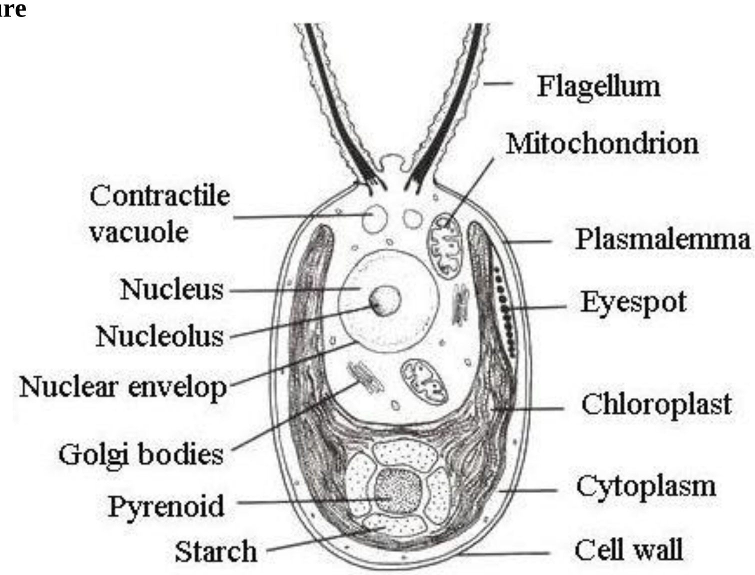

Fig. 6.7.1. Internal details of a chlorophycean cell

- **a. Cell wall:** The cell wall of green algae like other land plants is composed of cellulose and pectins, polymers of xylose or mannose linked to proteins. In many genera, the walls are frequently encrusted with calcium carbonate, silica and less frequently with minerals like iron oxide. It is usually three-layered; inner firm part is composed of lamellae, the outer mucilaginous and middle forms pectic layers (6.7.1).

b. Flagella: The flagella in chlorophyta differ greatly in number, insertion and morphology. They may be acronematic or pentonematic. The flagella have typical 9:2 fibrillar organization and are isokont and acronematic in most green algae, while in some forms they are pentonematic.

c. Cytoplasm: The protoplasm is bounded by a plasma membrane, which is composed of lipid bilayer and proteins embedded in it. The plasma membrane serves the function of transport of materials across it. Other organelles including Golgibodies, mitochondria, endoplasmic reticulum are similar to other eukaryoic cells. Nucleus contains a nucleolus.

d. Chloroplasts, pigments and reserve materials: Chloroplasts occur in a variety of patterns, which are visible under light microscope. This variation in chloroplasts forms an important criterion of classification. The chloroplasts are double membranous organelles. They may be cup-shaped, a meshwork, ribbon, oval discs or complete or incomplete rings. Photosynthetic lamellae or thylakoids are the sites of photochemical reactions. The 70s ribosomes and DNA are present as chloroplast genome and protein synthesis machinary. As in higher plants, the grana are composed of two to six stacks of thylakoid lamellae depending upon the algal species.

Primary photosynthetic pigments include cxhlorophyll a and b. Accessory pigments are α- and β-carotene and xanthophylls including heteroxanthin, lutein, zeaxanthin, violaxanthin, lycopene etc. Some siphonaceous chlorophytes have siphonoxanthin. End product of photosynthesis is starch, which is synthesized and accumulated in specifically differentiated protein bodies called pyrenoids. Glucose is the primary product of photosynthesis, which is converted into starch. Starch of green algae is similar to that of higher plants and is composed of amylose and amylopectin. All the photosynthetic pathways are similar to higher plants.

Many of the flagellated green algae show phototactic movement and have an **eyespot** or **stigma**. It consists of a number of layers of lipid droplets usually in the stroma between the chloroplast envelop and outermost band of thylakoid. The stigma is presumed to act as axillary body and improve the precision of movement by sensing the external stimuli. **Contractile vacuole** is present in vegetative cells of most of the Volvocales. In biflagellated genera, there are two contractile vacuoles one at the base of each flagellum. They may control the water content of cell when protoplasm has higher concentration of solutes than the medium. This leads to a total inflow of water, which is compensated by the water pumped out by these vacuoles, thus playing an osmoregulatory role.

6.7.3 Thallus organization: There are a variety of thalli met in various forms of Chlorophyta (Chapter 3, Fig, 3.5 for illustrative details):

a. Motile forms: Individual cells and colonies show motility by means of flagella. Individual cells have spherical, oval or ellipsoidal body with two anteriorly inserted flagella. Motile colony is an advanced type of thallus consisting of a number of flagellated cells united together by the mucilage. All cells in a colony are independent physiologically but behave as a coordinating unit. One good example is the coenobial colonies of *Volvox*. Others are net-like colonies of *Hydrodictyon* and loosely arranged colonies of *Eudorina*.

b. Filamentous forms: These are of various types; unbranched, foliaceously branched, truly branched and heterotrichous. They are described below:

i. Simple filaments: It is an advanced type over unicellular or colonial forms.It is considered that filaments are derived from motile unicellular forms through the introduction of vegetative division. Filaments consist of a large number of cells arranged in a row or abutting one another. Common examples are *Ulothrix*, *Oedogonium*, *Spirogyra* and *Zygnema*. The cells are multinucleate in most genera, except *Sphaeroplea*.

ii. Foliaceous forms: These forms are formed by the division of a filament in more than one plane. This division results in the formation of two rows of cells. Two parallel layers of thallus are the result of longitudinal division e.g. *Ulva*.

iii. True branched filamentous forms: These forms are more advanced than simple or foliaceous filaments. Branching arise as a lateral outgrowth of one or many cells. A branch may undergo further branching just as the main axis does.

iv. Heterotrichous forms: This refers to two types of branching i.e. prostrate and erect. In prostrate system, the branching arises from the basal part of the body and creeps parallel to the ground.

The erect portion of the body arises vertically from the prostrate system and is branched e.g. *Coleocheate, Protoderma* etc.

c. **Siphonaceous forms:** The body of the siphonaceous forms is characterized by the presence of aseptate multinucleate condition with a large central vacuole. The thallus forms a siphon like structure. Common examples are *Caulerpa* and *Codium.*

d. **Palmellate forms:** The body is a gelatinous colony consisting of irregular number of loosely arranged cells. The cells look-like *Chlamydomonas* but flagella are absent. Commom examples are the members of the family Tetrasporaceae.

e. **Coccoid forms:** These forms lead a sedentary life. They have evolved from motile unicellular forms by losing contractile vacuole and eyespot. Common examples are *Chlorococcum* and *Chlorella*.

6.7.4 Reproduction: The reproduction takes place by three means:

a. **Fragmentation:** A colony or filament may fragment to establish new colonies or filaments.

b. **Production of asexual spores:** Various types of spores have been reported.

i. ***Zoospores:*** They are motile, flagellated cells and most commomly formed. Entire protoplast of a cell may form a single zoospore. Mitosis may divide the protoplast into as many as 32 in numbers. They exit from the zoosporangium and are motile and naked for a time varying from minutes to days. Following this, they lose flagella, settle down, form a cell wall, and become vegetative cells. In addition to forming in sporangia, zoospores may be formed by meiosis in a zygote, or by mitosis from akinetes.

ii. ***Aplanospores:*** They are produced in aplanosporangia and are non-motile. They may be one or more in number and are produced under adverse environmental conditions. They develop distinct cell wall, which is different from the parents. They are of common occurrence in *Chlorella* and *Ulothrix*.

iii. ***Hypnospores:*** They are thick-walled non-motile spores that undergo a long resting period e.g. formed in *Sphaerella*.

iv. ***Akinetes:*** The vegetative cells are liberated into thick walled non-motile resting spores called akinetes, e.g. produced in *Cladophora* and *Pithophora*.

v. ***Autospores:*** These are basically aplanospores; the only difference is that they resemble parent cells and show normal wall formation. In this case the spore before coming out develops all the cellular structures of their parents. They are more commonly produced in *Chloroccocales*.

vi. ***Cysts:*** These are resting cells, enclosed in a thick envelop.

All these spores germinate under favorable conditions and give rise to a cell, colony or a filament.

c. **Sexual reproduction:** It may be **isogamous, anisogamous** or **oogamous**. For all these types, the gametes are produced. In isogamous and anisogamous reproduction, the gametes are not usually produced in specialized cells, but in case of oogamous, the gametes are produced in gametangia. In majority of the Chlorophyta, the gametes are motile, but in Zygnematales, the amoeboid gametes are produce. In isogamous reproduction, the opposite gametes are similar in size and shape, which may be called as + or – gametes. In anisogamous and oogamous reproduction, the gametes are non-similar morphologically or physiologically.

During fertilization, the gamete cells of one sex adhere to the other by agglutination reaction. After their mixing, the gametes of opposite sexes adhere by their flagella tips in clusters of many. Soon the anterior end of the complementary gametes fuse and the flagella set free themselves. The motile zygote then swims for sometime before settling and then secretes a thick wall.

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6.8 Charophyta
(Stoneworts)

The charophytes are green algae, which occupy an isolated group between Chlorophyta and Bryophyta. They are multicellular, live in fresh and brackish waters, and are mostly confined to bottom of the clear lakes. The cells are long either uni- or multinucleate. The members are important experimental organisms.

6.8.1 Classification: A single class Charophyceae comprises of a single order Charales and one family Characeae. This family has two sub-families Charae and Nitellae, with four genera and more than 300 species. *Chara* and *Nitella* are well known genera.

6.8.2 Cell structure: Cell wall is composed of cellulose. In the center of the cell is a large single vacuole. The cytoplasm is divided into ectoplasm or ectoderm and an endoplasm or endoderm. The ectoplasm contains chloroplasts and some other organelles. The endoplasm has numerous microfilaments, which are involved in cytoplasmic streaming and movement of materials (Fig. 6.8.1).

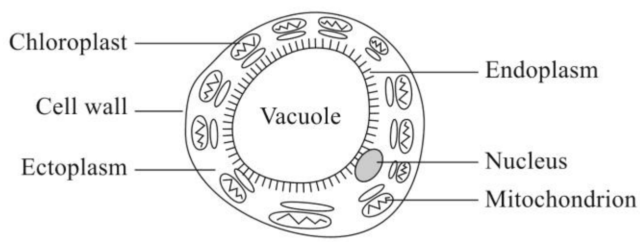

Fig. 6.8.1. Details of cell structure of *Chara*

6.8.3 Chloroplast, pigments and stored materials: The uninucleate cells have many small ellipsoidal chloroplasts in longitudinal spirally twisted rows. The photosynthetic pigments are chlorophyll a and b. Carotenoids are α- and β-carotenes while xanthophylls are antheraxanthin, neoxanthin, violaxanthin and zeaxanthin. Starch is formed in chloroplasts as the end product of photosynthesis.

6.8.4 Thallus morphology and growth: Body of charophytes can be seen macroscopically. They are erect in quite waters and bend with the current of running water and may be 30 cm or more in length (Fig. 6.8.2). Main axis of the plant body is conspicuously divided into nodes and internodes. Each node has a whorl of branches composed of a number of cells. These branches do not grow after attaining a certain length. The internodes consist of a single large cell with considerably large vacuole. The branching is of two types i.e. branches of limited and unlimited growth. The body is attached to the substratum by mean of uniseriately branched rhizoids.

Thallus growth is apical and takes place by means of a meristematic cell which divides transversly into 2 daughter cells or initials; the upper nodal and the lower internodal. The internodal cell will elongate to form the internode, while the nodal cell divides further to form the nodal zone and meristematic cell. From the nodal zone the branches arise (Fig. 6.8.2).

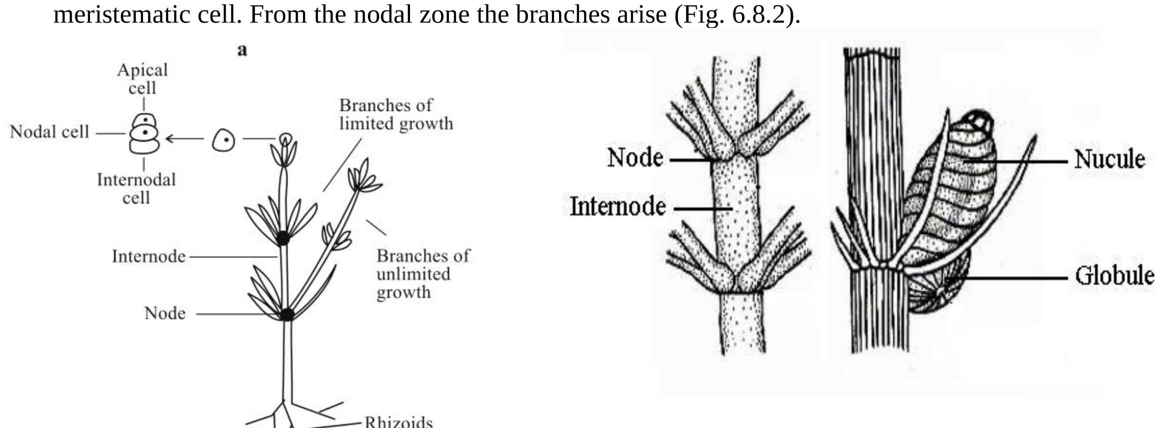

Fig. 6.8.2. Vegetative (a) and reproductive (b) filaments of *Chara*

6.8.6 Reproduction: It takes place by different means:

a. **Vegetative reproduction:** Any fragment of the body from node can produce rhizoids and adventitious shoots and can establish as a new individual body. Moreover, the rhizoids can spread and develope bulbs and give rise to colonies of erect photosynthetic shoots.

b. **Sexual reproduction:** It is of advanced oogamous type. Charophytes do not produce zoospores. The main sex organ is globule or anthredium while female sex organ is nucule or oogonium. In *Chara* they are born on single individual and nucule is above the globule. The members are monocious or dioceous; both globule and nuclule may be found on single or separate individuals. The anthrozoids are formed inside the globule in the form of filaments and are liberated at maturity. The microtubular anthrozoids are motile and composed of three regions; a) head region contains mitochondria and constitutes 1/4th of the body, b) middle part contains nucleus and forms half of the body and c) plastids are located in the tail region. On the anterior side there are two unequal flagella (Fig. 6.8.3).

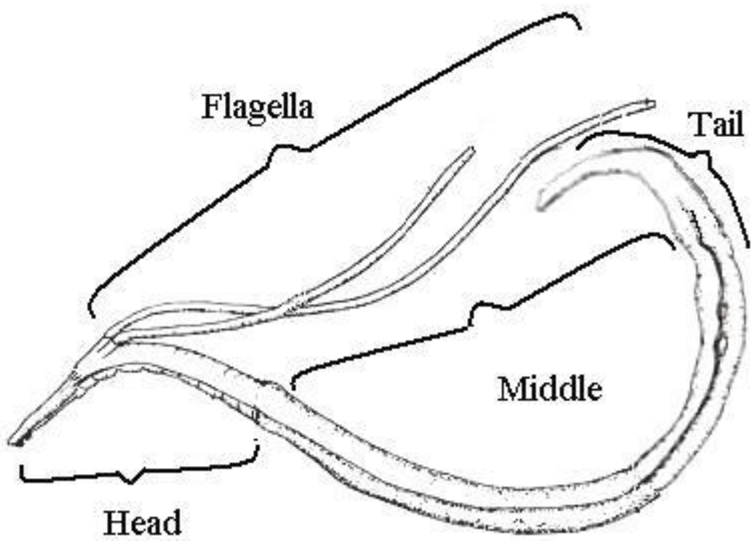

Fig. 6.8.3: Antherozoid of chara showing various regions and flagella

The nucucle in its center has oogonium, which contains an egg. When the egg is mature the nucule makes an opening in it for the entery of anthrozoids. The anthrozoids swim to the egg fuse with it and form the zygote. The zygote develops a thick wall around it and form the oospore, which is released to the outside environment.

At the time of germination the oospore undergoes a meiotic division to form 4 haploid nuclei, which are soon partitioned to two unequal cells. The upper cell has one nucleus and the lower cell has 3 nuclei and many reserve materials. Soon the nuclei in the lower cell degenerate and partition membrane between both the cells breaks away. Then this cell divides longitudinally. One of the two cells produces rhizoids and the other will grow out in opposite direction to form erect thread. This structure is called protonema. The mature individual arises as a lateral branch from protonema.

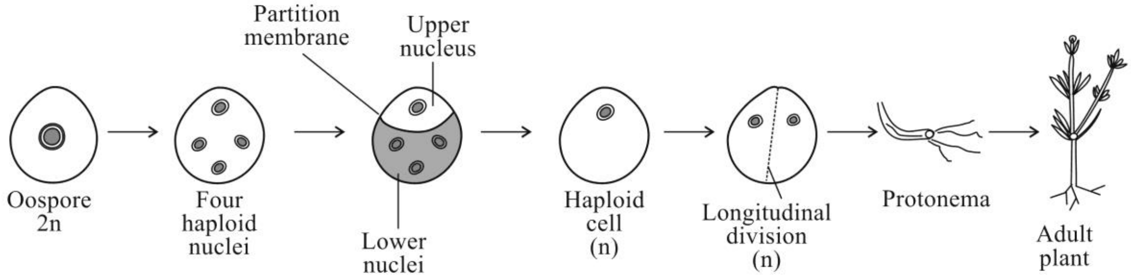

Fig. 6.8.4. Reproduction in *Chara*

6.8.7 Life cycle: Life cycle of Charophyta is haplontic and highly advanced oogamous type. The adult plant is haploid and produces nucule and globules. Oospore is the diploid stage in the life cycle of *Chara*, which undergoes meiosis and after a series of changes (as mentioned above), protonema is produced which give rise to haploid body.

Suggested readings

1. Bold, H. and Wynne, M.J. 1978. Introduction to the Algae: Structure and Reproduction. Prentice-Hall, Inc. Englewood Cliffs, New Jersey
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6.9 Phaeophyta
(Brown Algae)

Phaeophyta are brown seaweeds and nearly all marine. They form the largest group of algal division. The giant kelps are as long as 100 meters. Most of the phaeophytes live along rocky coastal seashores, especially in temperate regions. They dominate the intertidal zone, where they form great beds of seaweeds. They are primary producers for many consumers like invertebrate animals and microbes. The presence of large amounts of golden brown pigment and a high amount of carotenoids form major light harvesting components, and gives brown colors to the members.

6.9.1 Classification: The class Phaeophyta has been divided into three classes. The classification is based on the morphology of reproductive structures and alternation of generation:

A. **ISOGENERATAE (DICTYOPHYCEAE):** This class includes members with two morphological similar but cytological different generations in the life cycle. It constitutes five orders.

- **a.** **Ectocarpales:** Body of the members is filamentous. The filaments may be pseudo- or true-parenchymatous derived from heterotrichous habit. Growth is intercalary. Asexual reproduction is by zoospores produced in unilocular or pleurilocular sporangia. Sexual reproduction is isomorphic.
- **b.** **Sphacelariales:** Growth is apical; daughter cells undergo longitudinal division to give a polysiphonous structure. Sexual reproduction is isogamous.
- **c.** **Cutlariales:** Members show trichothallic habit. Asexual reproduction is by zoospores formed in unilocular sporangia. Sexual reproduction is aniosgamous. Life cycle may be iso- or heteromorphic.
- **d.** **Dictyotales.** Growth is by an apical cell. Thallus is parenchymatous showing little differentiation. Asexual reproduction is by non-motile tetraspores produced in unilocular sporangia. Gametophytic phase of life is reduced to eggs and sperms. Sexual reproduction is of advanced oogamous type.

B. **HETEROGENERATAE (LAMINARIOPHYCEAE):** This includes the members with two morphologically and cytologically different generations in their life cycle. This subclass has 6 orders:

- **e.** **Chordariales:** Growth is trichothallic and apical. Life cycle consists of a macroscopic diploid sporophyte and microscopic gametophyte.
- **f.** **Sporochnales:** Body is bulky and complex and growth is intercalary. Asexual reproduction is by zoospores formed in unilocular sporangia. Sexual reproduction is oogamous. Life cycle is heteromorphic.
- **g.** **Desmarestiales:** Body is uniaxial with complex cortication and intercalary growth. Asexual reproduction by zoospores. Sexual reproduction is heteromorphic and oogamous.
- **h.** **Dictyotales:** Thallus is parenchymatous and growth apical. Some body differentiation with dichotomous branching. Asexual reproduction by non-motile tetraspores produced in unilocular sporangia. Sexual reproduction is oogamous. Life cycle is isomorphic.
- **i.** **Laminariales:** Thallus bulky and parenchymatous with considerable morphological and anatomical adaptations. Growth intercalary. Asexual reproduction by zoospores produced in unilocular sporangia. Sexual reproduction oogamous and life cycle is heteromorphic.

C. **CYCLOSPORAE (FUCOPHYCEAE):** In this class the members possess a diploid generation only it has got only one order.

- **j.** **Fucales:** Parenchymatous thallus with complex morpho-anatomical differentiation. No asexual reproduction. Gametophytes are reduced to egg and sperms. Sexual reproduction is oogamous.

All these orders have 240 genera and about 1500 species.

6.9.2 Cell structure

a. **Cell wall:** It is composed of two layers with cellulose as the main component. The outer layer is amorphous and made up of alginic acid and fucoidin. The inner layer is made up of cellulose with the molecules arranged in the form of parallel microfibrills. The components of outer layer help to absorb water and tide over desiccation (Fig. 6.9.1).

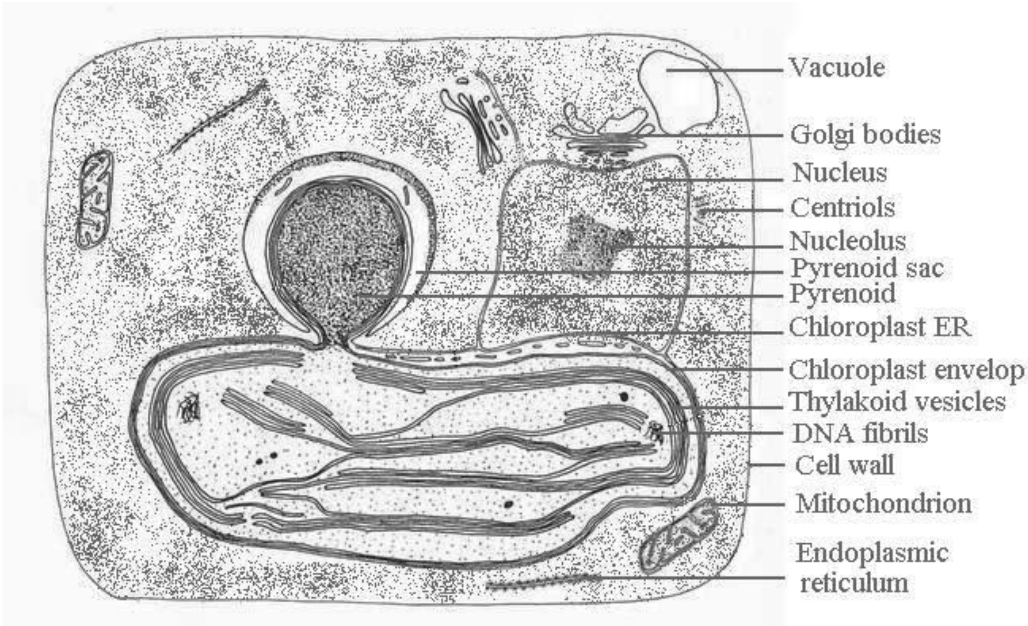

Fig. 6.9.1: Cellular details of a typical phaeophycean cell.

b. Flagella and eyespot: The vegetative cells are non-motile while zoospore and male gametes are motile. They have long anterior tinsel and short posterior whiplash flagella. The posterior flagellum usually has a swelling at the base, which fits well into the eyespot. The eyespot consists of 40-80 lipid droplets arranged in a single layer between the outermost band of thyllakoid and chloroplast envelope. The flagella and eyespot function in the same manner as described for other algae.

c. Plastids, pigments and reserve materials: The chloroplasts of algae are also called phaeoplasts, which are enclosed by two membranes of chloroplast endoplasmic reticulum. The outer chloroplast ER is usually continuous with nucleus on the outside of nuclear membrane in some orders and discontinuous in the others. Inside the chloroplast the thylakoids are present in a group of three per band. Microfibrils of DNA, both linear and circular, are attached to the thylakoid membranes. All the phaeophytes contain pyrenoids, which is a stalk-like structure originating from main body of chloroplast. Surrounding the pyrenoid, there is a membranous sac-like structure, which contain reserve material. Pyrenoids are absent at vegetative stage but are usually present in sporlings.

Phaeophyta contains distinct set of photosynthetic pigments i.e. chlorophyll a, c_1 and c_2 but never b. Fucoxanathin is the principle carotenoid and is responsible for giving brown color to these algae. Long-term storage product is lamanarin, which is a β-1, 3-linked glucan. The sugar alcohol, mannitol is initial accumulation product, which accumulates up to 25% of photosynthates.

d. Other cytoplasmic structures: Among the other cytoplasmic structures, the phaeophytes contains a single large nucleus having a nucleolus. The nucleus is surrounded by nuclear membrane, outside of which chloroplast endoplasmic reticulum is present. Chromosomal organization is well advanced and even X- and Y-chromosomes can be differentiated. Other structures such as mitochondria, Golgibodies and endoplasmic reticulum perform their functions.

Thallus organization: The thallus ranges in size from microscopic epiphytes to largest of marine algae up to one meter long.

a. External morphology: Externally the simplest brown algae are composed of erect branched or unbranched filaments arising from a prostrate, filamentous basal system i.e. heterotrichous organization (e.g. *Fucus*). The vegetative generation is saprophyte, which is differentiated into the following structures (Fig. 6.9.2).

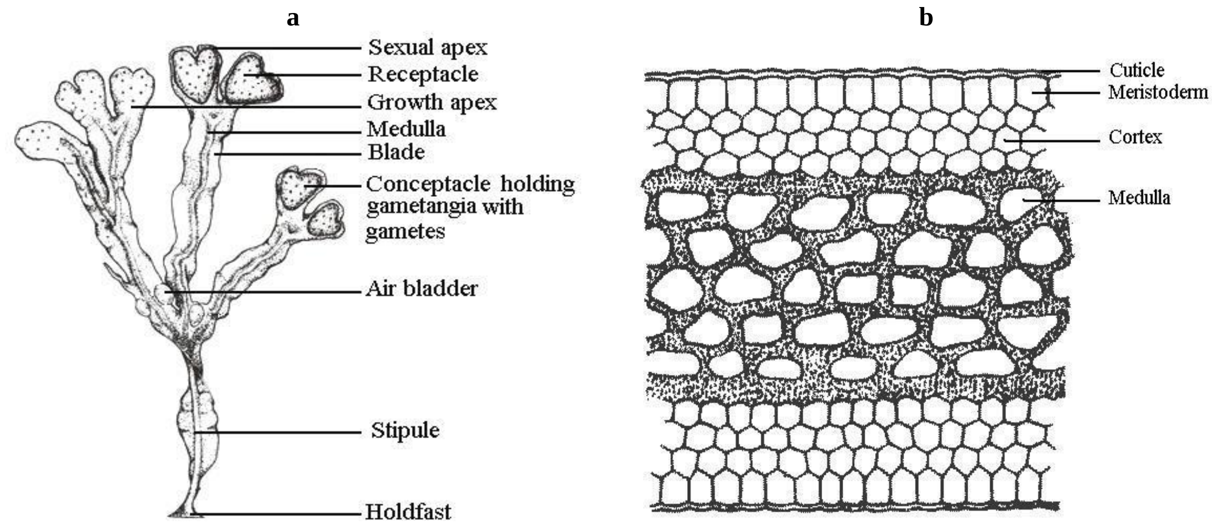

Fig. 6.9.2. External and (a) and internal morphology (b) of *Fucus* thallus, a typical phaeophyte

- ***i. Blade:*** This is a leaf-like structure
- ***ii. Frond:*** It forms main part of the body and it is composed of blades. A frond is dark brown in color, ribbon shaped, flat and dichotomously branched with distinct midrib.
- ***iii. Stipe:*** It forms a short cylindrical stem-like part, which is continuous to a greater part as midrib in the frond.
- ***iv. Air bladders:*** These are hollow and swollen structures found usually in pairs along the sides of thallus, close to the forking regions and are filled with air. They are absent in some members.
- ***v. Receptacles:*** They are formed at terminal ends containing conceptacles. They are formed at the time of reproduction in the swollen ends of the blades. The conceptacles bear sex organs and open to the outside through ostiol.
- ***vi. Conceptacles:*** They form male and female gametengia, which may be born on the same or different individuals. A longitudinal section of male gametengia reveals the presence of a number of sperms in them that are released to the outside by ostiole. The sperms are flagellated at maturity. In the female gametangia or oogonia, the egg cells are present, which may be 1, 2, 4 or 8 in numbers. The egg cells are non-motile and are released to the outside environment when mature.
- ***vii. Growth apices:*** These are the terminal somewhat swollen ends meant for vegetative growth of the thallus

b. Internal morphology: Transverse section of blades reveals the presence of the following tissues.

- ***i. Cuticle:*** Outside the epidermis is a fine layer called cuticle.
- ***ii. Epidermis or meristoderm:*** It is covered by mucilage and forms the outermost layer possessing photosynthetic chromatophores.
- ***iii. Cortex:*** Next to the epidermis is several layers thick paranchymatous zone, the cortex. Its outer few layers possess chromatophores, which are meant for photosynthesis, while the inner ones have no chromatophores. The inner layers function for the storage of reserve materials.
- ***iv. Medulla:*** It occupies central region and is well developed, it comprises of loosely arranged cells. The main function of medulla is conduction of water and nutrients, and mechanical support.

6.9.4 Reproduction: It takes place by vegetative, asexual and sexual means.

- **a. Vegetative reproduction:** It takes places by fragmentation. Any broken fragment attaches to the substratum and develops into a new independent thallus.
- **b. Asexual reproduction:** Both motile and non-motile asexual spores are produced in different types of sporangia:
  - ***i. Unilocular sporangia:*** In these sporangia, 4-128 biflagellate zoospores are meiotically produced and are haploid. They directly germinate to give rise to haploid individual. Such type of sporangia are absent in order Dictyotales and Fucales.
  - ***ii. Pleurilocular or neutral sporangia:*** These sporangia are produced on diploid individuals. The motile zoospores are mitotically produced in large numbers. Zoospores possess two unequal flagella; one flagellum is whiplash and anteriorly inserted and the other is tinsel, which is posteriorly directed. On germination they give rise to diploid body.

iii. ***Tetrasporangia:*** These are formed in few members of Phaeophyta and meant for the production of tetraspores. Tetrasporangia are diploid, which produce four haploid nuclei by meiosis. Soon each nucleus becomes surrounded by a mass of cytoplast and transforms into a tetraspore. Tetraspores are liberated by the dissolution of tetrasporengial wall. Two of liberated spores give rise to male while other two to female individual, which are similar in shape and size.

c. **Sexual reproduction:** Male and female gametes are produced in male and female gametangia; former being smaller in size than the latter (Fig. 6.9.3). Upon the maturity of the antheridium, biflagellate spermatozoids are released to the outside environment in many numbers. Oogonium, on the other hand, releases single egg prior to fertilization. Fertilization results in zygote formation, which germinates to initially form proembryo and then a mature sporophyte. Fertilization may be internal or external. In internal fertilization, the male and female gametes are produced on the same gametangia where they fuse to form zygote. In external fertilization both gametes are liberated to surrounding water, where they fuse to form zygote and give rise to vegetative body.

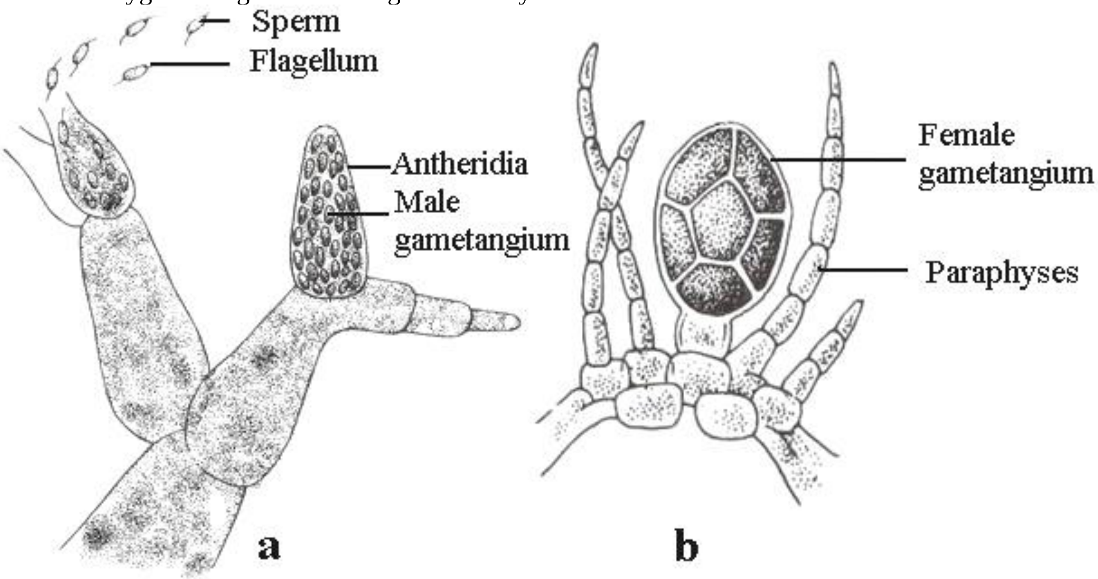

Fig. 6.9.3. Male (a) and female (b) gametangia of phaeophytes

All types of sexual reproduction are found in various members of Phaeophyta. **Isogamy** has been reported in Ectocarpales. The gametes are produced in pleurolocular sporangia in which zoospores are similar both morphologically as well as cytologically. **Anisogamy** has been reported in few members of Ectocarpales and most members of Cutlariales. In anisogamy two different gametes are produced on two different gametengia. Motile male gametes are produced in smaller while non-motile female gametes are produced in larger gametengia. **Oogamy** is commonly found in order Desmarestiales, Laminariales, Dictyotales and Fucales. Male sex organs are antheridia while female ones oogonia, which respectively produced sperms and egg.

Alternation of generation: It is of three types i.e. isomorphic, heteromorphic and diplontic

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6.10 Rhodophyta
(Red Algae)

The Rhodophyta is another large group of algae. They are distinct form other algal division in many respects. They a) lack flagella in any stage of their life cycle, b) contain red pigments, c) have no aggregates of thylakoids lamellae and d) show the production of specialized male sex cells called spermatia and female cells called carpogonia for sexual reproduction. The red algae are mainly marine in distribution but some fresh water species are also found. The marine species in tropical seas inhabit ridges and rocky shores. The fresh water members are attached to their substrata by means of rhizoids, whereas tendrils are used for attachment to the plants when the members are found as epiphytes.

6.10.1 Classification: The division Rhodophyta has single class Rhodophyceae, and two subclasses; a) Bangiophycidae or Bangiodae and b) Floridophycidae or Floridae, each are with special characteristics (Table 6.10.1).

Table 6.10.1: Differences between two subclasses of red algae

BANGIOPHYCIDAE	FLORIDEOPHYCIDAE
The cells are uninucleate	The cells are multinucleate
Members are unicellular to simple filamentous in habit	The forms are filamentous showing aggregation into pseudo paranchymatous thallus per cell
Single stellate chloroplast in axial position. Pyrenoids usually present	Several small discoid chloroplasts per cell located peripherally. Pyrenoids usually absent
Cell division intercalary thus showing a diffused growth.	Cell division is apical thus showing the erect growth
Pit connections between the cells of a tissue are absent.	Pit connections between the cells of tissues are well defined
Members are both fresh and marine water in distribution	Members marine in distribution
Monospores and neutral spores are produced for asexual reproduction	Asexual reproduction is by means of carpospores, bispores, tetraspores and polyspores
Spermatia and carpogonia are meant for sexual reproduction which are sessile in bearing, rarely monocious but frequently dioecious	Spermatia and carpogonia are meant for sexual reproduction, which are attached to the filament by a stalk

The subclass Bangiophycidae has one order **Bengiales** with the characters as given in the Table 6.10.1. However, the subclass Floridophycidae has the following orders with their salient characters:

a. **Porphyridiales:** Unicelled or multicelled members held together by mucilaginous walls.
b. **Hildenbrandiales:** This order was recently established based on the distinctive pit-plug ultrastructure. Secondary pit connections are abundant. Reproduction is asexual by fragmentation or by formation of gammae or stolons.
c. **Rhodochaetales:** Filamentous organisms with pit connections. Gametes formed by the mother cells
d. **Batrachospermales:** Heterotrichous thallus, multiaxial. Apical growth with one or more apical cells. Gonimoblast usually develops from the carpogonium. Monospores or tetraspores formed for asexual reproduction. Life cycle is haplobiontic.
e. **Gelidiales:** Thallus unaxial. Tetrasporangia are cruciate. Carpogonial branch consisting of a single cell, the carpogonium. Life cycle diplobiontic.
f. **Gracilariales:** Members are well known for commercial importance as source of agar. Thalli are cylindrical to flattened and branched with uniaxial consrtriction. Dioecious thalli with isomorphic life cycle.
g. **Cryptonemiales:** Thallus distinctly heterotrichous with uni- or multiaxial construction. Tetraspores may be cruciate or zonate. Life cycle diplobiontic.
h. **Gigartinales:** Thallus uni- or multiaxial. Generative auxillary cell, usually an intercalary vegetative cell. Tetraspores cruciat or zinate. Life cycle diplobiontic.
i. **Rhodymeniales:** Thallus with multiaxial construction. Gonimoblasts become profusely branched. Tetraspores are cruciate or tetrahedral. Life cycle diplobiontic.
j. **Ceraminales:** Thallus uniaxial. Simple branched filaments showing leafy expansions. Procarp with four celled carpogonial branch borne on pericentral cell which cuts off auxiliary cell after fertilization. Tetraspores tetrahedral. Life cycle diplobiontic.

6.10.2 Cell structure:

a. Cell wall: It is composed of two layers. Inner layer comprises of cellulosic microfibrils arranged as the network in most member. The outer layer is amorphous mucilaginous, polysaccharide in nature and makes up to 70% of dry weight of cell wall. In Bangiophycidae a cuticle has been reported outside the mucilage of the cell wall, which according to one school of thought is composed of β-1, 4-linked mannose while others think it is proteinaceious in nature. Some species show the deposition of carbonates of calcium and magnesium in the cell wall (Fig. 6.10.1).

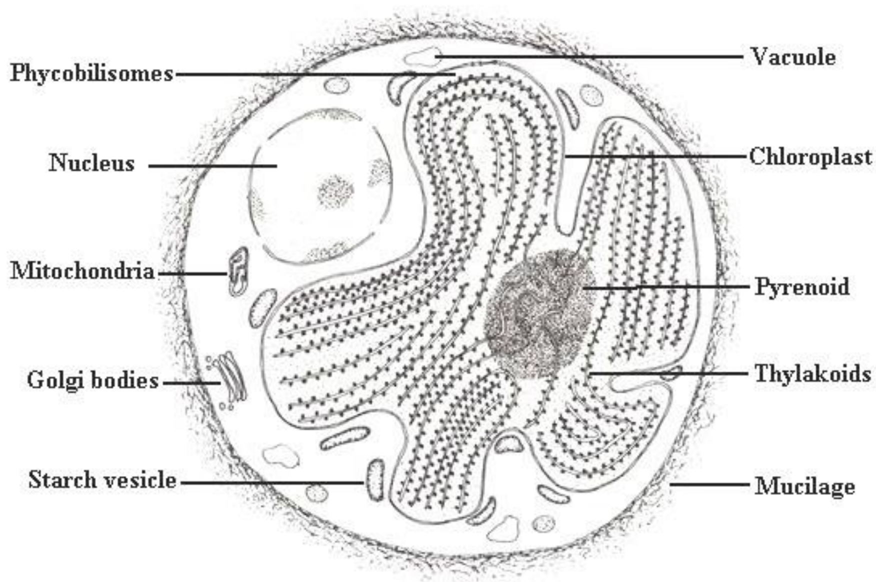


Fig. 6.10.1. Cell structure of a bangiophycidae (red algae)

b. Plastids, pigments and reserve material: In Bangiophycidae, the chloroplast is stellate i.e. star-like and has a well-developed central pyrenoid. In floridophycidae, the chloroplast is discoid and lacks pyrenoid. The chloroplast in both the sub-classes is surrounded by two membranes while the membranes of chloroplast endoplasmic reticulum enclosing both the nucleus and chloroplast, as reported in other algae, are absent. Inside chloroplast the thallakoid lamellae occur singly. DNA is present in the chloroplast as microfibrils. On the surface of thallakoids, there are discoid and spherical bodies called phycobilisomes. The discoid phycobilisomes contain phycocyanin while the spherical ones contain phycoerythrin.

The photosynthetic pigments include chlorophyll a and d as primary light harvesting components. Carotenodis are α- and β- and e-carotenes, xanthophylls are many in number and most prevellant ones are flavicene, loroxanthin, violaxanthin, zeaxanthin etc. The phycobilins contained in the phycobilisomes include R-phycocyanin, allophycocyanin and three forms of phycoerytherin. The phycoertherin is greater in amount and gives pinkish color to the Rhodophytes. The phycobilisomes act as light harvesting funneling system for transfer of energy to PSII in the thallakoids.

The reserve products are of two types. Short term storage product is glycerol-galactoside also called as florideoside. The 3-PGA is formed as initial product of photosynthiesis which appears just 30 seconds after illumination while the florideoside appears 2 hours after the PGA has been formed. Long-term storage product is Floridean starch, which accumulates in Floridean starch vesicles in the cytoplasm. The Floridean starch is similar to amylopectin of higher plants and stains violet red with iodine.

c. Other structures: Dictyosomes, endoplasmic reticulum and tonoplast bound vacuole are present in certain red algae. Mitochondria resemble those of higher plants. The cells of bangiophyceae are uninucleate while those of Floridiophycidae are multinucleate and this number may be as high as 4000 nuclei per cell in some red algae.

6.10.3 Thallus morphology: As given in Table 6.10.1 above, both the subclasses of red algae show differences in general thallus morphology (Fig. 6.10.2). However, members of Floridiophycidae show quite advancement in structure over the Bangiophycidae in many respects.

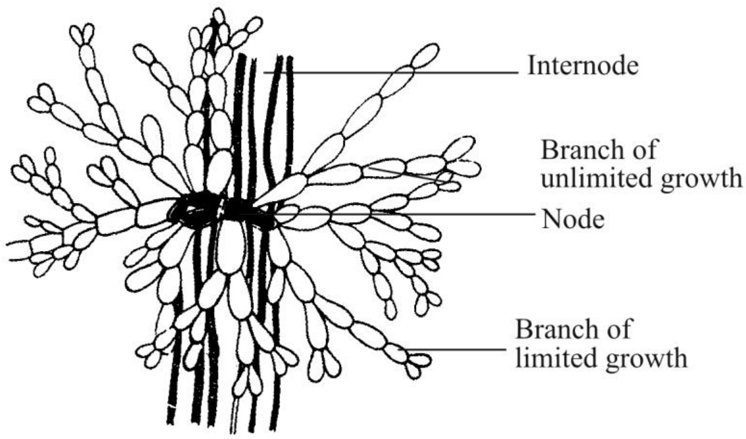
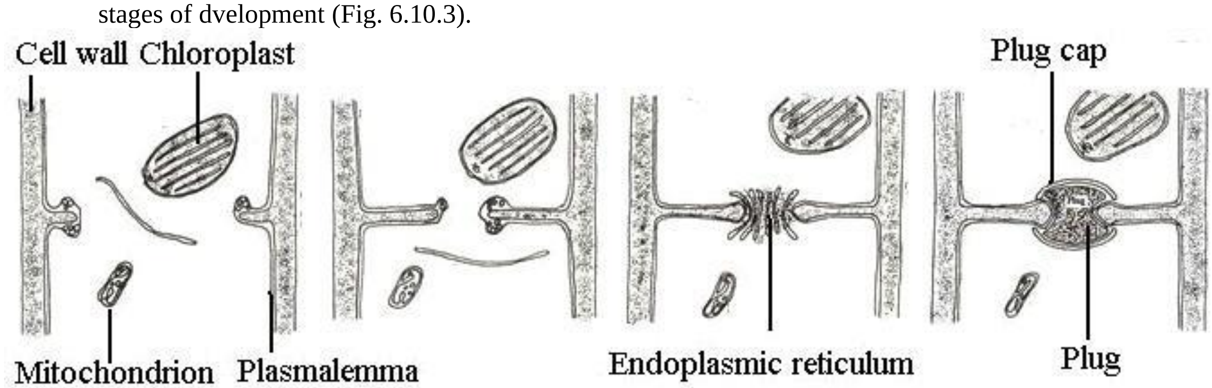


Fig. 6.10.2. Thallus branching pattern in red algae

Although both the subclasses show the branching of thallus filaments, the Florideophycidae show an erect and apical growth of branches with a heterotrichous habit, while the growth in Bangiophycidae is subapical and diffuse and thallus show parenchymatous habit. Two types of branching is seen in majority of Florideophycidae; the branches of limited and unlimited growth. They originate from the nodal region as projecting four to six pericentral cells and soon attain the shape of branch after repeated divisions. Another major difference is the presence of pit connections in Floridophycidae, which are lacking in Bangiophycidae.

6.10.4 **Pit connections:** On the basis of ontogeny, two types of pit connections have been distinguished in red algae, called primary and secondary pit connections. The nature, structures and development pattern of both is different:

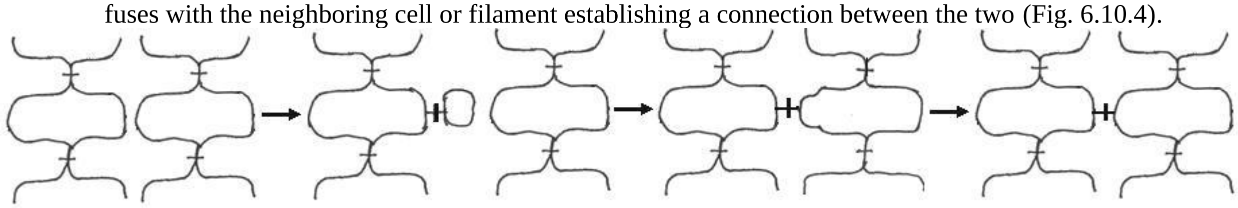
a. **Primary pit connections:** These are formed between the two cells during cell division. Following are the stages of dvelopment (Fig. 6.10.3).



6.10.3. Development of primary pit connections

i. Soon after nuclear division, a cross wall grows inward from the side walls.
ii. With the completion of cross wall there remains a hole or aperture in the center for the cytoplasmic continuity.
iii. Numerous vesicle traverse the aperture with electron dense material condensed all around them.
iv. The vesicles disappear and electron dense material fills the aperture. This material is enclosed by a membrane that attains the shape of a plug. In the end a flattened vesicle appears on each side of the plug to make the cap. The plasmalemma remains continuous from cell to cell. Plug is made up of polysaccharide-protein complex and forms a pit-like structure that helps the continuity of materials between the cells.

b. Secondary pit connections: During their formation, neighboring filaments or cells may establish mutual contacts. One of the neighboring cell or filament cuts a small cell as a result of unequal division, which fuses with the neighboring cell or filament establishing a connection between the two (Fig. 6.10.4).



6.10.4. Development of secondary pit connection between two filaments that lie close to each other (a), cutting off a small cell by one of the filament (b), fusion of small cell with the neighbouring filament (c) and establishment of a pit connection (d)

c. Advantages of pit connections: They function as a site of structural strength of the thallus. In some algae the plug of pit connection becomes dislodged between cells of a developing reproductive structure, leaving the protoplast completely continuous between the cells, thus allowing the passage of metabolites to developing reproductive cells.

6.10.5 Reproduction

a. Asexual reproduction: Production of monospores is the most common means of asexual reproduction in red algae. They are released as a single cell from monosporaniga. Monospores are always pigmented and larger than spermatia. During their formation, any cell in the vegetative filament undergoes unequal division. The smaller cell being released as monospore, which germinates and gives rise to a vegetative body (Fig. 6.10.5). This is common in Bangiophycidae. In florideophytes the asexual means of reproduction is by polyspore and tetraspore, which are produced in polysporangia and tetrasporangia, respectively.

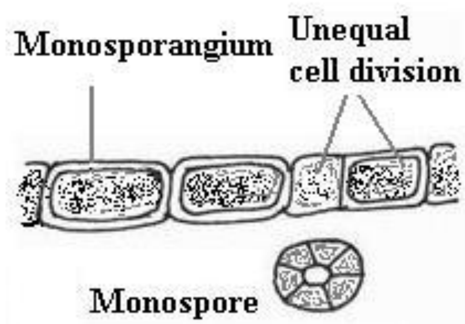


Fig. 6.10.5. Production of monospores

b. Sexual reproduction: This involves the production of spermatia, the male reproductive structure, and corpogonia, the female reproductive structure (Fig. 6.10.6).

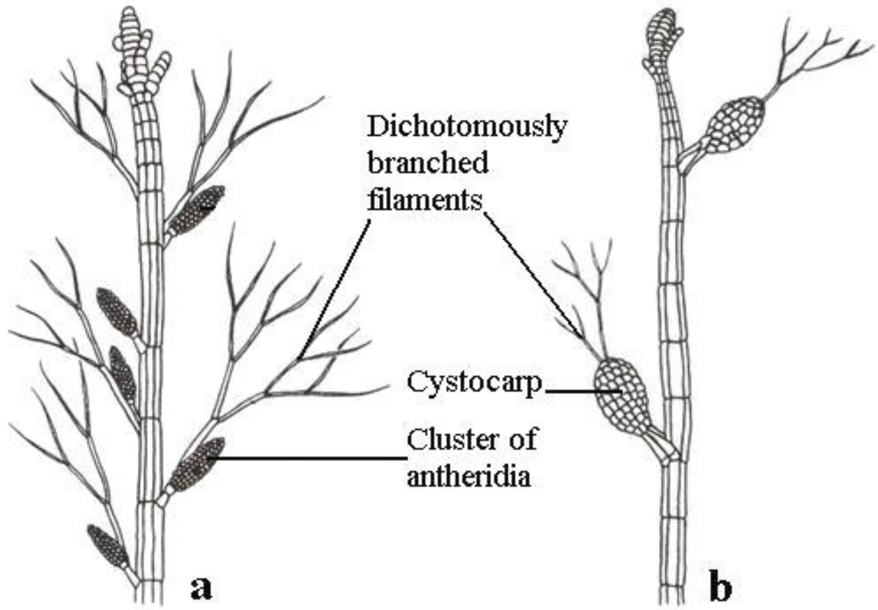


Fig. 6.10.6. Male (a) and female (b) thalli of red algae showing reproductive organs

i. ***Spermatia:*** They are spherical or oblong cells that are produced in spermatiangia. Spermatangia are formed singly, in pairs or group of 4 on terminal or subterminal cell called spermatangial initial. Each spermatium is a small rounded colorless structure, which is distinguishable easily from rest of cells in the filament. Following are the stages in the development and release of spermatia:
   - The young spermatium has a polar orientation, with the nucleus in the apical portion and one or more vacuoles in basal portion.
   - As the spermatangium ages, the vacuole containing mucilaginous substance forms the basal area. All the cellular structure metamorphose and one large vacuole is formed
   - At the time of release of spermatia, the wall of spermatingium gelatinizes near the apex. The pit connections are ruptured at this time.
   - Spermatium is pushed out with the pressure exerted by the mucilage. It is uninucleat and wall-less but is enclosed by the mucilage.

ii. ***Carpogonia:*** It is female reproductive organ. It consists of a dilated basal portion and usually a narrow elongate flattened tip, the trichogyne, which receives the male cell. Usually there are two nuclei in the carpogonium, one in trichogyne that disintegrate soon after carpogonia mature and other in basal part, which functions as female gamete nucleus. The carpogonium is borne on a branch of filament. Both carpogonium and branch bearing it are colorless.

iii. ***Fertilization:*** The spermatia are non-flagellated and are carried passively to the trichogyne of carpogonium with the current of water and get attached to the neck. At the time of contact, the nucleus in the trichogyne disappears. The wall of the trichogyne dissolves from the tip and male nucleus of spermatia moves to the carpogonial base where it fuses with the egg. After fertilization the zygote is formed which germinates to give rise to gonimoblast filament also called as carposporophyte

iv. ***Post-fertilization changes–the tetraspore production:*** After the gonimoblast filament has formed at female gametophyte, there is the formation of third generation in the life cycle, called tetrasporophyte, which eventually becomes reproductively mature and produces tetrasporangia. The tetrasporangia constitute the site of meiosis, leading to the production of four tetraspores either in a row (zonate), crosswise (cruciate) or tetrad (tetrahedral) manner (Fig. 6.10.7). During their formation, a wall is laid down inside the tetrasporangia by the protoplast, which has prominent dictyosomes associated with mitochondria. The tetraspores are released by the rupture of tetrasporangial wall. Two of the tetraspores after germination give rise to male and the other two to female gametophyte

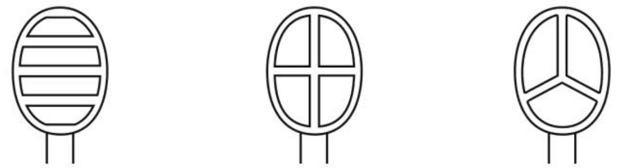


Fig. 6.10.7. Types of tetrasporangia

6.10.6 Life cycle: Two major life cycles have been recognized i.e. haplobiontic and diplobiontic in different members

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SECTION IV

MYCOLOGY

Chapter 7

General Account of Fungi

7.1 General characteristics

Biologists use the term fungus to include, "eukaryotic, spore-bearing and achlorophyllous, organisms that generally reproduce both sexually and asexually. Their somatic, usually branched filamentous structures are surrounded by cell wall containing chitin, cellulose or both of these substances, together with many other complex organic molecules."

7.2 **Lower and higher fungi.** The somatic body of the fungus consists of thread-like filaments called hyphae. Aggregation of hyphae is called mycelium, when present without cross walls constitute a **coenocytic mycelium**, a characteristic of lower fungi. The hyphae if divided by septa (cross walls) are called the septate mycelium and found in higher fungi.

7.2 **Details of cell structure:** The root-like hyphae form **rhizomycelium**, which may also be called pseudomycelium while well-developed septate mycelium is called **true mycelium**. The term **Plectynchyma** is used to designate all fungal tissue. **Pseudoparenchyma** consists of closely packed more or less isodiametric or oval cells resembling the parenchyma cell of vascular plants. **Prosynchyma** is a rather loosely woven tissue in which the component hyphae lie more or less parallel to one another and their typically elongated cells can be distinguished as such (Fig. 7.1). The hyphal tissue, when form compact mass is called **sclerotium.** The loosely interwoven hyphal mass is called **stroma.**

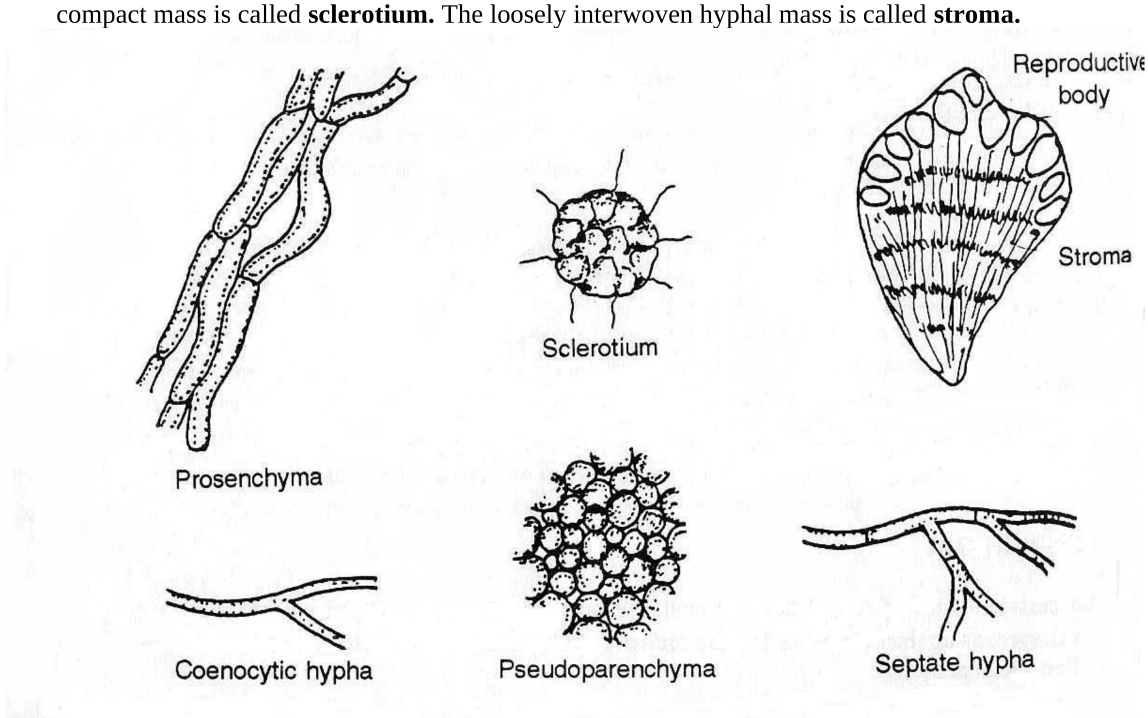

Fig. 7.1. Fungal thallus consisting of different types of tissue

7.3.1 **Boundary layer:** The principal components of the fungal cell wall are various polysaccharides, but proteins, lipids and other substances are also included. The chemical composition of cell wall is not same in all the fungi; however, chitin is characteristically present in the walls of most fungi. Other constituents include, cellulose-glycogen (Acrasiomycetes), cellulose-β-glucan (Oomycetes), chitin-β-glucan (all higher fungi) and mannan-β-glucan (Ascomycetes).

7.3.2 **Cytoplasmic details:** Under light microscope the tips of hyphae are seen to contain a phase-dark spitzenkorper (apical body), which disappears when growth stops, reappears when growth restarts, and it changes the position in the apex when a hypha changes direction of growth. Microfilaments and microtubules are major components of the cytoskeleton. Other cytoplasmic components of fungi include ribosomes, strands of endoplasmic reticulum, vacuoles, lipid bodies, glycogen storage particles, microbodies, Golgi bodies, filasomes, multivesicular bodies, the microtubules and microfilaments that comprise the fungal cytoskeleton. Spherical structures known as Woronin bodies are also present in certain types of fungi and typically are associated with septal pores. Chitosomes are small spheriodal bodies, 40-70 nm in diameter, each surrounded by a 'shell', which is about 7 nm thick. The plasma membrane of fungi is similar to that of other eukaryotes, consisting of a phospholipid bilayer and associated proteins and sterols. Its main role is to regulate the uptake and release of materials, and relaying signals from the external environment to the interior of the cell a process known as signal transduction. Fungi have Golgi bodies, endoplasmic reticulum and vesicles serving as secretary system. Proteins that are destined for export from the cell are synthesized on ribosomes attached to the ER, enter the lumen of the ER after synthesis and are then transported within the ER to the Golgi apparatus. Within the cisternae of the Golgi bodies these proteins undergo modifications, including partial cleavage and reassembly, folding into a tertiary structure and the addition of sugar chains. They are packed into vesicles which bud from the maturing face of Golgi bodies. The vesicles are transported to the plasma membrane and fuse with it, delivering the contents to the exterior or inserting them into the membrane.

The cytoplasm also contains vacuoles having several functions, including the storage of compounds and the recycling of cellular metabolites. Vacuoles are often seen as conspicuous rounded structures in the older parts of hyphae. Recently, it has been demonstrated that vacuoles are narrow tubules which can dilate and contract with the peristaltic movement of inflated elements. The tubular vacuoles contain carboxyfluorescein, which form a more or less continuous system which passes through dolipore septa of Basidiomycetes.

7.3.3 Storage products: Mycorrhizal species of fungi accumulate phosphates in the form of polyphosphate. Calcium is stored in vacuoles which can be released into the cytoplasm as part of the intracellular signaling system. The compounds used for energy storage and translocation in fungi are quite different from those of plants but are strikingly similar to those of insects. The main energy storage compounds are lipids, glycogen and trehalose. Trehalose is the main translocated carbohydrate. Polyoles such as mannitol and arabitol or ribitol are found in Zygomycota. Oomycota have none of these carbohydrates, rather their storage compounds are lipids and soluble mycolaminarins (β-linked polymers of glucose).

7.3.4 Nucleus and nuclear division: Fungi possess organized demonstrable nuclei each with a nuclear envelope, a nucleolus, and chromatin strands that become organized into chromosomes during division. Mitosis in most fungi is typically intranuclear (closed) and is characterized by the presence of centriols or small electron dense structures called spindle pole bodies. Compared to the nuclear division in plants and animals, the nuclear envelope does not break during prophase in fungi. It means that bulk of the nuclear envelope remains intact until late telophase when it breaks in the horizontal region and then reforms around the daughter nuclei. The typical fungal nucleus usually contains a prominent nucleolus that is often centrally positioned. Depending upon the species involved, the nucleolus can have one of three fates during division. It may persist and eventually undergo fission, it may become dispersed and no longer be visible in a dividing nucleus, or it may be discarded from the dividing nucleus into cytoplasm as an intact entity (Fig. 7.2).

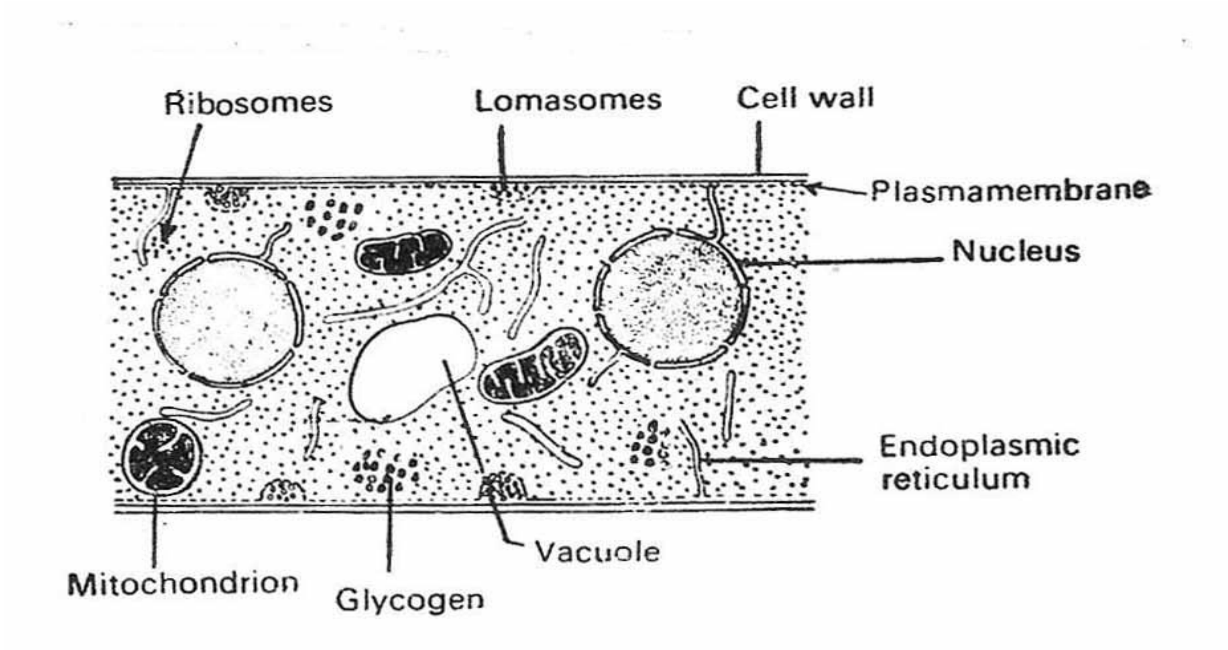

Fig. 7.2. Ultrastructure of a fungus hypha.

7.4 Modes of nutrition

Fungi that obtain their food from dead organic matter are called saprobes or **saprophytes**, and those growing on living matter are called **parasites**. Those fungi only growing on dead organic matter are called **obligate saprophytes** and those growing only on living matter are called **obligate parasites**. Originally saprophytic fungi but also capable of growing on living matter are called **facultative parasites**, while those which can also grow on dead organic matter according to the circumstances are called **facultative saprophytes**. Those fungi, which can kill the host tissue in advance of their invasion, are called **perthotrophs**; those colonizing dead organic tissue are called **necrotrophs**, while those parasitizing living and dead tissue are called **hemibiotrophs**. The fungi engulfing their food in a pseudopodia-like fashion are called **phagotrophic**, while those forming specialized structures such as haustorium, appresorium or infection peg have **absorptive** mode of nutrition. Hastorium is a knob like structure which may be oval, elongated or flattened and is used for the attachment and nourishment of the fungus from the host. Appressorium is a pressing organ of the fungus used for the typical absorptive mode of nutrition. Infection peg is minute outgrowth from appressorium or from germ tube used for infection by the fungi.

7.5 Reproduction

Fungi employ three methods of reproduction: **vegetative** or **asexual**, **sexual** and **parasexual**. In the formation of reproductive organs either sexual or asexual, the entire thallus may be converted into one or more reproductive structures. Fungi that follow this pattern are called **holocarpic**. In the majority of fungi, the reproductive organs arise from only a portion of thallus, while the remainder continues its normal somatic activities; the fungi in this category are called **eucarpic**. Union of protoplast is called **plasmogamy**; union of nuclei is called **karyogamy**, meiosis restores the haploid condition. In a true sexual cycle these three processes occur in a regular sequence and usually at specified points. In parasexuality these processes occur at unspecified intervals and with uncertainty. If there is only one free-living thallus, haploid or diploid, in the life cycle of a fungus, that life cycle is called **haplodiplontic** (or haplobiontic; Fig. 3.6). If haploid thallus alternates with a diploid, the life cycle is said to be **diplohaplontic** (or diplobiontic; Fig. 3.7).

Vegetative Reproduction: Fungi employ a large number of methods of asexual reproduction. Fission is the transverse splitting of a cell into two. Fragmentation is the cleavage of hyphae (e.g., Actinomyces). Budding is the protrusion of a bubble like structure from the weak portion of parent hyphae (e.g., yeast fungi).

Asexual Reproduction: Arthrospore is formed by rounding off of the cleaved hyphae (e.g., *Oidium mangiferae*). Chlamydopsores are formed by the formation of a tough resistant wall around the spore (e.g., smut fungi). Conidia is the asexual spore formed on a stalk of hyphae called conidiophores (e.g., *Spilocaea pomi*).

Sporangiospores are formed in a sac like sporangium, which after cleavage of the protoplasm is transformed into different compartments and each compartment secretes a wall around itself and becomes a sporangiospore (e.g., *Rhizopus stolonifer*). When the mycelium is converted into resistant compact mass it is called sclerotium (e.g. *Rhizoctonia solani*).

Sexual Reproduction: Following methods of sexual reproduction are known in fungi (Fig. 7.2)

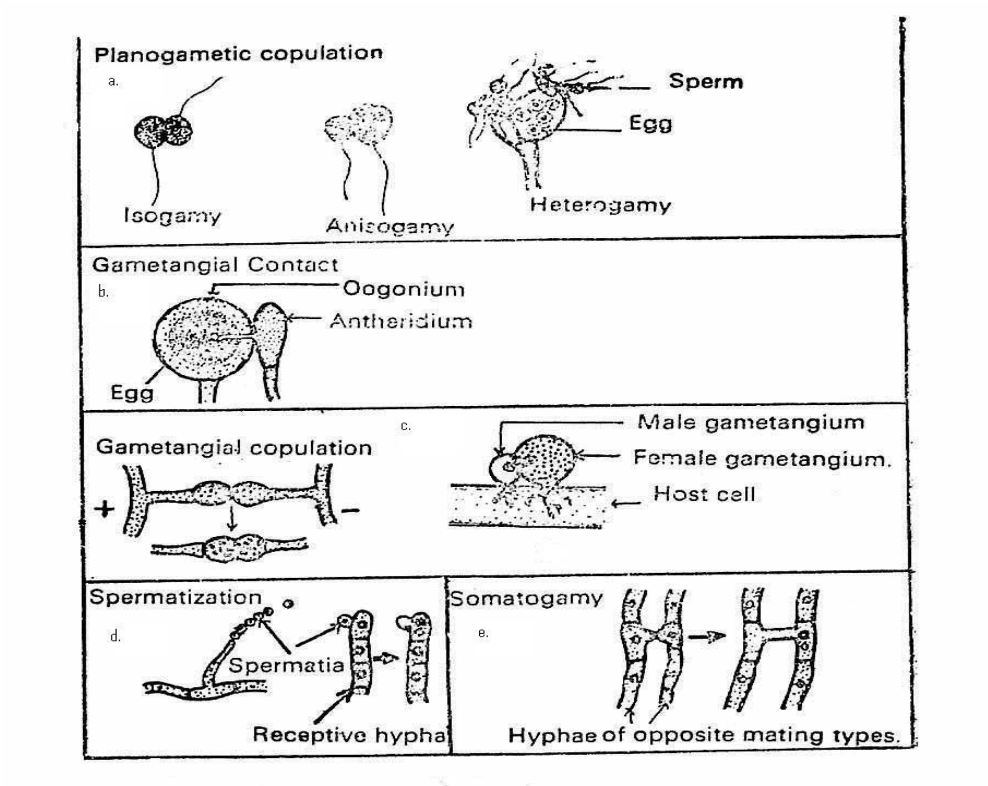

Fig. 7.2. Various methods of sexual reproduction in fungi.

a. **Planogametic copulation:** It is the union between two moving gametes, either by isogamy or aniosgamy (heterogamy). Isogamy is also called isoplanogametic copulation. Planogametic copulation occurs in Chytridiomycetes.
b. **Gametangial contact:** Anthridium (male sex organ) is united with oogonium (female sex organ) and transfers its protoplasmic contents and results in the formation of sexual spore (e.g. oospore in oomycetes).
c. **Gametangial copulation:** One gamete bearing structure copulates with another compatible gamete bearing strain and results in the formation of sexual spore, for example zygospore in zygomycetes (Fig. 7.2).
d. **Spermatization:** Spermatia formed on spermatiophores fall on the receptive hyphae of compatible strains of rust fungi. After fertilization (spermatization) aeciospores are formed (e.g. *Puccinia graminis* f. sp. *tritici*).
e. **Somatogamy:** Union of somatic structures of two compatible strains (e.g., Ascomycetes).

On the basis of sex, most fungi may be classified into three categories:

a. **Hermaphrodite** (monoecious), in which each thallus bears both male and female organs that may or may not be compatible.
b. **Dioecious,** in which some thalli bear only male and some thalli bear only female organs. Very few dioecious fungi have been reported.
c. **Sexually undifferentiated,** in which sexually functional structures are produced that is morphologically indistinguishable as male or female.

Fungi in the above sex categories belong to one or another of the following three groups, on the basis of compatibility.

a. **Homothallic Fungi:** Those in which every thallus is sexually self-fertile and can therefore reproduce sexually by itself without the aid of another thallus. Obviously no dioecious fungus can be homothallic. Fungi in this category exhibit no mating types.

Heterothallic Fungi: Those in which every thallus is sexually self-sterile, regardless of whether or not it is hermaphrodite, and requires the aid of another compatible thallus of a different mating type for sexual reproduction.

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Chapter 8

Ecology and Distribution of Fungi

8.1 Habitats

Fungi live in a variety of habitats. Plant pathogenic fungi can survive in soil for many years in the form of specialized (spore-like) structures (e.g. sclerotia). These can continue to live and grow on dead organic matter for certain period of time. But they have to infect the living tissue for some time to increase the number of propagules. Examples of such fungi are *Fusarium oxysporum* f. sp. *ciceris* causing chickpea wilt; *Rhizoctonia solani* causing root rot of cotton and several other plant species.

Seed-borne fungi are involved in inducing several epidemic diseases. Examples are smuts and bunts of cereals; seed rot, damping off of seedlings and root rot. The spores of such fungi can survive on the seed surface or inside the seed in the form of dormant mycelium. Air-borne fungi can cause foliar diseases such as leaf spots or blights or soft rot diseases, if they manage to penetrate the host through injury, bruises and scratches. Such fungi can secrete enzymes such as pectinase, protopectinase, pectin methyl esterase, which can dissolve the middle lamella and the tissue is macerated to become soft and pulpy. A fungus can be soil, seed and air-borne simultaneously. Some fungi are restricted to only one type of habitat and may not survive in another for not being suitable for their growth and multiplication. In fact the ecology and distribution of fungi is greatly influenced by the specific type of environment, which determines not only their mode of survival but also their growth and multiplication.

8.2 Types of environments

Fungi are most commonly found in aquatic or terrestrial environment. The survival and performance of fungi depends on the physical, chemical and biological environment. Physical environment include temperature, light, humidity, rainfall, wind speed and direction, solar radiation, leaf wetness, dew point, soil temperature and moisture, soil pH etc. Chemical environment include micro- and macro-elements in the growth media. For optimum fungal growth balanced nutrition is required, while imbalance nutrition modifies fungal population. Biological environment consist of activities of various microorganisms in addition to fungi. The interaction of these organisms determines the frequency, association and distribution of virulent and avirulent propagules of fungi.

8.2.1 Aquatic fungi: Based on their biology, the representatives of the aquatic fungi are the aquatic hyphomycetes, which can be divided into two groups.

- **a. Ingoldian fungi:** They are often found growing on submerged leaves, wood and twigs in well-aerated bodies of water. The conidia are produced under water and when freed, become trapped in surface foam produced by water action. Many of these species have branched tetraradiate or multiradiate conidia. Examples include pyrenomycetes (*Nectria*), discomycetes (*Hymenoscycphus*) and loculoascomycetes (*Massarina*). Some basidiomycetes also produce tetra radiate conidia and basidiospores, and an entomophthoralean genus (Erynia) has tetra radiate conidia.
- **b. Helicosporous aquatic fungi:** They are also called aero-aquatic fungi. The members are found in still and stagnant marine waters. Although they survive in water and mud of low oxygen content, they need higher oxygen levels for colonization of new substrates. The conidia often have three-dimensional shapes such as spirals and many-celled cage like structures, formed at the air-water interface where they are produced. Trapped air makes these conidia buoyant. Other conidia of this group are coiled when produced later to unwind and become sigmoid upon release, also called "fungi with a twist." Examples are *Lulworthia* (Pyrenomycetes), *Hymenoscyphus* (Discomycetes) and *Tubeufia* (Loculoascomycetes).

8.2.2 Edaphic fungi (soil fungi)

Rhizoctonia, Pythium, Sclerotium and *Fusarium* are the important soil-borne fungi, which can survive in soil for long time. In the same soil many antagonistic microorganisms are also present. The important antagonistic fungi are *Trichoderma* and *Gliocladium* species. They are widely distributed all over the world and occur in almost all types of soils. When the fungal resting structures such as sclerotia, chlamydospores, oospores, conidia, etc. are added to the soil they do not germinate; a condition called soil fungistatis. It is a widespread natural soil toxicity, which inhibits propagule germination. The cause for soil fungistatis is complex. A complex balance of stimulators and inhibitors in soil microenvironments controls fungistatis. The fungistatis in soil can be removed by addition of nutrients in soil such as crop residues, root exudates and various amendments.

8.2.3 Aerophytic fungi (air-borne fungi): Common airborne conidia include those of *Cladosporium*, *Alternaria*, *Stemphyllum*, *Curvularia*, *Aspergillus*, *Penicillium*, *Acremonium*, *Fusarium*, *Nigrospora*, *Zygosporium*, *Aurobasidium* and *Pithomyces.* The branch of mycology dealing with the studies of air-borne mycoflora is called aeromycology. Equipments used here include special trapping devices that ensure the collection of even very small spores that affect the collecting surface. Atmospheric conditions are used to extrapolate spore dispersal, distribution and landing. In this regard a number of formulae have been developed for modeling spore fall under different conditions. The capture of spores on a surface depends upon their terminal velocity, a function of the square root of the spore radius. A petri dish makes an effective trap that will collect diaspores from the air. The number of spores in the air usually differs depending upon the pattern of rain. Number of conidia decrease dramatically just after rain, while ascospores increase. Time of day, temperature, and place of collection are other variables that have been found to affect spore trapping.

8.2.4 Thermal fungi: Keeping in view the temperature requirements of fungi, these can be placed under three groups, i.e., psychrophilic (cold loving), mesophilic (growing at moderate temperature) and thermophilic (heat-loving). A few fungi are psychrophilic, with the ability to grown at or below 0ºC and with upper limits of about 20ºC. These fungi include several yeasts and mycelial species of permanently cold regions of the world, and a few species that cause spoilage of meat in cold storage. *Cladosporium herbarum* and *Thamnidium elegans* are found on cold-stored meat, but their normal habitats are leaf surfaces (*Cladosporium* sp.) and the animal dung (*Thamnidium* sp.).

Most fungi are mesophilic, growing within the range 10-35ºC, although with different tolerances within this range. The optimum temperature ranges between 20 and 30ºC. For routine purposes these fungi can be grown at room temperature (22-25ºC). About 100 fungi can be considered thermophilic, with a minimum temperature of about 20ºC, an optimum near 40ºC and a maximum extending to 50-60ºC. However, there are variations within this range, but these fungi are common in composts, in birds' nests and in non-heated soils (Fig. 8.1).

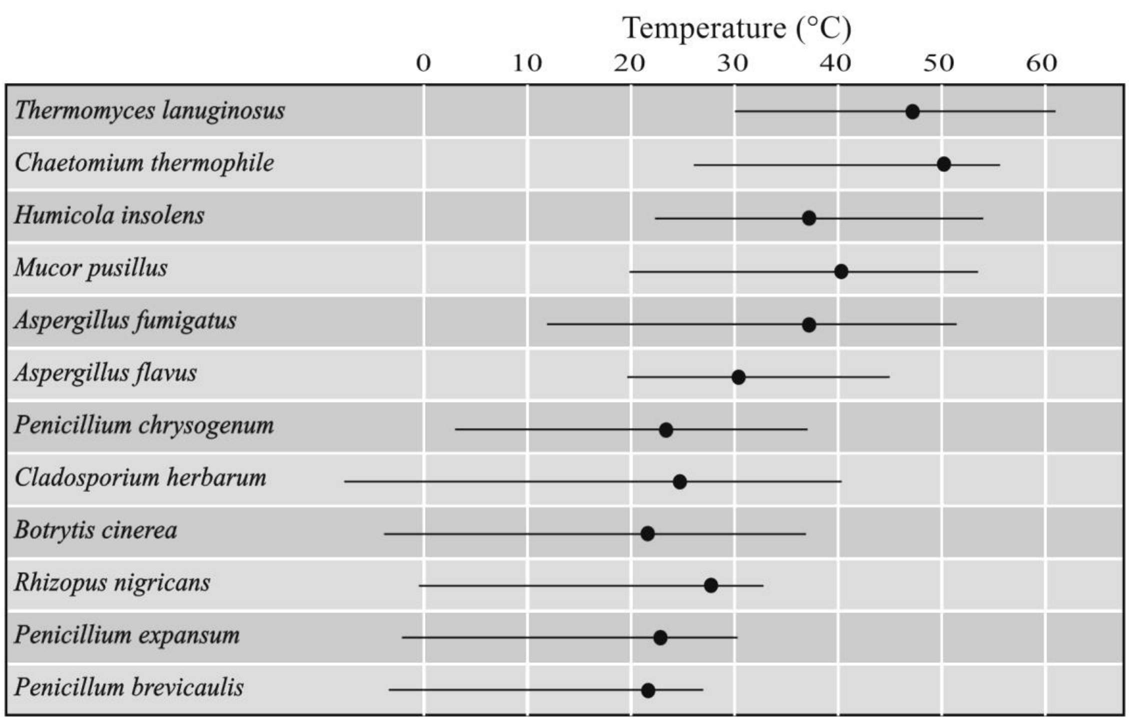

Fig. 8.1. Temperature ranges for the growth (optimum •) of some representative fungi

Thermophilic fungi are mostly found in composts used for the production of mushrooms and made from any type of decomposable organic matter, stacked into a heap with adequate nitrogen, moisture and aeration. Some cellulolytic fungi such as *Chaetomium thermophile, Humicola insolens, Thermoascus aurantiacus, scytalidium thermophilium* and *Aspergillus fumigatus* can grow within a range of 57-60°C. For example in *C. thermophile* (maximum temperature about 55°C, optimum about 50°C) may start earlier than *H. insolens* (maximum about 55°C, optimum about 37°C). Both these fungi are known to grow before *A. fumigatus* (maximum 52-55°C, optimum 37-40°C), which is relatively late colonizer when the temperature falls to about 40°C as the temperature falls below 35-40°C, the thermophile fungi start to decline, but *A. fumigatus* remains active.

8.2.5 Epiphytic fungi (plant parasitic fungi): *Alternaria, Phylosticta, Phoma, Dendrophoma, Cuvularia, Pestalotia, Gloeosporium* and *Septoria* are the genera of fungi living on the leaves. Some of these fungi live in peaceful coexistence with the host, while others grow and cross the limits of parasitism and start damaging the host. *Botrytis cinerea* and *B. fabae* are colosely related fungi. *B. cinerea* invades the compromised tissues of many plants, whereas *B. fabae* is a host-specialized parasite of broad bean (*Vicia faba*) and its few closely related species. The ovoid conidia of *B. fabae* are 20-25 μm long, compared with only 10-15 μm for *B. cinerea*. This difference can affect the efficiency of impaction onto leaves, especially to the wide leaves of broad bean plants. The spores of both fungi germinate when placed in water drops on the surface of broad bean leaves. But *B. cinerea* usually fails to penetrate the leaf cuticle, whereas *B. fabae* penetrates and causes hypersensitive response. This difference in initial penetration has been explained by their nutrient reserves. *B. cinerea* will penetrate and cause a necrotic spot if sugars are added to the inoculum drop or sometimes even if antibiotics inactivate the normal leaf surface microorganisms so that the fungus can use the leaf surface exudates. The aged spores of *B. fabae* taken from old parts of agar colonies failed to penetrate because their endogenous reserves had been depleted, but they could penetrate when supplied with exogenous sugars. Thus, like *B. cinerea* many epiphytic fungi have developed strategy as general invaders of senescent tissue. They can produce many more spores from a given amount of resource but depend on nutrients released from compromised host tissue. *B. fabae* produces fewer spores from the same amount of resource, but each of them has sufficient reserves to initiate infection to the healthy host. The reaction of broad bean leaves to various species of Botrytis has been shown to explain the degree of parasitism of these epiphytic fungi (Fig. 8.2).

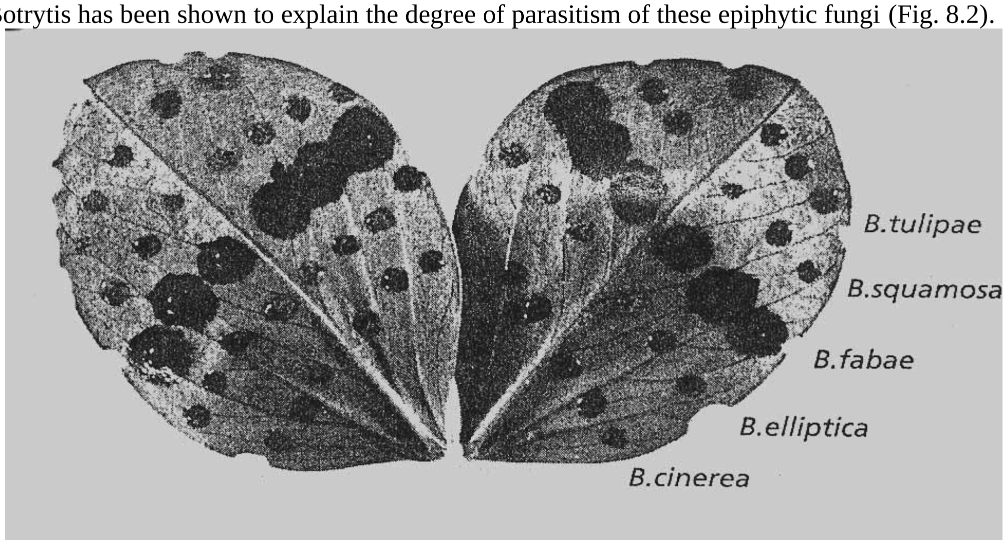

Fig. 8.2. Comparison of levels of damage (5 days after inoculation with different species of *Botrytis*) on leaves of broad bean. Only *B. fabae* have caused severe spreading lesions, but all species have caused localized necrosis of the leaf tissue.

8.2.6 Epizoophytic fungi (animal parasitic fungi): Some fungi parasitizing small animals generally utilize cellulose and lignin substrates that are low in available nitrogen. Bacteria, copepods, colymbolas, amoebae and nematodes all are attacked. Examples of such endoparasitic species include *Verticillium, Meria, Harposporium anguillulae*, all of which produce conidia that are ingested by nematodes. Some species produce extensive mycelia and capture nematodes by various somatic structures including constricting and non-constricting hyphal rings and adhesive branches, nets and knobs. In addition lectin, nematodes attracting pheromones and toxins probably are involved. *Dactylella bembicoides, Dactylaria* *bronchopaga, Arthrobotrys dactyloides,* form constricting rings, *A. oligospora,* form a complex of adhesive hyphae. In *Dactylaria candida* both nonconstricting rings and adhesive knobs are involved in the capture of prey. Placing dung, decaying wood and mushrooms, bryophytes, or soil on agar plates can isolate nematodes and nematode-destroying fungi. As the fungi and nematodes spread out on the agar, the life and death can be viewed with the compound microscope.

8.3 Factors affecting fungal distribution

The survival and distribution of most fungi depends upon the prevailing conditions of temperature, pH, aeration, water and light. Phycomycetes fungi producing zoospores require free water for the production, movement and germination of the zoospores. The great majority of fungi depend upon wind rain splashes, irrigation water, birds, insects other animals and humans. The spore dissemination in almost all fungi is passive, although their initial discharge may be forced. The distance to which spores disseminate varies with the agent of dissemination. Wind is probably the most important distributing agent of spores of a great majority of fungi and spreads fungal spores over larger distances. For specific fungi other agents such as water or insects may play a much more important role than wind in the dissemination of their spores. The chemical composition of the substrate and the presence of other microorganisms in the ecological environment are also very important factors influencing fungal distribution.

8.3.1 Physical factors

a. **Temperature:** Optimum temperature for any fungus is a key player in the growth and distribution of fungi. Free mycelium survives only within a certain range of temperature (-5 to +45°C) and in contact with moist surfaces inside or outside the host. Most kinds of spores however, can withstand broader ranges of both temperature and moisture and carry the fungus through the low winter temperatures and dry summer periods. Spores however, also require favorable temperatures and moisture in order to germinate. In order for the fungal growth to occur, the fluidity of the cell membrane must be maintained within certain limits. All microorganisms seem to achieve this range by varying the composition of lipid membrane. Saturated fatty acids (as in butter) are less fluid than unsaturated fatty acids at any given temperature. A comparison of nine thermophilic fungi with nine mesophilic fungi of the same genera showed that the thermophiles consistently had a higher ratio of saturated to unsaturated lipids in their membranes. When the thermophilic fungi were grown near their lower temperatures they changed their membrane lipid composition so that the proportion of unsaturated lipids was higher.

b. **pH:** Many fungi grow between 4.0-8.5 or some times 3.0-9.0. They show relatively broad pH optimum range of 5-7. Several fungi are acid tolerant including some yeast, which grow in the stomachs of animals, and some mycelial fungi. Examples are *Aspergillus*, *Penicillium* and *Fusarium* spp. which will grow at pH 2, but their optimum pH is 5.5-6.0. Truly acidophilic fungi seem to be rare, and the most cited example is *Acontium velatum*, which can grow in 1.25 M sulfuric acid. It can initiate growth at pH 7, but rapidly lowers the pH of culture media to about 3, which is probably close to its optimum. There are many naturally acidic environments where the acid-tolerant or acidophilic fungi can grow. In contrast there are few strongly alkaline environments, although several fungi will grow up to pH 10-11 in culture e.g. *Fusarium oxysporum, Penicillium variabile.*

   In general pH response, fungal growth curves may be relevant to natural situations. For example, *Pythium* spp. are generally intolerant of very low pH but occur in soils above pH 4-5, *Stachybotrys chartarum* is found predominantly in neutral and alkaline soil and *Trichoderma* spp. are characteristic of acidic soils. Fungi can alter the pH around them and thus to some degree create their own environment. The most general method of doing this is by selective uptake and exchange of ions. For example NH_4^+ is taken up in exchange for H^+, so the external pH can be lowered to 4 or less leading to growth inhibition of acid sensitive fungi such as *Pythium* spp. Conversely, the uptake of nitrate (NO^3-) can cause the external pH to rise by 1 unit. Fungi can release organic acids, which lower the external pH. Some of the aggressive tissue-rotting pathogens (*Sclerotium rolfsii* and *Sclerotinia sclerotiorum*) of plants release large amount of oxalic acid lowering the pH to about 4.0. Thus environmental pH can help to orientate fungal growth to a great extent.

c. **Aeration:** Most fungi are strict aerobes, in the sense that they require oxygen in at least some stage of their life cycle. Even *Saccharomyces cerevisiae*, which can grow continuously by fermenting sugars in anaerobic conditions, needs oxygen for sexual reproduction. All fungi need CO_2 in at least small amounts for carboxylation reactions that generate fatty acids, oxaloacetate, etc. Fungi that grow in anaerobic conditions often have a high CO_2 requirement, whereas several aerobic fungi can be inhibited by high CO_2. However, the significance of this in natural environment is difficult to judge.

d. Moisture: All fungi need physical presence of water for diffusion of nutrients into the cells and for the release of extracellular enzymes. Fungi also need to take up water to maintain their cytoplasm. In order to retain the existing water a fungus must generate a potential equal to the external water potential. Water-stress tolerant fungi are economically important in the spoilage of cereal grains and other stored food products. None of these fungi can grow if the grain is dried up to 14% moisture level. But this is not always true, because at 15-16% moisture contents stress-tolerant *Aspergillus* spp. start growing. In fact *Aspergillus* and *Penicillium* spp. typically cause post-harvest spoilage, but the most stress tolerant species such as *A. amstelodami* and *A. restrictus* are the initiators followed by *A. fumigatus* and *Penicillium* spp. In contrast, *Fusarium* spp. commonly are regarded as field fungi because they initiate spoilage in field conditions if there is a wet harvest season but they are intolerant of severe water stress. The fungi that grow commonly on the surfaces of living leaves show a different type of adaptation to water stress. *Cladosporium Alternaria* and *Aureobasidium* do not grow at low water potentials but have remarkable ability to withstand periodic wetting and drying. These fungi have adapted to the fluctuating moisture conditions of the leaf surface and the same adaptations probably enable these 'sooty moulds' to grow on kitchen and bathroom walls.

e. Light: Visible light (~380-720 nm) has relatively little effect on somatic growth, although it can cause a zonation of some fungi on agar. In contrast to somatic growth, light can profoundly affect reproduction or other differentiating events. Several fungi produce circular zones of asexual sporulation corresponding to daily alterations in light and darkness. Light has other effects on fungal reproductive structures, notably in eliciting phototropism of the sorangiophores of some zygomycota and of the ascal tips of some ascomycota. The light responses of fungi often are clearly related to ecology; the light responsive fungi almost invariably are those that produce air-borne spores.

8.3.2 Chemical factors: Most fungi are grown on chemically undefined media such as potato dextrose agar, malt extract agar or corn meal agar, which are acidic (pH 5-6) and carbohydrate rich. In contrast to these media nutrient agar, yeast dextrose agar and several others, which are most commonly used to culture bacteria are neutral or alkaline (pH 7-8) and rich in organic nitrogen. This difference reflects, in part, the difference in habitats of the more common fungi and bacteria, but it also reflects the generally higher requirement for organic nitrogen on the part of bacteria. Many other types of agar media are used to culture specific fungi, or to promote specified developmental stages, or for selective isolation of particular species from mixed communities.

In order to determine the minimum nutrient requirements, a fungus must be grown on chemically defined basal medium. Given a sugar source they can synthesize all other cellular components from this and the mineral components. However, following chemical factors can influence this generalization:

a. Some fungi need to be supplied with one or more vitamins, the most common requirements being for thiamine (vitamin B_1), biotin or both. These vitamins play essential roles in basic cellular metabolism so that the fungi that do not synthesize them can certainly obtain them from the natural habitat. However, multiple vitamin requirements are rare in fungi.

b. Some fungi can not utilize nitrate or ammonium but instead require a source of organic nitrogen. In these cases the requirement usually can be met by supplying a single amino acid such as asparagine. Several basidiomycota fall in this category.

c. Some fungi have more specific individual requirements, again related to their habitats where these requirements will be met. For example, some Oomycota (e.g. *Phytophthora infestans*) need to be supplied with sterols for growth; the order *Leptomitales* within the oomycota (e.g. *Leptomitus lacteus*) need sulphur containing amino acids such as cystein because they cannot use inorganic sulphuur; some of the fungi from animal dung need the iron-containing haem group, a component of cytochromes in the respiratory pathway.

The above description refers to the minimum requirements for growth, not necessarily the optimum growth, and to complete life cycle. For example, several *Pythium* and *Phytophthora* spp. do not require sterol for hyphal growth, but they need them for both sexual and asexual reproduction. Finally many fungi will have extra nutrient requirements for growth in sub-optimal environmental conditions. For example, *Sacchromyces cerevisiae* has relatively simple requirements for growth in aerobic culture but needs a wide range of vitamins and other compounds for growth in anaerobic conditions, when some of the basic metabolic pathways are inoperative.

8.3.3 Biological: Mycologists generally recognize three types of fungal interaction:

a. **Competition**: The ability of one species to exclude another by competition (by being faster or more efficient in exploiting a resource (space, substrate etc.). Example is control of 'Take all disease of wheat' caused by *Gaeumannomyces graminis* by *Phialophora graminicola.*
b. **Antagonism**: The ability of one species to exclude or replace another (by directly affecting other organism through antibiotic production). Example is control of root rot of cotton caused by *Rhizoctonia solani* through antagonistic effect of *Trichoderma harzianum*.
c. **Commensalism or mutulism**: The ability of two species to interact to the benefit of one or both and with no negative impact on the other species. Examples are symbiotic association of algae and fungi resulting in lichen and mycorrhizal associations with plants (Please see chapter 10).

Suggested readings

1. Agrios, G. N. 1997. Plant Pathology. 4th ed. Academic Press, Inc., New York.
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3. Ingold, C. T., 1971. Fungal Spores and their dispersal. Clarendon Press, Oxford.
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Chapter 9
Fungal Classification

Fungi comprise an important group of organisms and considerable efforts have been made to understand their structural and functional relationships. Based on these features, a number of changes have occurred in fungal taxonomy over the past few decades.

9.1. Systems and criteria of fungal classification

Mycologists have used various characters to classify fungi including morphology, anatomy, ultrastructural features, biochemistry, nucleic acid sequences, gross morphology and conidial ontogeny. Techniques such as, microscopy, chromatography and protein electrophoresis have been useful in comparison of fungal pigments and isozymes. The DNA sequence characters, rRNA and PCR techniques are being used for phylogenetic analysis now-a-days.

A number of schemes have been proposed to classify fungi. Very first systematic fungal classification was proposed by Clements and Shear (1931) as shown in Table 9.1. Various other systems proposed from time to time have been compared. In this book, the classification proposed by Hawksworth et al., (1995) and described by Alexopoulos et al., (1996) has been followed (Table 9.1).

Table 9.1. Classification of fungi described by various mycologists.

Clements and Shear (1931) (Hyphae coenocytic or septate, presence of sex cells	**Alexopoulos (1962) (Morphological characters)**	**Ainsworth (1966) (Detailed Morphological characters)**	**Alexopoulos and Mims (1979) Modes of nutrition, types of zoospore flagella, holocarpic or eucarpic, fruiting bodies)**	**Hawksworth (1994) Phylogenetic relationship as determined by DNA sequence, isozyme analysis, TEM, SEM and other advanced characters**
Fungus	**Plantae**	**Fungi**	**Mycetae**	**Kingdom: Fungi**
Phycomycetes	Mycota Myxomycotina Myxomycetes	Myxomycota 1. Acrasiomycetes 2. Hydromyxomycetes 3. Myxomycetes 4. Plasmodiophoromycetes	Gymnomycota Acrasiogymno-mycotina 1.Acrasiomycetes Plasmodiogymno-mycotina 2. Protosteliomycetes 3. Myxomycetes a. Ceratiomyxomycetidae b. Myxogastromycetidae c. Stemonitomycetidae	Kingdom: Stramenopila Phylum Oomycota Phylum Hyphochytridiomycota Phylum Labrinthulomycota Kingdom: Protista Phylum Plasmodiophoromycota Phylum Dictyosteliomycota Phylum Acrasiomycota Phylum Myxomycota
Ascomycetes	Eumycotina Plasmodiophoromycetes	Eumycota Mastigomycotina 1. Chytridiomycetes	Mastigomycota Haplomastigomycotina 1. Chytridiomycetes	Kingdom: Fungi Phylum: Chytridiomycota

	Chytridiomycetes Hyphochytridiomycetes Oomycetes Zygomycetes Trichomycetes Ascomycetes a. Hemiascomycetidae b. Euascomycetidae Series Plectomycetes Series Pyrenomycetes Series Discomycetes Series aboulbeniomycetes c. Loculoascomycetidae	2. Hyphochytridiomycetes 3. Oomycetes Zygomycotina 1. Zygomycetes 2. Trichomycetes Ascomycotina 1. Hemiascomycetes 2. Plectomycetes 3. Pyrenomycetes 4. Discomycetes 5. Laboulbeniomycetes 6. Loculoascomycetes	2. Hyphochytridiomycetes 3. Plasmodiophoromycetes Diplomastigomycotina Oomycetes Amastigomycota Zygomycotina 1. Zygomycetes 2. Trichomycetes Ascomycotina Ascomycetes a. Hemiascomycetidae b. Plectomycetidae Hymenoascomycetidae a. Laboulbeniomycetidae b. Loculoascomycetidae	Phylum: Zygomycota Phylum: Ascomycota
Basidiomycetes	Basidiomycetes a. Heterobasidiomycetidae b. Homobasidiomycetidae Series Gasteromycetes	Basidiomycotina 1. Teliomycetes 2. Hymenomycetes a. Phragmobasidiomycetidae b. Holobasidiomycetidae 3. Gasteromycetes	Basidiomycotina Basidiomycetes a. Holobasidiomycetidae b. Phragmobasidiomycetidae c. Teliomycetidae	Phylum: Basidiomycota
Deuteromycetes	Form Class Deuteromycetes	Deuteromycotina 1. Blastomycetes 2. Hyphomycetes 3. Coelomycetes	Deuteromycotina Form Class: Deuteromycetes a. Blastomycetidae b. Coelomycetidae c. Hyphomycetidae	

9.2. Fungal Phyla and their significant characters

Kingdom "Fungi" includes Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota. "Stramenopila" are monophyletics having flagella and include Oomycota, Hypochytridiomycota and Labyrinthulomycota. The phylogenetic relationship among fungi has been designed based on DNA sequence analysis and ultrastructural features. Following important characters were used:

9.2.1 **Acrasiomycetes** (acrasid slime molds): The members diverged early in the eukaryotic lineage along with certain amoebae having discoidal mitochondrial cristae

9.2.2 **Myxomycetes** (plasmodial slime molds) and **Dictysteliomycota** (dictyostelid slime molds) having tubular mitochondrial cristae diverged independently of each other.

9.2.3 **Stramenopila** (having Oomycota, Hyphochytriomycota and Labrinthulomycota and several groups of algae): the members are with chlorophyll a and c, and are in the monophyletic lineage.

9.2.4 **Ascomycota:** The members evolved from red algae.

9.2.5 **Fungi** (chytridio, zygo, asco and basidio): They restricted to monophyletic lineage with a close relationship to animals through a choanoflagellate -like ancestor

9.2.6 **Plasmodiophoromycota:** Based on rDNA analysis it carries a relationship with ciliates

9.2.7 Organisms previously placed in kingdom Protista were not given this status due to their polyphyletic nature

9.2.8 The fact that why chytridiomycota were placed in kingdom **Fungi** instead of **Stramenopila** is based on their study on DNA sequence analysis. Previously chytridiomycetes and oomycetes were placed and studied under Mastigomycota based on their flagellar character. Now it has been considered as a primitive character looking like animals. The reason why oomycota were placed in stramenopila along with hyphochytriomycota and labrinthulomycota is their similarity due to DNA sequence analysis, flagellation and tubular mitochondrial cristae and beta-1, 3 or beta-1, 6 linked glucans as storage products.

Ascomycetes and Basidiomycetes have been considered having sister group relationships. Why zygo and chytridio are considered separate groups is due to lack of sufficient evidence and also because few species of these groups have been included in DNA sequencing to date and few morphological and biochemical characters are known to support each as monophyletic group.

9.3 Nomenclature

Naming of fungi and their classification falls under the rules contained in **International Code of Botanical Nomenclature** (Greuter *et al*., 1994). At each International Botanical congress (held every four years) a Committee for Fungi is appointed to make recommendations on proposals to conserve or reject names and comment on changes being considered in the rules relating to fungal nomenclature. When modifications of the existing code are approved at the congress, the code is updated. Rules of nomenclature apply to Typification, use of Priority and citation of Authority.

9.4 Detailed study of fungal phyla

9.4.1 Myxomycota: The fungi included in Myxomycota are called true slime molds, plasmodial slime molds or acellular slime molds. These are characterized by a free-living thallus, acellular, multinucleate somatic phase. The plasmodium which behaves as a unit at all times and eventually gives rise to fructifications (sporophores). Flagellated swarm cells are produced probably by all species, which after fusion form a young plasmodium that moves and exhibits a reversible shuttle streaming of its protoplasm, forms a resistant stage consisting of a sclerotium and finally a reproductive phase that culminates in the form of a sporophore.

The phylum myxomycota contains the single class myxomycete that is subdivided into three subclasses containing a total of six orders i.e., *Liceales, Echinosteliales, Trichiales, Physarales, Stemonitales* and *Ceratiomyxales.* These are distinguished on the basis of sporophore development, type of sporophore produced, method of spore production, spore color, presence or absence of capillitia (threadlike structures bearing spores) and plasmodial type.

Three basic types of plasmodia have been characterized in the myxomycetes. The smallest type is the **protoplasmodium** characteristic of Echinosteliales. It remains microscopic throughout its life. It is more or less homogenous forms no veins, and exhibits a very slow irregular streaming instead of a rapid, rhythmic reversible streaming of the other plasmodial types. A protoplasmodium usually gives rise to only a single sporangium when it fruits. The second plasmodium known as **aphanoplasmodium** is difficult to see. It is not granular, forms a network of very fine transparent strands, the veins are not conspicuously differentiated into jellified and fluid regions, and the streaming protoplasm seems to be confined by a very delicate membrane. Streaming is rapid and rhythmically reversible as in *Stemonitales*. The **phaneroplasmodium** characteristic of *Physarales*, also resembles protoplasmodium in the beginning but it soon grows larger and becomes more massive. Its protoplasm is very granular, visible at early stages, and its jellified and fluid portions of the veins are easily distinguishable and the rhythmic reversible streaming is very conspicuous.

9.4.2 Plasmodiophoromycota: Plasmodiophoromycota is well defined as a monophyletic group by several characters including its cruciform nuclear division. These fungi are also known as endoparasitic slime molds. Evidence suggests (rDNA analysis) that it belongs to ciliate protists. This phylum contains single class order and family i.e., Plasmodiophoromycetes, Plasmodiophorales, Plasmodiophoraceae. Two genera are important from plant pathological point of view, i.e. *Plasmodiophora* and *Spongospora*. *Plasmodiophora brassicae* causes club root of crucifers while *Spongospora subterranea* is involved in causing potato scab.

9.4.3 Dictyosteliomycota & Acrasiomycota: They are cellular slime molds. Distinguishing characters of both divisions are given in Table 9.1

Table 9.1: Characters that distinguish Dictyostelid and Acrasid Slime Molds

Characters	**Dictyosteliomycota**	**Acrasiomycota**
Pseudopodia of amoebae	Filose (leaf like)	Lobose*
Mitotic apparatus (spindle pole bodies)	Present	Absent
Pheromone	cAMP, others	Unknown
Migration of slug	Present	Absent
Prespore vacuoles	Present	Absent
Sorocarp differentiation	No germination	Stalk cells germinate
Spores and cyst walls	Cellulose	?
Flagella	Non flagellate	Biflagellate cells in some
Sexual reproduction	Reported macrocysts	Unknown

*(seperation of granular endoplasm and nongranular ectplasm)

9.4.4 Oomycota (water molds): The members have biflagellate zoospores, with a longer tinsel flagellum forwardly directed and shorter backwardly inserted whiplash flagellum. The sexual reproduction is oogamous type. Cell wall composed of primarily of β-glucans also contains small amount of cellulose. Mitochondria are with tubular cristae. There are three orders of this division

a. **Saprolageniales:** Thallus holocarpic or eucarpic and mycelial periplasm minimal; usually several oospores in an oogonium.
b. **Peronosporales:** Eucarpic, spores formed within the sporangium or if not then usually within an evanescent vesicle arising from the sporangium, monomorphic, reniform.
c. **Saprolegniales:** Members of this order are also known as ‘water molds’. The zoospores are formed in zoosporangia. Oogonia never develop periplasm. A peculiar feature of this group is the production of two types of zoospores (primary and secondary) called dimorphism or ‘diplanetism’ a term used in old literature.

9.4.5 Chytridiomycota (*Chytridium, Synchytrium*): The class Chytridiomycetes is characterized by a single posterior whiplash flagellum of their zoospores. It is divided into four orders: Chytridiales, Harpochytriales Blastocladiales and Monoblepharidales. Members of Chytridiales lack true mycelium and contain rhizomycelium. This order has several families: Chytridiaceae, Olpidiaceae, Synchytriaceae, Megachytriaceae, Rhizidiaceae and Phlyctidiaceae. *Synchytrium endobioticum* causes black wart disease of potato while *Physoderma zea-maydis* causes brown spot of maize.

9.4.6 Zygomycota (*Mucor, Rhizopus*): The class Zygomycetes is characterized by the production of sporangiospores, zygospores and presence of chitin in their cell wall instead of cellulose. Members of Mucorales are chiefly saprophytes, asexual reproduction by spores or occasionally by conidia. In case of Entomophthorales the fungi are parasitic on insects and their modified sporangia are discharged with force while in case of Zoopagales the conidia are passively discharged. Mucorales has been divided into 11 families. Mucoraceae sporangia have a distinct columella projecting in the sporangia. The spores are passively discharged while in case of Pilobolaceae the explosive shooting of the entire sporangium takes place. The two genera of Mucoraceae, Mucor and Rhizopus can be differentiated on the following points:

Mucor	**Rhizopus**
The mycelium consists of one kind of hyphae	The mycelium is distinguished into stolons (aerial hyphae) and rhizoids (root-like hyphae)
Sporangiophores may arise at any place	Sporangiophores arise from the junction of rhizoids and stolons
Sporangiophores are long and delicate	Sporangiophores are much shorter, stout and stiff
Sporangiophores remain adhered to the columella and not disseminated easily	Sporangiophores easily blown by wind and thus cause frequent contamination in laboratory
Meiosis occurs before the dormancy sets in zygospore	Meiosis occurs at the time of zygospore germination

9.4.7 Ascomycota: They have the following characteristics:

a. Somatic structures consist of septate hyphae containing chitin or cellulose and the wall appear to be two layered, with a thick, translucent inner layer and a dense, thin outer layer
b. Ascomycetous yeasts have hologenous walls.

c. In some ascomycetes the septal wall invaginates to form a closure line, a small circular opening (micropores) just like the plasmodesmata of plant cells. This pore is left near the center of the septum through which the plasma membrane and cytoplasm extend from one hyphal compartment to the next.

d. Woronin bodies may plug these micropores. In some filamentous ascomycetes membrane-bound pully wheel-like septal pore organells are distributed in parts of the mycelium so that structures involved in sexual reproduction are separate from other regions of the mycelium.

e. Concentric bodies are also found in *Venturia inaequalis* the origin and function of which is unknown.

f. Somatic structures of ascomycetes, in addition to producing appressoria and haustoria, form two types of hyphopodia.

g. Some ascomycetes mycelia produce nooses, traps, coils and sticky pegs that trap nematodes e.g. trap formation in *Arthrobotrys* may be induced by nematodes presence or by the addition of proteinaceous material into a culture. The fungus mycelium is more attractive to nematodes when traps are present and the modified trap hyphae produce lectin (carbohydrate binding proteins) that bind to specific sites on nematode surface. For this reason, the traps may also attach to other organisms including fungi with similar cell surface carbohydrates.

h. Ascomycetes mycelium may be organized into plectenchyma, prosenchyma and pseudoparenchyma; the last two associated with reproductive and resting structures.

i. **Classification of Ascomycota:** The present classification is based upon morphological, biochemical and molecular studies.

```
Ascocarp, Ascogenous hyphae, specialized ascus tip, conidium elaboration, Woronin bodies
                                        ||
Forcibly discharged asci,                       !
simple septal pore, ascus, EMS_____ !_______________Filamentous Ascomycetes
                                        |                  |
                                        |       _________||
                                        |       |          |_____________________ Saccharomycetales
                                        |_____ |               (characterized by DNA sequence analysis)
                                        |       |____________________ Archiascomycetales
                                        |                              Taphrina
                                        |                              Protomyces
                                        |                              Saitoella
                                        |                              Schizosaccharomyces
                                        |
                                        |______________________________Basidiomycetes
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j. **Reproduction**:

i. ***Vegetative reproduction:*** It takes place by budding, fission and fragmentation.

ii. ***Asexual reproduction:*** Chlamydospores, conidia, soredia and isidia are the commonly produced asexual spores. The capacity of the fungus to produce more than one form or type of spore in its life cycle is called pleomorphy.

iii. ***Sexual reproduction:*** Sexual reproduction takes place by gametangial copulation, gametangial contact, spermatization and somatogamy. Ascospore formation is characteristic of this division. The **ascosporogenesis** begins with the union of ascogonium and anthridium through a trichogyne tube. Pairing of nuclei takes place, which migrate into ascogenous hyphae. Septa are laid and any dikaryotic cell bends to form hook-like crozier which is soon transformed into ascus mother cell, tip cell and basal cell (Fig. 9.1). These two cells unite to restore the binucleate condition, while karyogamy occurs in the ascus mother cell. After meiosis haploid nuclei are formed which divide mitotically to produce eight nuclei. Each of these secretes a wall around itself and forms ascospore. Thus formation of ascopore and then sexual fruiting bodies is completed through the process of "free cell formation"

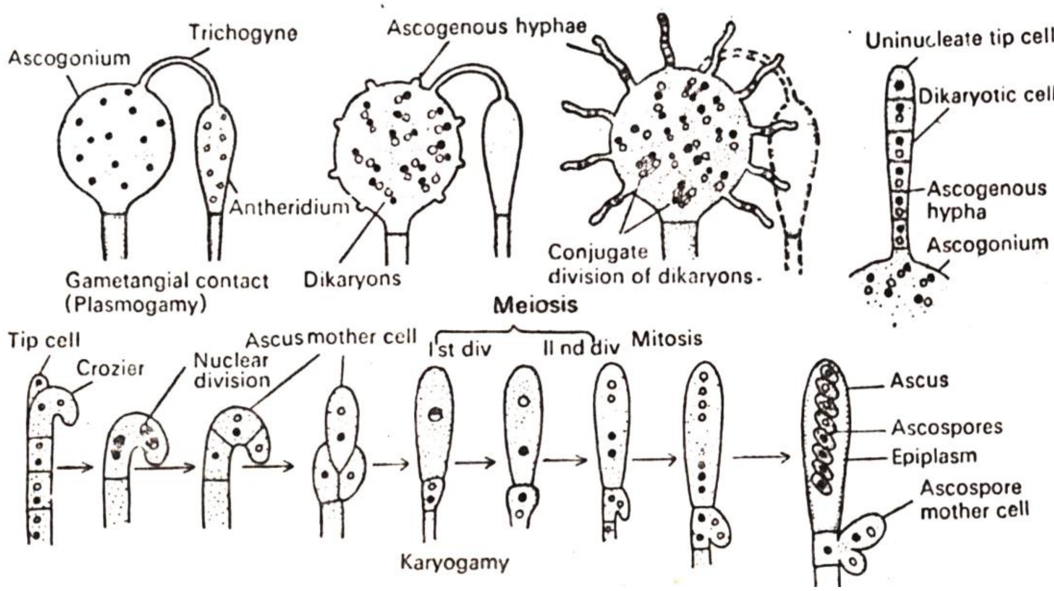

Fig. 9.1. Stages in the development of ascus in ascomycetes.

k. Habitat and importance: Majority of asexual ascomycetes are either saprobes or weak parasites of plants. Few species trap and consume nematode. Others are lichen symbionts endophytes of angiosperms and gymnosperms and mycorrhizae formers. Some are antagonistic on fungi and lichens. A great majority of asexual ascomycetes cause serious disease of plants and humans.

9.4.7 Basidiomycota: They include mushrooms, boletes, puffballs, earthstars, stinkhorns, bird's-nest fungi, jelly fungi, bracket or shelf fungi and rust and smut fungi. The basidioomycetes are characterized by the presence of a club shaped structure, known as basidium on which basidiospores are formed on four sterigmata. These fungi undergo extensive dikaryophase in their life cycle, which may arise from primary, secondary or tertiary mycelium. There are two advanced characters of basidiomycetes; clamp connections and dolipore septum. Clamp connection is a hook-like structure associated with the conjugate division of the dikaryons in the secondary mycelium. It is a by pass for the nuclei, if they can not pass through the septal pore as may happen due to presence of a dolipore septum. This septum around the central pore projects laterally to form a barrel-shaped pore. The pore on the two sides is surrounded by a cap-like structure, called the parenthesome or nuclear cap. It is made up of a double membrane and its function is to shut the pore.

Based on phylogenetic relationship Basidiomycota have been divided into following classes:

A. HYMENOMYCETES: This class has been characterized by the presence of dolipore septum, septal pore cap, glucose/mannose/xylose as reserves. It has the following orders: Agaricales, Aphyllophorales, Auriculariales, Dacromycetales, Ceratobasidiales, Tulasnellales.

B. USTILAGINOMYCETES: This is characterized by septal pore margin flared or not, no septal pore cap, glucose, mannose or galactose as reserves. It has two orders i.e. Ustilaginales, Exobasidiales.

C. UREDINIOMYCETES: Characterized by simple pore cap, no septal pore cap, mannose/glucose/fructose/lactose. The orders are Uredinales, Septobasidiales, Sporidiales

i. Agaricales: The order includes mushrooms. The members may be poisonous or non-poisonous. *Agaricus bisporus* is edible mushroom and is most commonly cultivated; *Amanita phalloides* is poisonous mushroom. They grow in lawns, fields and forests round the year. The extensive mycelium remains hidden in the soil; only the fruiting body or the basidiocarp is visible. The fruiting body has a stipe (stalk) and a pileus (a circular cap). Its annulus (a skirt like ring of tissue) surrounds the stipe a little below the pileus. The gills (lamellae) can be distinctly seen if the stipe is removed and the pileus is inverted. The pileus on the under surface bears numerous vertically hanging gills, which converge from periphery towards the stipe. The gills are of different lengths and bear basidia all over the surface. The basidia produce basidiospores in astronomical numbers.

Mushroom cultivation: There are many species of edible mushrooms notably those belonging to genera *Agaricus*, *Lentinus*, *Morchella* etc. *Agaricus bisporus* is cultivated in Europe, North America and elsewhere. *Volvariella volvacea* (the padi straw mushroom) is grown in India and Pakistan. *A. bisporus* is grown on a mixture of horse manure and straw, which must undergo some decomposition before the mushroom can grow well on it. The mixture is allowed to ferment in compost heaps of 1-2 meters height under controlled conditions of humidity, aeration and temperature. The well-decomposed manure mixture is filled in trays. The compost is now mixed with mycelial pieces obtained from the pure cultures of the fungus. This is called 'spawning.' Hyphae permeate the compost. After 2-3 weeks the compost beds are covered with a thin layer, (2.5 cm) of soil or peat—vermiculate mixture. This is called "casing." Without casing the fruiting bodies are not formed. The stimulating factor provided by the casing is not known. After a month, fruiting bodies start making appearance. Higher temperature of the bed (15-21 °C) favors mycelial growth while a lower temperature (13-15 °C) favors fruiting body formation. So the temperature is kept below 15 °C after the initiation of fruiting.

ii. ***Aphyllophorales:*** The order differs from Agaricales in: (I) having a complex fruiting body and (ii) the absence of the "veil" around the hymenophore. There are more than 20 families in order. The Polyporaceae or 'bracket fungi' are lignicolous (lignin decomposer) terrestrial, humicolous and sometimes parasitic, causing 'heart rot' of conifers and decay of timbers.

iii. ***Ustilaginales:*** The members of this order are called smut fungi in which teliospores are formed from the cells of secondary dikaryotic mycelium by developing a thick resistant wall. Basidiospores are formed directly on a septate or non-septate promycelium produced by the teliospores on germination. There are no streigmata. The basidiospores are passively discharged. Except one small family, Graphiolaceae, smuts do not form a basidiocarp. Mycelium is intercellular and forms haustoria, which draw nutrition from the host cells. Clamp connections and dolipore septums are absent in these fungi. This order is divided into three families: Ustilaginaceae, Tilletiaceae and Graphiolaceae. The genera of Ustilaginaceae produce septate promycelium bearing lateral basidiospores. In Tilletiaceae, the promycelium is a hollow tube, which bears the basidiospores at the tip. The Graphiolaceae is different from both the families in having a basidiocarp. *Ustilago and Sphacelotheca* belong to Ustilaginaceae while *Tilletia*, *Neovossia* and *Urocystis* belong to Tilletiaceae. Smut fungi cause following very important diseases. Details of these diseases have been given in chapter 12.

iv. ***Uredinales:*** The members of this order are called rust fungi, which are obligate parasites of angiosperms, gymnosperms and ferns. Basidiocarp is absent and therefore there is no tertiary mycelium. The hyphae remain in the intercellular spaces of the host tissue and obtain nutrition through haustoria. The structure of teliospores forms the basis of identification of the rust genera. The rust fungi form five different spore states that differ morphologically and cytologically. These are pycnia, aecia, uredinia, telia and basidia. The fungus containing all the five states is called macrocyclic rust or long cycled rust. In demicyclic rusts uredinia is missing. Microcyclic life cycles have only telia. The macrocyclic and demicyclic rusts may be autoecious or heteroecious but the microcyclic rusts are by necessity always autoecious. The rust fungi cause following very important diseases: *Puccinia graminis* f. sp. *tritici* (stem rust of wheat) *P. g. avenae* (stem rust of oats), *P. g. hordei* (stem rust of barley), *P. g. secalis* (stem rust of rye), *P. recondita* f. sp. *tritici* (leaf rust of wheat) *P. striiformis* f. sp. *tritici* (stripe rust of wheat), *P. malvacearum* (hollyhock rust), *P. kikuchiana* (sugarcane rust), *Gymnosporangium juniperivirginianae* (cedar apple rust) and *Hemiliea vastatrix* (coffee rust).

Life Cycle of *Puccinia graminis tritici*: Infection of wheat takes place by aeciospores or urediniospores carried through wind taken from barberry or wheat grown in several areas serving as green bridge for the fungus. Aeciospores when land on the wheat crop first live in peaceful co-existence with the host indicated by very minute rust pustules on wheat leaves. As the environmental conditions favour the disease, fungus produces enormous number of urediniospores, which serve as the most destructive phase. In fact physiological metabolism of the fungus is very high and several successive generations are produced within weeks. As the crop grows towards physical maturity, less number of urediniospores and increasing number of teliospores are porduced. Teliospores can not infect wheat again; these germinate to produce promycelium (Fig. 9.2). Minute sterigmata bear basidiospores, which are forcibly discharged and infect barberry. Pycniospores are formed in pycnia, spermatia can fertilize receptive hyphae.

After spermatization aeciospores are formed in aecial cups on the lower surface of barberry ready to be disseminated again. For genetic recombination infection of barberry plays a crucial role in the life cycle of rust fungus and enhances the chances of evolution of new races. However, asexual recombination has also been reported by many researchers to be an important mechanism of evolution of new races.

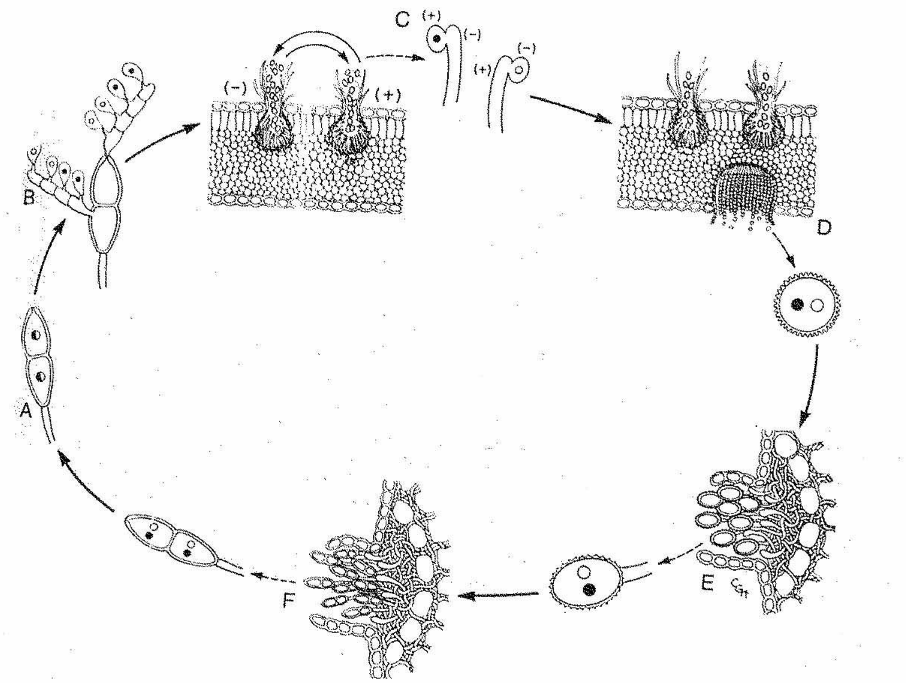

Fig. 9.2: Life cycle of a typical rust fungus. Teliospore (A), basidiospores on promycelium (B), spermatia and receptive hyphae (C), aeciospores in aecia (E) and uredodpores in uredia (F).

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SECTION V
LICHEN AND MYCORRHIZAL ASSOCIATIONS

Chapter 10
Lichens and Mycorrhizae

Lichens and mycorrhizae are the symbiotic associations. de Bary introduced the term "symbiosis" in 1879 to include several relationships involving the living together of unlike organisms. However, some authors have preferred to use a narrower definition of symbiosis, while others retain a broad definition much like that of de Bary. Thus symbiosis may be defined as "a condition in which two animals, two plants, or a plant and an animal live as mutual beneficiary to each other".

10.1 Lichens

Lichens (Latin, lichen, from the Greek word meaning "tree moss") are unusual organisms because they consist of fungal threads and microscopic green alga living together and functioning as a single organism. The main body of lichen is called a thallus and does not look like either the fungal or algal parts (Fig. 10.1a). Both partners receive some benefit from this symbiotic association. Simply, the alga within the thallus photosynthesizes sugars that the fungus can live off and in return the fungus provides protection to the alga. Lichens do not have roots, stems and leaves so they must receive moisture or nutrients from wet substrata or rainfall.

10.1.1 **Systematics:** There are as many as 20,000 different kinds of lichen known and new ones being discovered all the times. These are treated as species by lichenologists, but are not species in the same sense as animals or plants. Because lichens are formed through a combination of alga and fungus, it is not possible to study the phylogeny of lichens *per se*. Current work on the systematics of lichens is focussed on the question of the origin of lichens, and particularly to answer "How many times have lichens originated among fungi?" It is believed that lichens have developed independently in the Ascomycota and Basidiomycota, but no one is entirely certain how many times lichenization has occurred in each of these groups.

10.1.2 **General features:** Lichens have been described as "dual organisms" because they represent symbiotic associations between two (or sometimes more) entirely different types of microorganism. Mycobiont is a fungal partner and photobiont is a green alga or a cyanobacterium. A few lichen fungi (approximately 20) are members of Basidiomycota, but the vast majority is members of Ascomycota, and they often produce conspicuous fungal fruiting bodies (ascocarps), the apothecia. Almost half of the recorded fungi in the world are ascomycota, and nearly half of these are found only in lichens. Although their spores are dispersed from the fruiting bodies, these fungi do not seem to have an independent role in nature because they are extremely slow-growing and generally lack the enzyme systems for degrading complex polymers.

In contrast to mycobiont, there are only 100 photosynthetic partners. The most common are single-celled **Chlorophyta** of the genus *Trebouxia*, which are found in many lichens of temperate and arctic/alpine regions, including all species of the common lichen genus *Cladonia*. *Trebouxia* species seldom grow as free-living cells in nature; instead they seem to be specialized lichen symbionts. Another common photobiont is the filamentous green algal genus *Trentepohlia,* especially in Mediterranean and tropical regions. This and other algal genera of the tropical lichens can grow independently in nature. About 10% of lichens have **Cyanophyta** (e.g. *Nostoc*) as photosynthetic partner. However, some lichens that contain green algae can also have cyanobacteria in special wart-like structures on the lichen surface, termed as cephalodia. They are found in about 3-4% of lichen species and their role is probably to exploit the nitrogen-fixing ability of cyanobacteria.

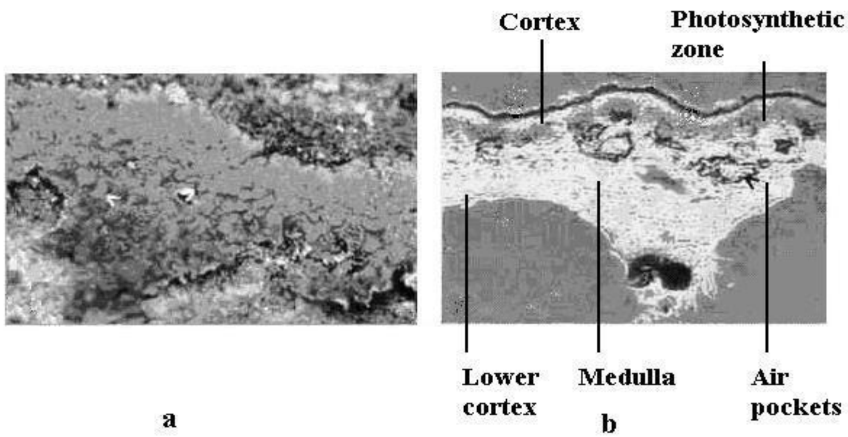

Fig. 10.1. External (a) and internal structure (b) of a typical lichen thallus

a. Anatomy: Despite the wide diversity of the basic growth forms, all lichens have a similar internal morphology. The bulk of the lichen's body is formed from filaments of the fungal partner, and the relative density of these filaments defines the layers within the lichen. At its outer surface, where it comes in contact with the environment, the filaments are packed tightly together to form the cortex (Fig. 10.1b). The dense cortex serves to keep out other organisms, and helps to reduce the intensity of light, which may damage the algal cells. The algal partner cells are distributed just below the cortex in a layer where the fungal filaments are not so dense. This is very similar to the arrangement in a plant leaf, where the photosynthetic cells are loosely packed to allow air circulation. Below the algal layer is the medulla, a loosely woven layer of fungal filaments. In foliose lichens, there is a second cortex below the medulla, but in crustose and squamulose lichens, the medulla is in direct contact with the underlying substrate, to which the lichen is attached.

b. Physiology: The mycobiont has two principal roles; i) protection of photobiont from exposure to intense sunlight and desiccation and ii) absorption of mineral nutrients from the underlying surface or from minute traces of atmospheric contaminance. Likewise, the roles of photobiont are i) to synthesize organic materials from carbon dioxide and ii) to fix atmospheric nitrogen (in case of cyanophytes) into ammonium (and then organic nitrogen compounds) and provide to mycobiont. In some ecosystems such as desert soils, tundra heaths and Douglas-fir forests of the Pacific, lichens can provide the major input of nitrogen which supports other forms of life. Thus, through the lichen partnership, the photobionts are protected and able to grow in conditions in which they could not grow alone.

Lichens are remarkable for their ability to withstand prolonged drying and to resume activity rapidly after rewetting. Most lichens that contain green algae can recover from drought by absorbing water from humid air and then begin to photosynthesize. However, the lichens that contain cyanobacteria can only resume photosynthesis after absorbing free (liquid) water.

The drought-tolerance of lichens is likely to be conferred by a water-repellent (hydrophobic) coating on the hyphal walls of the medulla. Small peptides that are rich in sulphur-containing amino acids have been found on the hyphal walls of many free-living fungi. They are termed 'hydrophobins' and they probably also occur in lichen fungi. The presence of these compounds would ensure that the medulla around the photosynthetic cells does not become waterlogged, allowing the diffusion of gaseous carbon dioxide for photosynthesis. Of interest, the hydrophobic materials seem to be produced only by the fungus, because cells of *Trebouxia*, which have a naturally hyrophilic surface, become covered with a hydrophobic material when grown in the presence of a lichen fungus. The rewetting of lichens is thought to start by water absorption in gelatinous matrix of the cortex. After this water moves through the medulla in the wall space of the fungal hyphae or perhaps by capillary action in regions where the hyphae have a hydrophilic surface

c. Ecology: Lichens grow readily and luxuriously on rocks, soil, trees or artificial structures in unpolluted habitats. They can live in unfavorable terrestrial habitats throughout the world, including the Arctic, Antarctic and deserts. They are considered pioneer species in some habitats, because they are often the first organisms to invade newly exposed rock or soil. Following the colonization of a substrate, lichens may promote soil formation by adding organic material and dissolving minerals from the rock.

Lichens are amongst the slowest-growing organisms, but their tolerance to environmental extremes enables them to colonize habitats where few other macroscopic organisms can grow. They grow where neither the fungal partner nor the photosynthetic partner could survive alone, because they benefit from their unique symbiotic association. However, most lichens are highly intolerant of atmospheric pollution, particularly sulfur dioxide, so they are found mainly in rural environments rather than cities. Only a few species, such as *Physcia grisea* and *Xanthoria parietina*, are found commonly in towns. Partial reason for this tolerance is extreme efficiency of lichen fungi in accumulating nutrients from trace levels in the atmosphere. An extreme demonstration of this is the ability of lichens to accumulate radioactive isotopes from the environment.

10.1.3 Association types: Based on general shape the body, lichens are placed in four broad categories.

- **a. Crustose:** Crustlike, growing tight against the substrate. In these forms, the upper cortex is entirely absent, algae are scattered below the outermost rock crystals and the medullary hyphae penetrate irregularly several millimeters into the rock. Only the acsocarp at the rock surface give clue to the presence of lichen on the rock surface.
- **b. Squamulose:** Tightly clustered and slightly flattened pebble-like units. Growing on peaty soil, this lichen has a scale-like squamulose (arrowhead) structure but also produces erect stalked cups termed podetia,.but the rims of the podetia bear many conspicuous red ascocarps.
- **c. Foliose:** Leaflike, with flat sheets of tissue not tightly bound. Lichen body with a distinct lower cortex and attached to the substratum by means of rhizoids. Some large foliose lichens may be 300 mm or more in diameter
- **d. Fruticose:** Free-standing, thallus may be round or flattened, unbranched or richly branched. Internal structure is radial with a dense outer cortex, a thin algal layer, a medulla and a more or less hollow center. Thallus body is anchored to the substratum by rhizinae. They range in size from 1 or 2 mm to 5 meter

10.1.4 Reproduction in lichens

- **a. Vegetative propagation:** Most lichens are dispersed by vegetative propagation. Dry lichen thallus is brittle, so fragments can break off easily and transported by wind or animals.
- **b. Asexual means:** Lichens reproduce in two basic ways. Firstly, lichen may produce soredia, or a cluster of algal cells wrapped in fungal filaments. These may disperse and form new lichens. A second way for the lichen to reproduce itself is through isidium, which are much like soredium except that isidia are enclosed within a layer of protective cortex tissue. An isidium is much more like miniature lichen.
- **c. Sexual means:** Many lichens produce apothecia or other fungal fruiting structures, to disperse the spores of the fungal partner. The spores in these cases (ascospores) are formed in asci as the result of sexual reproduction. When these spores germinate they must contact the cells of a photosynthetic partner to establish a new lichen thallus. This process of "reassembly" of lichen can be demonstrated in experimental conditions, and evidence suggests that it occurs in nature in similar way.

10.2 Mycorrhizae

Mycorrhizae are symbiotic soil fungi, present in most soils that attach themselves directly onto the roots of most plants. If the conditions are favorable, a viable mycorrrhizal colony can help the plant become more vigorous, more salt tolerant, less fertilizer dependent and more tolerant of moisture to chronic low levels.

10.2.1 General features: In its most common usage, symbiosis is used to describe the intimate association between two distantly related species that are mutually benefiting from this association. These associations are obligatory ones in *senso stricto*, wherein neither organism can survive if the two organisms are separated.

In the mycorrhizae, the fungus will usually receive carbohydrates of some sort from the plant and there will be enhancement of mineral transport to the plant. In addition to the enhanced nutrient uptake, different categories of mycorrhizae may protect roots against pathogens, produce plant hormones and translocate carbohydrates between plants. However, there are some generalizations that can be made, concerning mycorrhizae:

- **a.** Mycorrhizal infection area occurs only on the smallest order of secondary roots. These are the root tips that are still growing, elongating and increasing in girth. So a very small part of the root system of a plant which will be infected by the mycorrhizal fungus and only part of the root system will absorb water and minerals. However, the fungus has a much more extensive growth in the soil.
- **b.** In all mycorrhizae only the cortical cells of the root are invaded by the fungus, as revealed from the cross section of a young root.

c. The mycorrhizae occur in practically all plants with the exception of the families Brassicaceae, Cruciferae, Chenopodiaceae and Cyperaceae; all other families form mycorrhizae.

d. It is believed that for many plants that usually form mycorrhizae, they would be unable to survive in their natural habitat without this symbiotic relationship. This has been demonstrated to be true for numerous plants.

10.2.2 Association types

a. **Ectomycorrhizae**: Characterized by forming an external sheath of mycelium around the root tips and hyphal cells do not penetrate the cell walls (intercellular) although they may go between cells in the cortex (Hartig net).

b. **Endomycorrhizae**: Characterized by the lack of an external sheath around root tip and the penetration of cortical cells (intracellular) by the fungus mycelium.

c. **Ectendomycorrhizae**: Mycorrhizal type that seems to be intermediate between ecto- and endomycorrhizae. Mycelium sheath around root is reduced, or may even be absent, but Hartig net is usually well developed as in ectomycorrhizae, but the hyphal cells may penetrate the cortical cells as in endomycorrhizae.

d. **Vesicular-arbuscular mycorrhizae (VAM):** This category of mycorrhiza can be found throughout the world, but more abundant in the tropics than in temperate regions. It is associated with more plants than any of the other categories of mycorrhizae. Fungal partner is from Zygomycota. The name of this type of mycorrhizae comes from the distinct structures that can be seen inside the cells of the infected roots, the rounded **vesicles,** and the branched tree-like **arbuscules**. There is also extensive mycelium in the soil, but none of it is organized in any fashion. The vesicles and arbuscules contain the stored minerals that are needed by the plant. These structures lose in the root cells and in this way the minerals become available to the plant.

e. **Orchid** m**ycorrhizae:** This category of endomycorrhizae includes mostly the members of the Basidiomycota. All orchids are infected with this type of mycorrhizal fungus. Orchid mycorrhizae are functionally different than the above types because of the unique nutritional needs of orchid plants. In most plants, the seed contains a food supply that will feed the embryo until germination occurs. The orchid seeds are very minute and contain a very small food reserve for the embryo. This food supply is usually depleted by the time that the first few cell divisions of the embryo have occurred. Because of the lack of food in the embryo of the orchid, the fungus not only supplies minerals, but also organic compounds such as carbohydrates and metabolites like vitamins

f. **Ericaceous mycorrhizae:** The mycorrhiza formed in this group is between fungi in the Ascomycota, and more rarely in the Deuteromycota, and species in the families Epacridaceae, Ericaceae and Pyrolaceae. Two subgroups of these mycorrizae are Ericoid and Monotropoid. The former have evolved in association with plants that are continually stressed by factors within the soil. The soil is typically extremely acid, low in available minerals because mineralization is inhibited. Plants with these mycorrhizae seem to have a high tolerance to stresses.

g. **Monotropoid mycorrhizae:** Thery are associated with families Monotropaceae and Pyrolaceae are two families of plants which are achlorophyllous. Thus, plants in these families are more dependent upon their mycobiontic partners than plants which can carry out photosynthesis

10.2.3 Factors affecting mycorrhizal distribution: First, the mycorrhizae are relatively fragile. They thrive when the organic content of the soil is high but languish when soil is low in organic content. Mycorrhizae are destroyed when the soil is fumigated, sterilized, solarized or drenched with most of the pesticides used to control nematodes, grubs, or weeds. They are also sensitive to high levels of chemical fertilizer. There is a difference of opinion as to the mechanics. Some researchers think that excessive chemical fertilizer burns the hyphae just as it burns roots and the performance of the mycorrhizae falls off because they have been injured. Others say that the high levels of chemical fertilizer, especially phosphorus, because the plant roots shift feeding patterns away from the mycorrhizae. There is, however, general agreement that avoiding high levels of chemical fertilizer, particularly phosphorus, promotes a more vigorous feeding through the mycorrhizae. The best management of mycorrhizae is to simply use composts with added manures to feed the plants while at the same time feeding the mycorrhizae.

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SECTION VI
PATHOLOGY

Chapter 11
Host-Pathogen Interactions

11.1 Pathogenic and mutualistic relationships among prokaryotes and eukaryotes

A parasite is an organism, which can grow at the expense of host nutrients. A host is any organism, which can support the survival of another organism. If a parasite harboring the host draws nutrition above economic injury level, it may become pathogen— an organism, which can incite disease.

When a pathogen lands on the host plant, a signal is triggered about its presence. If the host is resistant, quick response to that pathogen results in the production of defense chemicals named phytoalexins. The pathogen is localized and is not allowed to grow as indicated by hypersensitive reaction (minute lesion or very small necrotic spot). This type of host-pathogen interaction is termed as 'incompatible'. If the host is susceptible, response to the pathogen is passive and production of phytoalexins is slow due to the lack of resistant genes against the virulent pathogen. Thus the pathogen is allowed to grow and this type of host-pathogen interaction is termed as 'compatible'. Whether a pathogen will grow on the host plant or not is governed by "gene for gene" theory. According to this theory, "for each gene giving resistance to the host, there is a corresponding gene for avirulence in the pathogen and vice versa".

Host-parasite interaction is a broad term used to describe relationship among prokaryotes and eukaryotes. Those living organisms of particular interest to the plant pathologist are the fungi, bacteria, nematodes, insects, and viruses. The relationship among the prokaryotes and eukaryotes can be described as power relationship indicated by "the weak" and "the strong." Thus 0 = rate of an activity; + = acceleration of activity by another class; - = deceleration of activity by another class. In regard to any metabolic activity, weak and strong individuals can be classified in 10 different relationships towards each other.

- **11.1.1** **Predation** (praeda – prey): (- +); weak prey damaged by strong predator which benefits.
- **11.1.2** **Allotropy** (allos – other; trophe – nourishment): (0 +); weak feeds the strong.
- **11.1.3** **Symbiosis** (sym – together; blown – to live): (+ +) mutual aid, both organisms benefit.
- **11.1.4** **Amensalism** (a – away; mensa – table): (- 0); weak harmed, strong unaffected.
- **11.1.5** **Neutrality:** (0 0); neither type is helped or hindered.
- **11.1.6** **Commensalism** (com – with; mensa – table): (+ 0); weak benefits, strong unaffected.
- **11.1.7** **Synnecrosis** (syn – together; Nekros –dead body): (- -); both harmed.
- **11.1.8** **Allolimy** (allos – other; limos – plague, diseases): (0 -); weak starves the strong but does not benefit.
- **11.1.9** **Parasitism** (para – beside; sitos – food): (+ -); Weak benefits at the expense of strong.
- **11.1.10** **Pathocism** (+ -); weak damages the strong above economic injury level.

11.2 Types of epidemiology and causes of diseases

Host-pathogen interaction is greatly influenced by physical, biological and ecological environment. Factors influencing the development of plant disease epidemics are studied in epidemiology. The patterns of an epidemic can be studied in quantitative epidemiology based on data collected for pathogen population in host population in relation to an environment. The development of an epidemic in plant population can be studied in botanical epidemiology. Any host-pathogen combination with multitudes of host and pathogens genotypes can be called a pathosystem. Within the pathosystem the host-pathogen interactions are governed by the laws of population genetics and of population dynamics; the pathosystem responds to its environment and to the influence of man. Answer to the question that why an epidemic moves differently in different locations, can be studied in comparative epidemiology.

A plant disease epidemic is a dynamic process in time and space which results due to a continuously irritating biotic or abiotic agent, reducing the quality of the produce or quantity or both of them above economic threshold level. Some genetic disorders, physiological abnormalities or morphological deformities can also be considered in a disease concept. Regarding the causes of plant diseases two major categories can be identified.

11.2.1 **Infectious:** Inoculum is any part of the pathogen or whole of the causal complex. The inoculum which can incite disease is called infectious. It may consist of spores, fragments of mycelium, fruiting body or dikaryotic or monokaryotic hyphae of fungi, mass of bacteria, nematodes, and viruses. A single spore or a single pathogen can cause disease depending upon the favorable environmental conditions. However, for a disease to occur in epidemic proportions a certain quantity of inoculum is required. Thus the initial inoculum level is very important in the spread of an infectious disease. The pathogenic fungi, bacteria, nematodes, phanerogams, protozoa, viruses, viroids, phytoplasma, spiroplasma, rickettsiae-like bacteria, xylem-limited fastidious prokaryotes and phloem-limited fastidious prokaryotes can cause infectious diseases if they are able to successfully infect a susceptible host in a conducive environment.

11.2.2 Non-infectious: Non-parasitic diseases caused by inanimate agents are non-infectious diseases. These diseases may result due to fluctuation in light, temperature (low/high), unfavorable oxygen, unfavorable soil moisture, injurious atmosphere, lightening injury, imbalance of nutrients (excess/deficiency of nutrients), agricultural malpractice's (mechanical and chemical injuries caused by machinery, fungicides, insecticides and herbicides, industrial by-products (fumes, smoke) and products of plant metabolisms (as occur in storage). Some of these diseases are curable and the diseased plant can be restored to normal life if the abiotic cause is eliminated.

11.3 Pathogens and disease symptomatology

Symptoms are external manifestations of pathogen-host interaction, recognizable by human eye or with the aid of hand lens, stereoscope or compound microscope. Internal symptoms are difficult to be seen except through biological, infectivity or serological assays (e.g., PVX). The whole group of symptoms caused by a given pathogen is known as **syndrome**. They form the clinical picture of the disease (shisham decline, mango and guava decline). **Signs** are evidence of the presence of the living causal agent of the disease. The white powdery appearance of powdery mildew fungi is a good diagnostic feature of powdery mildew disease.

11.3.1 Kinds of symptoms

a. **Symptoms due to the presence of pathogens or appearance of plant part affected:** A pathogen growing within the host tissue is usually invisible but can be identified by its products or reproductive parts present on the host plant. In some cases the entire body of the pathogen including both vegetative and reproductive portions is external to the host and it can be seen readily on account of its mass which sometimes is constituted in the form of following symptoms:
   - ***i.*** ***Mildew:*** These appear as white, grey, brownish, or purplish patches of varying size on leaves, herbaceous stems or fruits. In downy mildew the superficial growth is a tangled cottony or downy layer, while in the powdery mildew enormous numbers of the spores are formed as superficial growth of the fungus giving a dusty or powdery appearance.
   - ***ii.*** ***Rusts:*** These appear as relatively small pustules of spores, usually breaking through the host epidermis. The pustules may be dusty or compact, and red, brown, yellow or black in color.
   - ***iii.*** ***Smuts and bunts:*** The affected part of the plant shows a black or purplish black dusty mass. Smuts symptoms appear in floral organs, particularly the ovulary and the pustules are considerably larger than the rusts. Dried shrivelled grain with or without black powdery mass is called bunt.
   - ***iv.*** ***White blisters:*** Shiny raised pustules appear on the affected plant parts and resemble with rust-like lesions. But these have nothing in common with rusts, so the name of disease from white rust of crucifers may be changed to white blister disease.
   - ***v.*** ***Scab:*** A roughened or crust-like lesion on the diseased organ. If it is only on the surface 1-2 mm deep, it may be called shallow scab. However, when the pathogen invades the tissue (>1-2 cm) it is called deep scab.
   - ***vi.*** ***Exudation:*** Sooty mold diseases are due to the inhabitation of various fungi on the honey dew or secretions of plant in the form of gummosis and their inhabitation by air-borne fungi. Similarly bacterial exudates are found on the affected plant parts.

b. **Symptoms due to some effect on or change in the host plant:** These symptoms are produced due to the activity or life processes of some living organisms and the reaction of the host tissue to such activity. The pathogen may be found within the affected tissues, upon the surface, in some cases it may develop certain structures internally and others externally. Fruiting bodies of the pathogen may accompany more striking changes in the host organ. Examples are pycnidia, acervuli, conidiophore, conidia, sori, sclerotia etc:
   - ***i.*** ***Anthracnose:*** A blemish spot or blotch type appearance on the upper portion of fruit and irregular withering of leaves is called anthracnose. It is often accompanied by die back of branches and twigs.
   - ***ii.*** ***Blight:*** The general and rapid killing of plant parts. The field looks as scorched by the fire. In case of early blight of potato necrosis of the tissue shows concentric zones giving a target-board effect, while in late blight there is general death of the plant parts.
   - ***iii.*** ***Blast:*** Spindle shaped spot on the leaves. It may be leaf blast, node blast or neck blast.

iv. ***Curling or rolling:*** There may be upward curling or rolling. The downward curling or rolling is very rare. This may be accompanied with twisting of the leaves.

v. ***Canker:*** Raised corky and rough pustules or grayish color tough raised areas on the leaves, stem, branches and fruits.

vi. ***Damping off:*** Sudden death or collapse of the seedlings. The fungi attack at the base of the plant and the whole plant may topple down on the ground.

vii. ***Dwarfing:*** The reduction in size of the plant due to the shortening of nodes. It is also called stunting.

viii. ***Malformation:*** Abnormal growth structures. They may result due to hypertrophy (excessive cell enlargement) and hyperplasia (excessive cell multiplication).

ix. ***Necrosis:*** Death of the tissue is called necrosis. It may be of any shape or size or even cover indefinite damaged areas of plants.

x. ***Root rots:*** Shredding of root bark, distortion of the tissue and putrifying smell. The plant can be easily pulled out from the soil.

xi. ***Soft rots:*** Softness and pulpiness of the tissue with a slimy and watery liquid oozing out from the affected parts.

xii. ***Spot:*** Localized damage to the plant tissue. It may be circular, oval, oblong, elongated, rectangular or angular in shape, while the color may be yellow, reddish brown, brown, grayish and dark brown, black, olive, purplish or any other.

xiii. ***Stripes or streaks:*** Wide spread lines or stripes (usually in centimeters) running parallel to the leaf. When the lines are narrow, these are called streaks (usually in millimeters).

xiv. ***Wilts:*** Sudden withering and drying of plant. If withering is due to shortage of water it is called temporary wilting, and it can be cured to some extent if the whole tissue is not dead. It is permanent if it is due to pathogenic attack and can not be cured or recovered due to irreparable damage to the host tissue.

11.4 Host defenses and their mechanisms

In general a host defends against the pathogens by two mechanisms: structural and biochemical. A resistant plant has preexisting defense structures that may hinder the growth of pathogens or may act as repellent. Presence of cuticle, hairy structures, and waxy surface are some of the structures used by the host against the attack of pathogens. Formation of corky layer, abscission layer (layer of sterile cells) and tyloses (outgrowth of protoplast of adjacent living parenchyma cells protruding into xylem vessels through pits) and deposition of gums are defense structures in response to the infection by the pathogens. Swelling of parenchyma cells, cell wall thickening, callose papillae and cytoplasmic defense reactions form cellular defense structures. In many host-pathogen interactions, after penetration of the pathogen, the cellular membranes disintegrate and stop further invasion by the pathogen, so producing a necrotic or hypersensitive defense.

Biochemical defense include certain inhibitors against pathogens, lack of recognition factors between the host and the pathogens, lack of host receptors and sensitive sites for toxins, lack of essential nutrients for the pathogen and the inhibitors present in the plant cell before infection. Biochemical inhibitors may also be produced in plants in response to injury by the pathogens. The level of phenolic compounds such as phytoalexins may be increased in defending host. The pathogenic infection may induce the synthesis of enzymes such as phenyl ammonia lyase. Defense through inactivation of pathogen enzymes and toxins and through induced resistance are the characteristic forms of biochemical defense mechanism.

11.5 Modulations in the physiology of host

Modulation in the physiology of infected plant is observed on the rate of photosynthesis. In a diseased plant the rate of photosynthesis is reduced to one fourth of the normal rate of uninfected plant. Depletion of green pigment results in the loss of photosynthetic area thus reducing the assimilation of photosynthetic products and finally the yield.

As a result of infection by the pathogens, translocation of water and essential nutrients is inhibited. Clogging of xylem vessels may interfere with the upward translocation of water and inorganic nutrients. The absorption of water through roots is hindered. The translocation of water and essential nutrients through xylem vessels is greatly reduced as exhibited by wilt-like symptoms. Physical presence of the pathogen or the production of high molecular weight substances in xylem or phloem may hinder the translocation of nutrients.

Respiration in diseased plants is greatly influenced by pathogenic attack. The rate of respiration in a susceptible plant increases rapidly and continues to increase depending upon the amount of green tissue. In case of resistant plants the rate of respiration increases in the beginning then after some time it becomes normal. In fact a susceptible plant responds to the pathogen passively with the slow release of phenolic compounds probably due to the lack of resistant genes. Thus the plant tries to manufacture phenolic compounds by short-cut methods such as pentose phosphate pathway—a less efficient way of energy production and utilization compared to gycolysis and Krebs cycle. Thus less ATP is synthesized and utilized. In a susceptible diseased plant uncoupling of oxidative phosphorylation results in the break-up of oxidation-reduction reactions and the diseased tissue acts as a metabolic sink. This metabolic sink consumes all the energy trapped/manufactured through photosynthesis and the plant tries to fulfil the increased demands by increased rate of respiration. In resistant plants response to pathogenic attack is quick and involves active defense mechanism. Thus the task of production of phenolic compounds is accomplished through increased rate of respiration.

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Chapter 12
Important Economic Diseases and their Management

12.1 Importance of disease

According to an estimate about US$ 3000 billion losses occur in plants and plant products annually throughout the world due to more than 100,000 microbial pathogens, 10,000 species of insects, 1000 species of nematodes and 30,000 species of weeds. In Pakistan alone these losses have been estimated to be to the tune of Rs. 3600 millions in normal years. Additional losses due to plant diseases may occur in epidemic years. For example, the average national loss due to leaf rust epidemic in wheat was estimated at 10 percent or 830,000 tons of wheat grain with a value of US$ 86 millions. The chickpea blight epidemic reduced the production of chickpea by 17 and 48 % in years 1978 and 1979, respectively, resulting in an estimated loss of about US$ 90 millions. The losses due to banana bunchy top virus during 1988-91 have been estimated at Rs. 915 millions. Epidemics of cotton leaf curl virus have induced Rs. 28 billion losses to cotton industry during 1989-95.

12.2 Disease cycle

A series of events leading to infection by pathogens is called pathogenesis. The process through which carry over of the disease takes place from one season to another is called disease cycle. It includes primary infection (initiation of disease in the beginning), secondary infection (further development of disease from already existing inoculum), and spread of the disease in relation to epidemiological conditions, formation of resistant structures by pathogens or dormancy period, overwintering/oversummering of inoculum, and resurgence of pathogens for the initiation of infection. The study of disease cycle or disease perpetuation gives several options to manage disease by studying the stages of the life cycle of the pathogen.

Principles and methods of plant disease management

12.2.1 Avoidance from pathogen: In order to avoid the contact of the pathogen with the host, time of sowing may be changed or the crop may not be cultivated in a field with history of a particular disease. If a pathogen is widespread, selection of a field in a certain geographical area such as hilly places is very useful. For example, for potato seed production and multiplication northern areas of Pakistan are very important sites against potato leaf roll virus (PLRV). *Myzus persicae* is a vector of PLRV with minimum population in hilly areas compared to plains. A change in the planting geometry, such as depth of sowing, row-to-row distance and cultivation on ridges may be helpful to avoid the contact between the pathogen and host.

12.2.2 Exclusion of the pathogen: Exclusion means to prevent the entry of a pathogen in a certain geographical area through quarantines, notification and certification. Every country has quarantine rules and regulations regarding the movement of an agricultural commodity in or out of a country for the sake of exclusion. However, these rules should be based on scientific facts and formulated keeping in view the socioeconomic conditions of a country.

12.2.3 Notification: It means to warn the probable occurrence of a pathogen in a certain geographical area using audio-visual technology, radio, and television etc. It is not only to warn the farmers about the occurrence of a disease but also encourages them to take precautionary measures. Certification is to ensure that a certain product, seed or other vegetative material is free from pathogen. After careful identification and diagnosis a certificate is issued about the health status of the plant material.

12.2.4 Protection: When a pathogen has entered into a certain area, the next step is to protect the crop from infection by spraying protectants or adopting such strategies, that are helpful to protect the crop from infection. The objective of spraying protectants is to create a barrier (in the form of thin film of toxic substance) between the host and the pathogen. Other methods to protect the crop from a vector-carrying virus may be to create a physical barrier for the landing insect or using a repellent or inter-cropping with a non-host crop etc. Seed treatment is an important measure to protect the primary infection especially in seed-borne or soil-borne plant pathogens.

12.2.5 Eradication: This is the last effort to combat with pathogens, when the above-mentioned principles have not been followed. It may include elimination of alternate host or even diseased primary host, removal of collateral hosts, spraying eradicants, fallowing the land, intercropping, killing the vectors, destruction of diseased plant debris, soil fumigation and sterilization, screening varieties/lines against economically important pathogens, breeding for disease resistance, genetic engineering and biotechnology and several other methods. The objective of eradication is to hit the site of infection and to eliminate the pathogens completely.

IMPORTANT DISEASES AND THEIR MANAGEMENT

A. VIRAL DISEASES

Viral diseases are of greater importance compared to fungal, bacterial and nematode diseases, because these are difficult to control. The chemicals (so called viricides) are not available. Moreover, viral disease symptoms are often confused with nutrient deficiency diseases or abiotic stresses. One important feature about viral diseases is that sometimes-viral symptoms are masked or latent infection is difficult to identify. Infectivity assays, biological assays or serological tests are required to identify viral latent infection.

During the last 10-15 years viral diseases are emerging as potential threat to the economy of Pakistan. Cotton leaf curl virus, banana bunchy top virus, and mosaics of potato, tomato and tobacco are taking heavy toll and continue to be major limiting factors in the successful cultivation of these crops.

12.4 Cotton leaf curl virus (CLCuV)

12.4.1 Occurrence: Cotton leaf curl virus (CLCuV) was first recorded on individual plants at Multan in 1967, but it never attained an epidemic form, and successful cotton production continued up to 1988. In 1992-93, about 300,000 acres of cotton were affected by CLCuV, and the disease incidence shot up to 80% and yield losses estimated at 35-50%. Now the disease occurs in all the cotton growing areas of Pakistan, i.e. Punjab>Sindh>NWFP. These observations suggested an urgency of intensive and extensive investigations on host-virus-vector complex under the influence of prevalent climatic conditions in order to develop and implement a sustainable pest management program for the cotton growing system. In 1991-92, the disease cropped up to epidemic proportions due to: substantial augmented population of whitefly, wide range of alternate hosts, non-availability of resistant varieties, development of resistant strains against insecticides and favoring climate for disease perpetuation.

12.4.2 Symptoms: The disease is characterized by the upward or downward curling of leaves. The veins of the leaves are thickened and more pronounced on the underside of leaves. Initially the small veins are thickened, which gradually link together, extend and coalesce to form a continuous reticulation. This process makes the leaf to curl. The veins become abnormally dark and opaque. New leaves are very much distorted by curling and shortened up to 60%. Thick veins may become "enation"— fin like outgrowth. Thus upward or downward curling of leaves, vein thickening and enation are the characteristic symptoms of CLCuV. The disease affects plants of all ages, but young and weak plants are most vulnerable to virus and vector attack. Growth of the affected plants is arrested, yield and lint quality are significantly reduced.

12.4.3 Host range: At least 30 plant species in 13 botanical families are reported to be infected with one or more Begomoviruses (Geminiviruses) including cotton leaf curl virus. The largest number belongs to the family Malvaceae and there are several hosts in the families Solanaceae, Cucurbitaceae and Papilionaceae. Cotton leaf curl virus can be transmitted from *Gossypium hirsutum* to *G. arboreaum*, *G. davisoni* and *G. raimondii* by grafting and whitefly.

12.4.4 Causal virus: The virus causing leaf curl on cotton has been identified as Gemini virus belonging to genus Begomovirus of the family 'Geminiviridae'. Geminiviruses are plant viruses with circular ssDNA genome that are replicated by the host plant DNA polymerase. It has been adequately identified on the basis of its ecology (distribution, host range, losses), biology (transmission), serology (ELISA), electron microscopy (particle morphology) and molecular hybridization (PCR). Particles observed in electron microscopy were monomers, dimers and paired dimers.

CLCuV was initially identified by TAS-ELISA using polyclonal antiserum to ICMV (Indian cassava mosaic virus) and monoclonal antibodies of ACMV (African cassava mosaic virus) and OLCV (okra leaf curl virus). Then PCR (Polymerase chain reaction) was employed as a strong molecular diagnostic tool to identify geminiviruses including CLCuV as well as host range of the virus. A set of primers based on CLCuV sequence was designed to specifically detect CLCuV through DNA amplification. Complete sequence of CLCuV consists of 2725 nucleotides.

CLCuV, being a national problem, several research and extension organizations were involved in the study of the virus, primarily for its identification, transmission, evolving resistant cotton varieties and cultural practices to prevent the spread of virus. Collaboration was also received from some international organizations.

a. Disease cycle: Cotton leaf curl virus is transmitted in nature by whitefly (*Bemisia tabaci*) Genn.), but not by contact, sap or carried through seed or soil. Whitefly as a pest is a source of damage to cotton crop and other crops every year. Apart from being a potential vector of Gemini virus whiteflies debilitate the plants by continuous sucking of sap from the infested host. It also excretes honeydew on the foliage, which favors the development of sooty molds thereby reducing the photosynthetic area. It is a polyphagus insect, occurs almost throughout the year, has a wide host range and produces several generations per year (10-12). Presence of different strains of *B. tabaci* in Pakistan has not been established as yet. As soon as seed germinates in the soil, and primary leaves are produced, whitefly starts landing on cotton, which is regarded as the most preferred host of whitefly. In greenhouses and glasshouses, whitefly occurs as an insidious pest. Both the adults and larvae can transmit the virus in a persistent manner by feeding on phloem. Females are more efficient than males, and a single individual is able to transmit CLCuV. Whitefly acquires the virus from cotton, collateral hosts, and ornamental plants and weeds hosts, and transmits it in cotton. Whitefly cultures collected from CLCuV infected plants transmitted the disease as successfully as those maintained in the controlled environment. They became viruliferous and completed the infection cycle (virus acquisition to virus inoculation) within 6.5 hours. Typical disease symptoms i.e., leaf curling darkening of veins and enation formation appeared within three weeks.

12.4.5 **Disease management:** It must be known that there is no direct control of virus disease. Once the plant gets infected it will remain so for its life. Therefore, all measures are taken to protect the plants from whitefly. The time necessary to control the vector must be shorter than the time needed for a viruliferous insect to inoculate a healthy plant with a virus, at least as far as when primary infection is concerned. An IPM strategy involving cultural, biological and chemical controls combined with disease resistant/tolerant cotton varieties is most desirable.

- **a.** Destroy all weeds and alternate hosts serving as virus reservoirs for CLCuV before planting cotton in the field. Also eradicate ratooned cotton plants if any.
- **b.** Maintain an appreciable distance between cotton fields and okra eggplant and tobacco fields. It is better to grow these alternate hosts away from cotton.
- **c.** Do not grow cotton in the fruit orchards, because fruit and shade trees provide protection to whitefly.
- **d.** Avoid use of increased doses of nitrogen fertilizer because it results in an overall increase in the attack by whitefly. It increases insect fertility due to high N, content of leaves as well as better protection because of dense canopy.
- **e.** Seed treatment with a suitable chemical and soil treatment may provide safety to cotton seedlings and protect them from an early attack of virus.
- **f.** Pest monitoring (whitefly) and pest scouting and population threshold are pre-requisites of initiating chemical control of the vector. Consult the area manager for the economic threshold, selection of chemicals, time and frequency of spraying. Do not spray chemicals of one group, haphazardly and indiscriminately, but alternate the chemicals of another group. This will overcome the problem of resistance against chemicals in whitefly.
- **g.** Plant disease resistant/tolerant cotton varieties should be cultivated. Farmers should not depend upon one variety rather they should plant 2-3 different varieties which will vary in their reaction against CLCuV.

12.5 Banana bunchy top virus (BBTV)

12.5.1 **Occurrence:** Banana is the most important plantation crop in Pakistan. It is mainly grown in Sindh, covering about 23,000 ha with a total production of 210,000 tones. Major area (90%) is under "Dwarf Cavendish." Banana was introduced in Sindh in 1913, but the best varieties came in fifties and sixties and extensively grown without any serious disease problem. By 1972 the disease was wide spread and found in all the districts of Sindh. The crop was, however, hit in 1988 by a serious and destructive viral disease known as "Banana Bunchy Top". It is economically important because it destroys the plants causing huge financial losses to the growers. Suckers of the diseased plants carry the virus, and constitute the most important source of spread from one place to another. The aphids accomplish secondary spread. Under these conditions, about 80% banana plantation was found to be infected by BBTV.

The disease is endemic to South East Asia. It is present in India, Srilanka, Philippines and neighboring countries as well. It has spread to Australia, Fiji and Taiwan, but is not present in

Western Hemisphere. It is supposed to have been introduced in Pakistan in late seventies to early eighties through planting material from Australia.

12.5.2

Symptoms: Symptoms vary with the type of infection: **Primary** or **secondary infection**. The primary infection arises from diseased suckers used for planting. Because of acute primary infection, growth of plants is slow and arrested. The plants are stunted and do not produce fruits. Secondary infection is caused during growth of the plant through insect vector (*Pentalonia nigronervosa* Coq.). The symptoms in two cases differ in disease severity. However, young plants infected much earlier show same 'symptoms' as the plants infected through suckers.

Leaves of BBTV infected plants are typically bunched together and form a dense rosette. Dark green streaks (0.5 to 2.5 cm) appear in the petioles and leaf veins, as well as on the secondary veins on underside of lamina. Dot dash like green streaks can easily be seen on petioles and lamina parallel to veins. There is transverse wrinkling along the length of completely rolled lamina. Young suckers are stunted, chlorotic and very rosetted. Leaves stand erect and are bunched at the top. Dwarfing marginal chlorosis and curling may also be seen on older leaves, which become brittle. Internally the phloem is affected. Chromatophores develop in the parenchyma around the phloem. As the virus is systemic, phloem becomes non-functional. Vascular tissue shows suppression of fibrous sheath.

In extreme cases the branches are choked and may split the stem. Bunches are always reduced in size and become unstable. In advance stage of the disease, root system is decayed and invaded by the secondary organisms like fungi, bacteria and nematodes.

12.5.3

Causal virus: BBTV belongs to Luteovirus group. The virus has been purified, and the particles observed under electron microscope measure 20-22 nm in diameter. It gave positive reaction in ELISA against monoclonal antibodies of Taiwanese strain of BBTV. Virus is not sap-transmissible.

12.5.4

Disease Cycle: Use of suckers from the infected plants is the main source of dissemination of BBTV. Secondary infection is caused by the aphid vector (*Pentalonia nigronervosa*) in a persistent manner. The vector was collected from Hyderabad in a BBTV infected field and cultured on healthy banana (dwarf Cavendish). It needs a very long feeding period (12-13 days) for acquiring the virus, but can inoculate banana plants within 2-4 hours. It can retain the virus for 13 days. Aphids occur round the base of pseudostem at soil level. They are also found between the outer sheath and the pseudostem, and occasionally are present in groups at the apex of plant, around the central leaf and on the bases of petioles. Nymphal stage of *P. nigronervosa* lasts for 10-14 days (average 10 days), fecundity 1-4 nymphs/day. Over a period of 10 days, it ranged from 9-26 nymphs/aphid (x =13.2), and life span of the aphid ranged from 19-26 days (x = 20.3). All this data indicates that the vector is actively involved in the spread of BBTV.

12.5.5

Management: All Cavendish banana varieties are susceptible to BBTV. Therefore, phytosanitary measures have to be adopted to minimize disease incidence and an effective viable and sound programme needs to be initiated.

"For example, banana plantation in Australia was abandoned in 1972 by legislation due to continuous prevalence and spread of BBTV. Inspectors could report and destroy 200-1500 cases every month. They sprayed the fields with Kerosene oil to kill aphids prior to destruction by herbicides. A permit is still required to move the planting material in an area." In the farmers plantation these measures are difficult to enforce. However, following measures can be taken:

a. Early detection, roguing and destruction of diseased mats from cultivated and abandoned plantations.

b. Stop movement of suckers (planting material) from BBTV infected fields and aphids infesting in neighboring area.

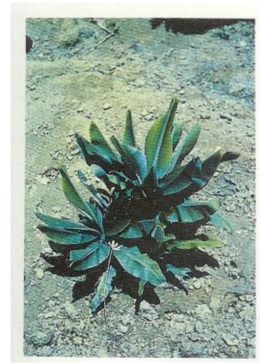
c. Control aphids by Kerosene oil but observe all possible care in spraying.

d. Maintain BBTV free areas, and always collect healthy material for planting.

e. Do not plant calocasia near banana fields. Elimination of BBTV is possible by invitro treatment of infected tissue at 40 ºC and 30 ºC for 16 and 8 hours for two months, but it is a cumbersome treatment under our conditions.


Cotton Leaf Curl Virus


Cucumber Mosaic Virus


Banana Bunchy Top Virus

12.6 Tobacco mosaic virus (TMV)

12.6.1 **Occurrence:** Tobacco mosaic virus (TMV) is the first recognized well-characterized and best-studied virus and is distributed throughout the world. Among all the viruses infecting tobacco crop in Pakistan, TMV is more common, important and serious appearing in all tobacco growing areas. The disease causes extensive damage due to reduction in yield and quality of product.

12.6.2 **Symptoms:** Initially light discoloration appears along the veins of young leaves. This is sooner followed by the development of light green to dark green areas, in a clear mosaic pattern, blisters and spots on the leaves. Tobacco plants infected early in the season are stunted, puckered and malformed. The disease severity is related to the degree of chlorosis and reduced level of photosynthesis. In general symptoms vary with the host, time of infection, growth and environmental conditions. Symptoms are often masked under high temperatures. The infected plants can easily be recognized in the field but not so in the nursery. Some tobacco varieties show moderate level of resistance to TMV.

12.6.3 **Causal virus:** TMV is extremely stable, mechanically transmissible and easy to purify in high quantities. The virus is rod shaped particle measured 300 x 18 nm with a central hollow tube of 4 nm diameter, made up of centrally placed ss-RNA (5%), particles sediment as 190s monopartite genome with a molecular weight of 2 x 10^6 d, covered by a protective coat protein (95%) consisting of a single protein species (m. wt = 17.6 x 10^3 d), purified virus preparations are opalescent absorbing UV spectrum with a minimum at 240-245 nm and maximum at 260 nm. Other important properties of TMV are: highly resistant to adverse conditions, survives for 50 years or more, thermal inactivation point in 10 minute exposure (TIP) 90 °C dilution end point (DEP) 1 x 10^{-5}, strongly immunogenic.

12.6.4 **Disease cycle:** The virus causes diseases in a wide range of hosts (about 50 plant spp in 9 botanical families). The virus is easily sap-transmissible to healthy plants and enters through wounds caused by wind, rain and cultural operations such as topping and clipping of shoots. Workers also transmit and spread the virus in tobacco crop by contact, chewing tobacco and snuffs. No insect or other vector is known. It is not seed-borne except tomato strain as seed contaminant. Disease also perpetuates from the diseased plant debris left over in the soil after harvest.

12.6.5 **Management:** Due to highly resistant and stable nature of TMV and different modes of spread, it is difficult to control the disease. However, following measures help to minimize the infection. These include: i) use of resistant/tolerant varieties, ii) regular roguing of diseased plants and weeds in the filed, iii) clean cultivation and sanitation. Workers doing different operations in the field and handling diseased plants must wash their hands thoroughly with soap, disinfectant and running water before they come in contact with healthy plant.

12.7 Tomato mosaic virus (ToMV)

12.7.1 **Occurrence:** Tomato mosaic is a common virus disease in all the tomato growing areas of Pakistan. Economic importance of ToMV has been recognized only recently when tomato yields were reduced and fruit quality was also affected. The disease generally remains unnoticed in the initial period of plant growth; in the nursery when seedlings are raised from ToMV contaminated seed, and seedlings are further infected by contact during transplanting. After the establishment of seedlings in the field disease development and spread is very quick and early-infected plants can be distinctly observed. Many different viruses such as TMV CMV, PVX, and PVY etc can cause Mosaic disease in tomato.

The common mosaic was earlier thought to be due to TMV, but extensive studies have now shown that ToMV is a distinct virus of the same genus" Tobamovirus".

12.7.2 **Symptoms**: Symptoms are generally influenced by temperature, day length, light intensity, plant age, virus strain and tomato cultivar. Leaves show slight and dark green mosaic or mottles with occasionally distortion of young leaves. Green areas are sunken giving leaf a rough appearance under cooler conditions. Plants are severely stunted and leaves are distorted to fern leaf. Seedling infection can kill the plant. The disease affects fruit setting; fruits are fewer, small sized and often deformed. At the end necrosis of stem, petioles, leaves and fruits can occur.

12.7.3 **Causal virus**: ToMV belongs to the genus "Tobamovirus." Its particles are rigid straight rods with helical construction, and measure 300 x 18 nm contain single stranded RNA consisting of about 5% of particle weight. TIP in tomato sap 85-90 °C, DEP 1 x 10^{-4} to 1 x 10^{-5}, in air dried tomato leaves virus survived for 24 years at laboratory temperature, sap remained infectious for 2-3 months and for many years when stored at 0-2 °C. The particles occur in all tissue of the infected plant, especially in seed but not in embryos. Inclusion bodies are produced in the leaves.

12.7.4 **Disease cycle:** ToMV is a stable virus and resistant to adverse climatic conditions. It is sap transmissible and principally transmitted by man through contact during cultivation. No natural vector is known. Seed transmission occurs mainly as external seed contaminations which gives rise to "infected seedlings" and diseased crop refuse are the main sources of infection.

12.7.5 **Management:**

a. Use of virus free seedlings is the most important and first step for the control of tomato mosaic. Seedlings should be raised in a sterilized bed or in a place where solanaceous hosts were not grown for 4-6 months.
b. Seeds should be subject to heat treatment (50-70 °C) for 24 hours.
c. Seed may be treated with 20 % solution of trisodium phosphate for about 2 hours. Thermo and chemotherapy inactivate the virus.
d. Avoid continuous cultivation of tomato in the infected areas, and follow proper rotation including other than solanaceous hosts.
e. Clean cultivation.

12.8 Mild mosaic of potato/potato virus X (PVX)

12.8.1 **Occurrence:** PVX is of common occurrence throughout the country but severely in potato growing areas. It has a wide host range, which includes potato, tomato, pepper, tobacco and Datura also. The damage in potato is not as serious as compared to PLRV or PVY. Nevertheless, PVX is one of the causes of degeneration in the crop.

12.8.2 **Symptoms:** PVX generally induces mild mosaic in potato, mottling or necrotic ring spots on tobacco and mosaic and slight stunting of tomato and pepper. The disease, in spite of wide occurrence, causes negligible or very slight interveinal mottling. In many cases, virus carried by the potato plants results in masked symptoms. At 25 °C the virus consists of several strains (mild to severe).

12.8.3 **Causal virus:** PVX has flexuous/filamentous particles measuring 575 x 13 nm with ssRNA constituting 6% of the particle weight. Virus is mainly found in the palisade cells and less frequently in the epidermis. Virus occurs in high concentration in various host plants. It has been purified and partially characterized for its sedimentation, UV absorption spectrum, immunogenicity and resistance in tobacco, potato and chillies. It belongs to the genus "Potexviruses". Some physical properties of the virus in tobacco sap are: DEP 1 x 10^{-3} to 1 x10^{-4}, TIP between 65-75 °C, LIV several weeks at 20 °C and for more than one year in stored preserved preparations.

12.8.4 **Disease Cycle:** No vectors are known, and transmission easily occurs by contact. Use of infected tubers is the main source of inoculum. The weed, *Datura stramonium* is a good reservoir of PVX.

12.8.5 **Management:** As mentioned above, PVX (other potato viruses also) is perpetuated and initiated in the field diseased seed stock retained from previous years' harvest. Therefore the use of virus-free tubers harvested from a healthy crop and elimination of chances of secondary infection are the main controlling factors. Obtain certified seed from a reliable source (indicates tolerance limit for PVX) and rogue out diseased plants from the field as soon as located.

12.9 Severe mosaic/potato virus Y (PVY)

12.9.1 **Occurrence:** It is also called as potato severe mosaic, tobacco vein banding virus, and potato acropetal necrosis virus, but PVY is the common name. It is prevalent in all the potato-growing areas of the country and inflicts appreciable loss in production. The infected plants are easily identified and located in the filed by its characteristic symptoms. It also infects tobacco, pepper and some weeds.

12.9.2 **Symptoms:** The symptoms of PVY vary from mild to severe mottle and "streak or leaf drop streak" along with necrosis of veins on underside of the leaflets. The leaves on the infected plant become completely necrotic but remain hanging. Top leaves are generally free from necrosis, but are mottled and slightly crinkled. Plants from infected tubers are stunted with brittle and crinkled leaves, and produce none or very small tubers. Three strains of PVY, designated as Y°, Y^{n} and Y^{c}, have been identified. The strain Y° is very common in Pakistan. Symptoms also depend on the variety of potato and strain of virus.

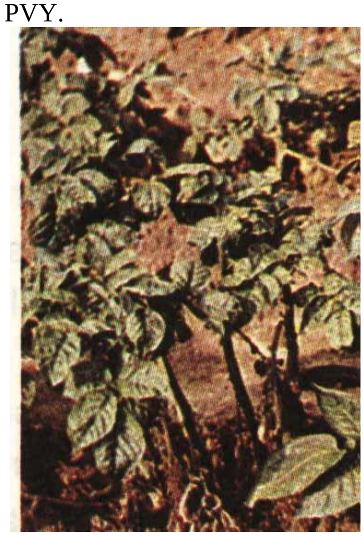
12.9.3 **Causal virus:** PVY belongs to the genus "Potyvirus". The particles are elongated, flexuous, helically constructed and measure 75 x 11 nm. The virus has been purified and partially characterized. The virus has ss-RNA, and induces cylindrical inclusions in the infected cells. It is sap transmissible. In tobacco sap, TIP is between 50-62 °C, DEP 10^{-3} to 10^{-4}, and mechanically transmissible.

12.9.4 **Disease Cycle:** The disease starts in field by planting infected tubers. The virus is mechanically transmitted by sap inoculation and by grafting. In nature PVY is transmitted by many aphid species in a stylet-borne or non-persistent manner. Among the aphid species transmitting PVY, *Myzus persicae*, (peach aphid) is the most efficient vector. Other species such as *Aphis fabae, Macrosiphum* sp. and *Aphis gossypii* are also important. As already mentioned, PVY is transmitted non-persistently. Pre-acquisition fasting period for one hour increases transmission efficiency of the vector. A single aphid can transmit the virus but a batch of 5-10 individuals gave the highest transmission. Longer acquisition or inoculations feeding periods reduce transmission ability.

12.9.5 **Management:** Do not plant infected tubers, rogue out diseased plants from the field and obtain certified seed from reliable sources and observe tolerance limits of PVY.

Potato Virus X

Tobacco Mosaic Virus



Potato Leaf Roll Virus

B. BACTERIAL DISEASES

Plant diseases caused by plant pathogenic bacteria are characterized by their peculiar symptoms. Water-soaked spots appear on the fresh bacterial infection. The slimy bacterial mass may be yellowish (usually due to *Xanthomonas* spp.) or creamy to whitish (usually due to *Pseudomonas* spp.). Bacterial soft rots of fruits and vegetables are characterized by various species of *Erwinia*. Fungi also cause leaf spots and blights but the sites of infection may exhibit mycelial growth of the fungus instead of water soaking of the infected tissue.

Most of the plant pathogenic bacteria are either saprophytes or facultative parasites. Very few bacteria such as xylem-limited or phloem-limited fastidious prokaryotes exhibit obligate parasitism in host plants. Except some obligate parasites, spraying agricultural antibiotics such as Agrimycin-100 or Streptomycin sulphate can control most of the pathogenic bacteria. Some fungicides also serve as weak bactericides, like Trimeltox forte and Cupravit. Since pathogenic bacteria are not difficult to control, very few epidemics in plants have been reported. In

Pakistan bacterial blight of rice, angular leaf spot of cotton and citrus canker are economically important bacterial diseases.

12.10 Bacterial blight of cotton

12.10.1 **Occurrence:** In Pakistan bacterial blight on cotton was recorded in 1965 near Multan. Gradually the bacterial inoculum multiplied and the disease attained economic importance. According to an estimate it can induce 50% crop loss under favorable environmental conditions. Particularly, in summer season when monsoon rains start earlier, the bacterial secondary spread may result in heavy losses to the cotton crop.

12.10.2 **Symptoms:** Initial symptoms appear in the form of water-soaked spots on the lower surface of leaves. These spots turn yellow and finally necrotic and also appear on the upper surface of leaves. The spots become angular, that is why the disease is also named as angular leaf spot of cotton. Photosynthetic area is reduced and leaf shedding takes place. Disease symptoms also appear on the stem in the form of black elongated lesions. This is called black arm phase. In severe cases of infection water-soaked spots also appear on the bolls. The bolls begin to rot and their lint is deteriorated. The branches become weak and may break due to weight of the bolls. Extensive leaf shedding indicates a large number of bare nodes that are very prominent from the lower side. The whole crop looks as if the fire has scorched it.

12.10.3 **Causal organism:** Bacterial blight of cotton is caused by *Xanthomonas campestris* pv. *malvacearum*, which is externally and internally seed-borne. It enters through the micropylar end and survives in the seed. The bacterium may also survive in the fuzz of the seed and on the previous year's diseased crop residue.

12.10.4 **Disease cycle:** When cotton is sown, the bacterium becomes active along with the germinating seedling and attacks the young emerging cotyledonary leaves. Some times the attack is so severe that the seedling collapses. If the plant is tolerant enough to survive the attack, it produces secondary leaves and thus the bacterium becomes systemic and attacks the secondary leaves. It blocks the xylem vessels and thus inhibits the transmission of water and essential nutrients to the above ground parts of the plant. Cool dry weather checks the disease while moderate humid weather favors. Rain splashes further spread the bacterium when it enters through the stomata and multiplies rapidly at 30-35 °C and >85 % relative humidity.

Several races of the bacterium have been discovered. Among these, race No. 18 is the most virulent and destructive race so far recorded in the world. The same race has been recorded from the Multan, Faisalabad, Sahiwal, Dera Ismail Khan, Tundo Jam, Sukrand, Rahim Yar Khan, Bahawalpur, Vehari and Haroonabad. The other races such as No. 2, 8, 10 and 12, which are less virulent, have been recorded from Sahiwal, Faisalabad, Multan, Bahawalpur, Lahore and Vehari areas of cotton. Unfortunately none of the commercially grown cotton varieties have durable resistance against the prevalent races of this bacterium, which is a challenge for the plant breeders, because the non-availability of resistant cultivars may provide the chance for the bacterium to spread in epidemic form if environmental conditions become conducive for disease development.

12.10.5 **Management:** Seed must be taken from disease free crop. Acid delinted seed should be used for cotton cultivation. Even then if disease symptoms appear, the crop should be sprayed with Agrimycin-100; the 2nd and 3rd spray may be conducted after 15 days interval depending upon the severity of disease.

The effective control of bacterial blight of cotton lies in the seed treatment with Agrimycin-100, plus one or two sprays of this antibiotic. Most of the scientists agree on the fact that one chemical is not sufficient to control the disease. Based on three-year experiment it was proved that a combined spray of Agrimycin-100 (100 g/ha) and Trimeltox forte (2 kg/ha) effectively controlled bacterial blight on cotton. The durable control of this disease is only possible through disease resistant varieties. It has been found that those cotton varieties which contain $\beta_2\beta_6$,$\beta_2\beta_3\beta_7$ and $\beta_2\beta_3\beta_7$ + βN contain durable resistance to prevalent races of *X. malvacearum*. Thus while breeding for disease resistance, genes from such varieties should be incorporated in the commercially cultivated varieties.

12.11 Bacterial blight of rice

12.11.1 **Occurrence:** This disease was recorded in 1976 in Pakistan. During 1980-85 disease appeared in varying intensity on IRRI 6, Pulman and Basmati 198. According to a survey conducted in 1985-86, bacterial blight of rice incidence was found 15-25, 10-15 and 20-25 % in Punjab, Sindh and NWFP, respectively. In fact this disease has spread in Pakistan due to continuous cultivation of susceptible varieties such as IRRI-9 and Basmati 385. Currently it is one of the major diseases of rice and a potential threat to the successful cultivation of rice crop in Pakistan.

12.11.2 **Symptoms:** Blight usually starts from the margins and tip of leaves and progresses downwards. In the beginning grayish-yellow stripes appear on the leaves, which become white or yellowish. As the disease progresses, whole leaf becomes necrotic. Due to systemic infection, disease affected plants become yellowish and the whole field looks as if it has been scorched by the fire. When the disease-affected plants are cut, the white or yellowish slimy mass is visible which is more prominent on the lower surface of newly infected leaves.

12.11.3 **Disease cycle:** The bacterium *Xanthomonas campestris* pv. *oryzae* is not seed-borne, rather it survives on the rhizosphere of weeds such as *Leersia* sp. grown in colonies along canals and ditches. The pathogen overwinters on rhizosphere of these alternate hosts and multiplies in spring when new shoots of the weeds begin to emerge. The bacterium is dispersed through irrigation water and infects rice seedlings in lowland nurseries or those transplanted in paddy. Secondary spread of the disease in severe form occurs usually in summer to early autumn under humid weather conditions (Temp. 30-35 °C and relative humidity > 90%). Epidemics are readily induced by rainstorms or flooding of paddy fields in this season. Excess application of nitrogen fertilizer also increases disease severity.

12.11.4 **Management:**

- **a.** Alternate hosts growing along canals and ridges should be removed to eliminate the natural habitats of the pathogens and its dispersal through irrigation water.
- **b.** Care must be taken for field sanitation by burning or taking out diseased rice straw from fields.
- **c.** Fertilization in either excess or in deficiency of potassium and phosphorous should be avoided.
- **d.** Infected nursery plants should not be used for further transplantation.
- **e.** Irrigation water should not be allowed to move from diseased field to healthy rice field.
- **f.** Tecloftalam, phenazine oxide, nickel dimethyldithiocarbamate and probenazole can be applied for chemical control of bacterial blight of rice. Probenazole (granule form) is applied to the paddy water before or just after transplanting, well in advance of disease occurrence. Other chemicals such as Agrimycin 100 can be applied in three sprays depending on the intensity of disease.
- **g.** Resistant/tolerant varieties i.e. Shaheen Basmati, KS-282, Super Basmati should be cultivated.

12.12 Citrus canker

12.12.1 This disease occurs commonly throughout the country and is considered as one of the major diseases of citrus. Its incidence has been recorded to be 12.5% on the citrus varieties grown in Faisalabad district. A major epidemic of citrus canker was reported in the United States in 1910. Destruction of any infected orchard and establishment of a new disease free orchard have now eradicated the disease completely from the USA. Our citrus growers cannot afford to adopt this type of strategy keeping in view the economic condition. Using appropriate disease management strategies can minimize the bacterial inoculum.

12.12.2 **Symptoms:** The disease appears on leaves, branches and fruits. On the young leaves, small yellowish spots develop first on the lower surface and then on the upper surface. In the beginning the spots are small and scattered and then become corky and hard and rose with age. The spots increase in number and size. The diseased area becomes dead and sometimes drops out leaving holes in the leaves. Similar diseased spots develop on twigs and fruits. Fruit fall is also common. The disease is very serious on Kagzi lime, Khatta (grape fruit) and Malta (sweet orange) while it is mild on sweet lime and Sangtra.

12.12.3 **Disease cycle:** The pathogen survives in the infected plant parts in the over wintering cankers and becomes active under favorable conditions of temperature and relative humidity (Temp 30 °C and RH > 85%) especially after rains. The dissemination takes place by splashing rains as well as by contact. The bacterium enters through stomata and may be carried by citrus leaf minor. The pathogen gets entry in a new orchard through diseased nursery plants or through small bits of diseased material, which is carried by winds from the neighboring diseased orchards.

12.12.4 Management

a. Use of healthy nursery plants
b. Removal and burning of diseased plant parts.
c. Regular pruning at appropriate time in the season.
d. Spraying Perenox, Cu oxychloride or Agrimycin 100 following label instructions.


Bacterial blight of cotton


Bacterial blight of rice


Citrus canker

C. FUNGAL DISEASES

Fungi cause a vast majority of plant diseases. In North America, for example, more than 8000 species of fungi cause nearly 100,000 diseases. A single crop, the tomato is attacked by more than 40 species of fungi. In Pakistan a total of 1258 fungi; 47 belonging to Myxomycetes, 88 to Phycomycetes, 304 to Ascomycetes, 544 to Basidiomycetes and 275 to Fungi Imperfecti have been published (Ahmad, 1956). Ghafoor and Khan (1976) listed diseases of economic plants in Pakistan, which is a wealth of information on fungal flora. Kamal and Khan (1968) have listed the names and times of appearance of 104 fungal diseases of 37 different crops, vegetables and fruit plants of Sindh province. Further information is being added to these compilations for the benefit of researchers and students of Mycology and Plant Pathology.

Fungi as plant pathogens are different from bacteria, viruses, and nematodes in their broad range of parasitism. They are saprophytes, facultative saprophytes, parasites, and facultative parasites, obligate parasites (biotrophs) and obligate saprophytes (saprobes or necrotrophs), hemibiotrophs and necrotrophs. Their presence on the host may be characterized by mycelial growth and some characteristic symptoms like powdery or downy mildews, blights, leaf spots, anthracnoses, rot, wilts, scabs and curling of the infected tissue. Fungi form specific structures for infection such as haustoria, appresorium, and infection peg and greatly rely on enzymes and toxins for invasion and colonization of host tissue. Fungi cause majority of economically important diseases in Pakistan.

12.13 Powdery mildews

12.13.1 **Occurrence:** These diseases can be characterized by the presence of whitish fluffy powder on the upper surface of leaves and other floral and vegetative parts of plants. The fungi involved in causing powdery mildew belong to the order Erysiphales and family Erysiphaceae in Ascomycetes. *Erysiphe*, *Phyllactinia*, *Podosphaera*, and *Sphaerotheca* are the genera of fungi whose species parasitize various economically important plants.*Erysiphe graminis* causes powdery mildew of cereals, *E. cichoracearum* causes powdery mildew of cucurbits, *E. polygoni* causes powdery mildew of pea, *Phyllactinia dalbergiae* causes powdery mildew of shisham, *Uncinula necatar* causes powdery mildew of grapes, *Sphaerotheca pannosa* causes powdery mildew of rose and *Podosphaera leucotricha* causes powdery mildew of apple.

12.13.2 **Symptoms:** Plant parts affected by powdery mildew show a whitish powdery consistency. This whitish powder can be dropped easily by shaking the affected plant parts. The surface beneath the powdery mildew becomes necrotic due to destruction of chlorophyll. Thus photosynthetic area is reduced and the ultimate effect is yield reduction. The disease-affected plants may be reduced in size and in severe cases of infection quality/quantity of the produce is affected adversely.

12.13.3 **Disease cycle:** The fungus survives adverse environmental conditions in the form of cleistothecia. When the temperature is warm and relative humidity is low ascospores are disseminated and cause infection. As long as the warm dry weather prevails fungus continues to sporulate and cause infection. Powdery mildews are favored, in general, by warm weather with exception of powdery mildew of cereals, which is favored, by warm moist weather. All powdery mildews are obligate plant parasites and survive adverse environmental conditions on alternate hosts (one of two kinds of hosts on which a parasitic fungus must develop to complete its life cycle) or collateral hosts (several weed plants other than primary host or alternate host which support the survival of a fungus).

12.13.4 **Disease management:**

- **a.** Eradication of alternate host or collateral host.
- **b.** Sulfur dusting (20 lbs/A) or lime dormant spray is effective to control disease.
- **c.** Crop sanitation.
- **d.** Cultivation of resistant variety.

Powdery mildew of cucurbits

Downey mildew of cucurbits

12.14 Downy mildews

White silky growth or white cottony growth on the lower surface of the leaves is called 'downy mildew'. The silky growth is actually the sporangiphores and sporangia hanging down through the stomata of leaves. These fungi require cool humid weather opposite to powdery mildews. Following are the economically important downy mildews in Pakistan.

12.14.1 Downy mildew of grapes

a. **Occurrence:** This disease is prevalent on the grapes grown in the regions of Baluchistan like Quetta, Ziarat etc. The exact data regarding incidence and losses is not available. In the United States when the weather is favorable downy mildew can destroy 50 to 75 percent of the crop in one season.

b. **Symptoms:** All the succulent tender parts of the vines are attacked leading to a partial or total destruction of the foliage, dwarfing and killing of the shoots and rotting and cracking of the berries. The first sign of the disease on the leaf is a small greenish yellow oily spot on the upper surface with indefinite borders. On the abaxial surface of the leaves a downy growth of the sporophores of the fungus appears. The mildew may cover the entire leaf, which may wither and dry. Killing and rotting of berries, along with weakening, dwarfing and killing of young shoots is also observed.

c. **Disease cycle and epidemiology:** The fungus overwinters in the form of oospores. Sometimes perennial mycelium has been observed in infected shoots. The oospores germinate in spring; produce zoosporangia and zoospores, which cause primary infection of the host. Secondary infection is caused by conidia through stomata on the lower surface of the leaves. The optimum temperature for the germination of oospores and conidia is 20-25 ºC. Incubation period varies from 5-18 days depending upon the temperature and humidity. Optimum temperature for the development of an epidemic is 18-24 ºC, minimum 12-13 ºC and the maximum is 30 ºC. Humid and cloudy weather favors an epidemic. Dry and hot weather prevents it.

d. **Management:** Spray with perenox at the rate of 2 pounds per 100 gallons of water. Sanitary measures such as cutting the primary source of infection by deep cultivation and plouging, thus preventing the germination of oopsores are desirable practices. Removing and burning the diseased leaves, shoots, berries that may contain the hibernating oopsores helps in preventing epidemics. Cultivation of resistant varieties is a valid option.

12.14.2 Downy mildew of grasses

a. **Occurrence:** This disease is widespread throughout the world. The hosts chiefly belong to the grass family and include sugarcane, sorghum and millet. E. J. Butler reported the disease in Indo-Pakistan subcontinent in 1907. In the beginning the disease was not so serious, but with the release of high yielding varieties and hybrids the disease attracted much attention. Losses may be as high as 30% in severe cases of infection.

b. **Symptoms:** The diseased plants may show stunting which may take place mainly due to the reduced internode elongation. Malformation of the floral bracts or chlorotic or necrotic lesions on the foliage may be observed. Excessive tillering from the crown and development of branches from the auxiliary buds along the culms (stem of plants) may take place in certain cases. Systemically infected inflorescence as well as the leaves in proximity to it may show various degrees of malformation and overgrowth. The ear is transformed wholly or in part into a loose head composed of small twisted, leaf like structures, which give it a green appearance. The glumes, stamens and pistils are usually replaced by leaf shoots, due to which no kernel development takes place. When leaves are attacked long chlorotic streaks extend over the entire length of the leaf. The downy mass of conidiophores and conidia are usually common on susceptible hosts grown in humid climate and are less common under dry conditions. Leaf necrosis and browning are followed by splitting, distortion and shredding of the invaded tissues especially as plants approach maturity.

c. **Disease cycle and epidemiology:** The oospores are frequently carried with the seed, but may remain viable in the soil and the diseased crop residue for 8 months to 10 years. As only a small percentage of spores germinate at one time, the oospore inoculum is present over a long period. Infection of the young plants occurs from the oospores in soil. The fungus mycelium is intercellular and provided with haustoria. Minimum, optimum and maximum temperature for the germination of conidia are 5, 8-20 and 35 ºC respectively. The conidia germinate between 5-35 ºC with an optimum at 17 ºC. Conidia cause secondary infection when the plant tissues are still susceptible and the weather is favorable. Mature plant tissues are relatively resistant.

d. **Management:** Seed treatment with Vitavax, Benlate and Agrosan following label instructions. Avoid cultivation in low lying and waterlogged fields. It will reduce the chances of infection.

12.15 White rust of crucifers

The name white rust is a misnomer, because the name rust is used only for the fungi belonging to the order Uredinales of class Basidiomycetes. The name should be changed to white blisters of crucifers. White rust of crucifers is common on several cruciferous crops such as cabbage, turnip, mustard and radish, horseradish, sarson, taramera and cauliflower.

12.15.1 **Symptoms:** The pathogen infects host plant by two types of infection: local and systemic. In the case of local infection isolated pustules or sori develop on leaves and stem. These pustules or sori are raised white shiny areas that are 1 to 2 mm in diameter. They may arise in close proximity and merge with one another to form large patches. The host epidermis ruptures but often not until sometime after the pustules are fully formed. When this disease occurs, the pustules have a powdery consistency. When young stems and flowering parts are infected, the fungus becomes systemic in the tissue and stimulates hypertrophy and hyperplasia. This results in enlarged and variously distorted organs. The distortion and abnormal development are particularly conspicuous on flower parts. Sepals become enlarged to several times of the normal size. Petals enlarge and chlorophyll rather than the usual flower pigment is formed. Pistils and anthers are likewise distorted and normal seed development is prevented. In a given flower some parts may be normal while others may be greatly distorted. Pustules may form as hypertrophied organs but they may be relatively rare on such tissue. Root galls have been reported on radish.

12.15.2 Disease cycle: The fungus, *Albugo candida* overwinters in the form of oospores except in perenial hosts such as horseradish in which the mycelium persists in the crown and occasionally in lateral shoots. The secondary infection takes place by short lived wind-borne conidia, which may germinate immediately under favorable conditions. Chilling is essential for the production of zoospores. After chilling the spores may germinate at temperature from 1 to 20 °C. Dehydration of spores to 30% moisture is also necessary for germination and more rapid rate of dehydration, prompter the germination. Moisture on the host is essential for germination as well as infection. Motile zoospores swim for a short time, become quiescent and produce germ tube. The germ tube penetrates through stomata and establishes on the host by intercellular mycelium and haustoria.

12.15.3 **Management:** Following control measures may be adopted:

a. Crop rotation avoiding susceptible crops should be followed.
b. Eradicate the cruciferous weeds.
c. Destruction of disease crop residue.
d. Spraying of crop in case of severe attack by Perenox.
e. Cultivation of resistant varieties such as Brown sarson, Selection A, Pele sarson, RL-18, RLL 84, Pela ria, Toria Selection A, Poorbi Ria, Ria Anmol 87.

12.16 Damping off disease of seedlings

12.16.1 Occurrence: Damp: moisture in air, on surface or diffused within solids. This disease is common all over the world. It occurs in agricultural and forest soils, in tropical and temperate climate and in almost every greenhouse. Damping off of seedlings occurs at two stages. In **pre-emergence damping off,** the young seedlings are killed before they reach the soil surface. The young radicle (part of plant embryo that develops into primary root) or plumule (part of embryo that forms the stem) are killed and there is complete rotting of seedling. In **post-emergence damping off**, the young infected tissue of the seedlings at the ground level becomes soft and water soaked. The seedlings are toppled over or collapse. Such symptoms are very common in seedbeds in nurseries.

12.16.2 Symptoms: The symptoms caused by the damping off fungi vary with the age and stage of development of the plant affected. Seeds of susceptible plants planted in infected soil are attacked by the damping off fungi. They fail to germinate, become soft and mushy, then turn brown, shrink and finally disintegrate. Seedlings that have emerged from the soil are usually attacked at the roots and sometimes at or below the soil line. The succulent tissues of the seedlings are easily penetrated by the fungus which invades and kills the cells very rapidly. The invaded areas become water-soaked and discolored and the cells soon collapse. At this stage the basal part of the seedlings is much thinner than the uninvaded parts and can not support the part of the seedlings above it. Hence, the seedlings fall over the soil. The fungus continues to invade the seedlings until the seedlings quickly wither and die.

12.16.3 Disease cycle: *Pythium debaryanum, P. aphanidermatum, P. ultimum* and *P. arrhenomans* are the fungi causing damping off disease. The mycelium comes in contact with seeds or seedlings or it enters through mechanical pressure and dissolution by means of pectinolytic and cellulolytic enzymes. The initial infection usually occurs at or slightly below the surface of the soil, depending on moisture level and depth of planting. Pre-emergence damping off is favored by low temperature (12-17 °C) and high moisture while post-emergence by high temperature (20-30 °C) and high moisture. The mycelium advances into the host tissue intercellularly. It bursts through the epidermis and forms small patches of aerial mycelium. The mycelium gives rise to sporangia. The sporangia may be terminal or intercalary in position and are variously shaped. Sporangia either germinate directly or produce vesicles in which more than 100 zoospores are produced. The zoospores after release either encyst themselves or come to rest and then germinate by germ tube to cause infection. Under unfavorable conditions fungus produces oospores by gametangial contact of anthridium and oogonium. Oospores may germinate directly by germ tube or they may develop mycelia which produce vesicle in which zoospores are formed. If the temperature is above 18 °C sporangia and oospores germinate by germtube while temperature from 10 to 18 °C induces germination by means of zoopsores.

12.16.4 Management: Seed treatment with chlorothalonil, thiram, captan, dichlone, ferbam and diazoben etc is an effective control measure. The systemic fungicide ethazole controls damping off seedling blights and root rots caused by *Pythium* and *Phytophthora*. It can be used as soil drench or seed treatment. In greenhouse damping off can be controlled by using sterilized soil. Cultural practices using good soil drainage, improvement of heavy soils, and improvement of air circulation among plots are helpful to reduce disease incidence. Planting should be done when temperature is favorable for fast plant growth. Application of excessive amount of fertilizer should be avoided. No crop should be planted in the same field for more than two consecutive years, because that would increase fungal population in the soil. Resistant varieties should be cultivated if available.

12.17.1 Rust diseases

12.17.2 Occurrence and causal organisms: Members of the order Uredinales cause rust diseases. The rust fungi are obligate plant parasites. In Pakistan three types of rusts occur on wheat. Stem rust occurrence is rare. However, leaf and stripe rust occur periodically and induce huge yield losses to wheat crop. Prior to the introduction of Mexican dwarf varieties, two epidemics of stem and leaf rust combined, occurred in 1947-48 (20-30 percent) and 1953-54 (14-20 percent) and one of stripe rust in 1958-59 (14 percent). During post introduction period there has been no epidemic of stem rust while 4 epidemics of stripe and leaf rusts occurred. The epidemics of stripe rust in 1972-73 (2-3 percent), leaf rust in 1975-76 (5-6 percent) stripe and leaf rust combined in 1977-78 (10 percent) and again of stripe rust in 1979-80 (30 percent in uplands of Baluchistan only) have been reported. Most of these epidemics did not cause huge damage to the wheat crop but the combined epidemic of leaf and stripe rust of 1977-78 reduced the total production of wheat by 2.2 million tons.

12.17.3 **Symptoms:** Scattered rust pustules appear on the leaves having dark brown colour and later on transformed to yellowish lesions, thus the name of disease emerged as leaf rust or brown rust. In case of yellow rust, stripes of rust pustules appear on the leaves and these run parallel along the midrib of the leaves. Black elongated lesions appear on the stem in case of stem rust. As a result of these symptoms photosynthetic area is reduced and effects on yield are prominent. The stage of crop is very important so for as the yield losses are concerned. In case of early infection huge yield losses are expected. But late infection sometimes does not induce great losses as the crop may escape from infection due to physical maturity.

12.17.4 **Disease cycle:** Rust fungus survives adverse conditions on alternate host (barberry in case of *Puccinia graminis* f. sp. *tritici*, causing stem rust in case of *Puccinia recondita* f. sp. *tritici* causing leaf rust). The fungus is polymorphic and produces basidia, pycnia and aecia on alternate host and uredia and telia on primary host. Aeciospores land on the wheat crop sown in plain areas and their development into uredospores is favored by 20-22, 22-24 and 24-26 ºC temperatures in case of stripe, leaf and stem rust respectively. Humid and wet weather is conducive to the spread of rust epidemic. In the absence of alternate host fungus may survive in the form of uredospores to uredospores disseminated long distance by wind from one wheat crop to another in one geographical territory or another. Thus wheat crop may serve as green bridge for the rust fungus. As long as the weather remains favorable fungus continues to produce several successive generations of urediniospores. When the crop matures fungus produces teliospores which germinate on alternate host to produce basidiospores on promycelium (Fig. 9.2). Pycniospores are formed on the alternate host and after spermatization aeciospores are formed on the lower surface ready to disseminate again for infection on the primary host and thus disease cycle continues.

12.17.5 **Management:** Cultivation of resistant variety such as Aquab 2000, Iqbal 99, Inqlab- 91, AS-2002. Avoid monoculture (large scale cultivation of single variety). Eradication of alternate host if possible. Spraying the crop with Mancozeb, Bayleton, Propiconazole and Folicur etc. following label instructions.

12.18 Smut and bunt diseases

Smuts and bunts occur at varying intensity in Pakistan and may cause appreciable yield loss depending upon the initial inoculum level, hot humid weather and susceptible cultivars. Following important smuts and bunts are prevalent in Pakistan.

1. Loose smut of wheat (*Ustilago tritici*).
2. Loose smut of barley (*Ustilago nuda*)
3. Covered smut of barley (*Ustilago hordei*)
4. Loose smut of oats (*Ustilago avenae*)
5. Covered smut of oats (*Ustilago kolleri*)
6. Grain smut of sorghum (*Sphacelotheca sorghi*)
7. Head smut of maize (*Sphacelotheca reiliana*)
8. Common smut of maize (*Ustilago maydis*)
9. Flag smut of sugarcane (*Ustilago scitaminea*)
10. Flag smut of wheat (*Urocysts tritici*)
11. Old bunt/stinking smut/complete bunt of wheat (*Tilletia caries*, *Tilletia foetida*)
12. New bunt/partial bunt/karnal bunt of wheat (*Tilletia indica*, *Tilletia barclayana*)
13. Bunt of rice (*Neovossia horrida*)

12.18.1 **Symptoms:** Black powdery mass is called smut. When it is loose and easily disseminated it is called loose smut, when the spikelets are intact and contain the black powdery mass inside the name is given as covered smut. Bunt is dried shrivelled grain. Completely smutted grain is called old bunt or stinking smut. The grain with partial damage due to smut fungus is called karnal bunt or new bunt. Smuts or bunts induce total loss to the crop yield qualitatively and quantitatively.

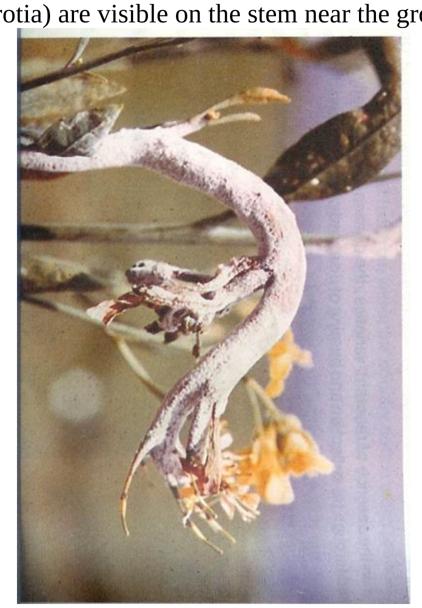
12.18.2 **Disease cycle:** Fungi causing smuts and bunts survive in the soil, infected plant parts, internally or externally seed borne and some air-borne. It depends upon the type of infection, whether seedling, blossom or local and nature of infection whether local or systemic. Loose smut of wheat or barley is induced by blossoming penetration type. The fungus penetrates by forming infection threads through the blossom and it remains dormant in the embryo until the wheat seed is sown for next year crop. As the seedling germinates fungus mycelium becomes active and grows systemically through the stem and finally produces smutted spikelets instead of normal healthy grains. In case of common smut of maize, bunt of rice and new bunt of wheat penetration takes place through leaves and flowers. Fungus is disseminated locally by air-borne sporidia and causes local infection. In all the other above mentioned smuts and bunts fungi penetrates through seedling and becomes systemic, after consuming starch of the grains, convert them into smut powder which may be covered or loose, grains may be infected partially or completely. The penetartion in sugarcane smut takes place in the buds coming out of the setts. Transmission may take place through diseased sets or spores adhering to the buds of setts at the time of planting or by ratooning smutted canes in the case of secondary infection by wind. Different smut and bunt fungi grow at different temperature; however, warm humid weather favors the development of these diseases.

12.18.3 **Management:** Loose smut of wheat and barley can be controlled through hot water treatment or anaerobic seed treatment. For the control of bunt of rice, common smut of maize and new bunt of wheat, resistant varieties, crop sanitation and rotation with non-host crops are effective. Seed treatment with Vitavax, Benlate has been recommended for the control of loose and covered smut of oats, covered smut of barley, grain smut of sorghum, head smut of maize, old bunt and flag smut of wheat and whip smut of sugarcane.

12.19 Root rot of cotton

Huge losses to cotton crop have been reported due to this disease. Now-a-days root rot of cotton is under control and is not among major disease of cotton in Pakistan. Development of root rot resistant/tolerant varieties has minimized the disease incidence.

12.19.1 **Symptoms:** The first apparent symptom of the disease is the sudden and complete wilting of the plant. A plant affected with this disease can be very easily pulled out from the soil and the tap as well as the secondary roots is seen to be rotten. On pressing the roots of a freshly wilted plant, yellowish, thick, sticky and bad smelling liquid oozes out. The bark of the root is shredded. In some cases, when diseased plant has remained standing in the field for some time the resting bodies of the fungus (sclerotia) are visible on the stem near the ground level point.


White rust of crucifers


Root rot of cotton

12.19.2 **Disease cycle:** *Fusarium* sp., *Armillaria* sp., *Rhizoctonia solani*, *R. bataticola*, *Sclerotium* sp. *Xanthomonas malvacearum*, *Meloidogyne incognita, M. hapla,* and *M. arenaria* have been found associated with root rot of cotton. However, *R. solani* dominates the affected parts and is considered to be the actual cause of the disease. Others may serve as predisposing factors or as primary/secondary invaders. The fungus survives in the form of sclerotia in the soil and forms specific anastomosis groups which have the capability to infect susceptible cotton varieties. It does not produce spores or undergo normal methods of reproduction. Hot humid weather favors the development of disease. Under adverse weather fungus forms sclerotia while under favorable weather it forms heterokaryotic mycelium which may infect the roots.

12.19.3 **Management:** Cultivation of resistant varieties i.e. CIM-443, CIM-445, CIM 901 and others. Intercropping with moth and removal of fodder by the first week of August after which the crop should be properly manured. Recommended agronomic practices should be followed to raise a good crop.

12.20 Gram wilt and blight

12.20.1 **Occurrence:** Wilt and blight are two very important diseases of chickpea in Pakistan. Several epidemics of either of these diseases have been reported. Both of these diseases are limiting factor in the successful cultivation of gram in arid or barani areas of Pakistan. None of the gram variety is completely resistant to wilt and blight.

12.20.2 Symptoms

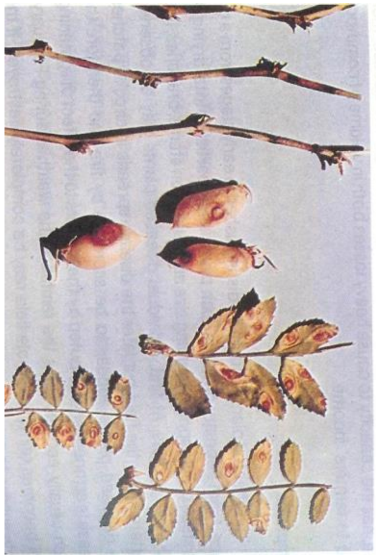
Gram wilt	**Gram blight**
The first apparent symptom is drooping of leaves, which is followed by wilting and necrosis of the tissues of the collar roots and the main roots. The affected plants can be easily pulled out from the soil and roots seem to be discolored. There are two definite and distinct phases of the disease. Seedling phase occurs in the month of Sept-Oct and mature phase in the month of March-April.	Greyish to dark brown spots appear on the leaves, branches and pods. Black elongated lesions on stem and branches may girdle around the stem and the stem/branch may break due to the weight of the pods. The spots become necrotic and the foliage may look as if it has been scorched by the fire. Few plants are affected first, but later on whole field may show blight symptoms. Shrivelled grains may result in pods.

12.20.3 Disease cycle

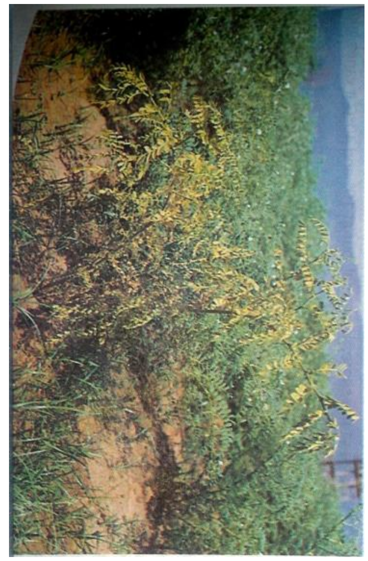
The pathogen (*Fusarium oxysporum* f. sp. *ciceris*) survives in the soil as saprophyte and attacks the susceptible seedling under warm dry weather. Primary and secondary infections take place by means of conidia. The mycelium grows intercellularly and blocks the xylem vessels, thus transmission of water and essential nutrients is inhibited.	The pathogen (*Ascochyta rabiei*) is seed, soil and air borne. Primary infection takes place through pycnidiospores released from the pycnidium. If the temperature is 18-20 ºC and rain showers are frequent, the fungus sporulates rapidly and causes secondary infection. Infected plant parts of previous year's crop and infected seed are important source of inoculum and may cause the epidemic under conducive environment.

12.20.4 Management

Crop rotation with non-host crop. Application of *Arachniotus* sp. or *Trichoderma harzianum* along with wheat straw one or two months before the sowing time. Cultivation of resistant varieties i.e. Paidar, NIAB 99, Punjab 91 Noor 91.	Cultivation of resistant varieties i.e. Paidar, NIAB 99, Punjab 91, Noor 91. Spraying the crop with Folicur, spotless or mancozeb at the initial appearance of disease symptoms and seconday spray after 15 days interval. Destruction of infected plant parts by all the farmers.



Gram blight



Gram wilt

12.21 Early and late blight of potato

12.21.1 Occurrence: Both these diseases are economically important now-a-days in the potato growing regions in Pakistan. Very few varieties are tolerant to these diseases. The inoculum of both the pathogenic fungi is wide spread and is capable of inducing huge yield losses under favorable conditions of disease spread. Early blight appears early in the season, during the months of Oct-Nov, while late blight appears during Dec-Jan, Thus in two diseases requiring quite opposite weather for their spread.

12.21.2 Symptoms:

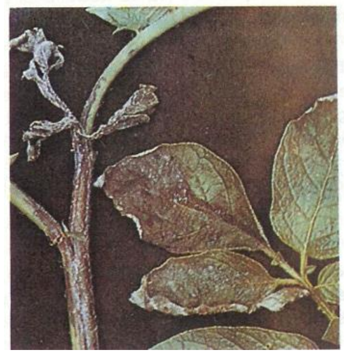
Early Blight	**Late Blight**
The most prominent symptoms are the formation of concentric zones on the leaves which give a target-board effect. Other symptoms include withering and drying of leaves from the margins. Necrosis of tissue progresses inwards with the depletion of chlorophyll. The whole field looks as if it has been scorched by the fire. Tuber size is reduced.	General and rapid killing of leaves from the margins. The necrosis of tissue is very rapid and within days the whole crop looks as if it has been scorched by the fire. Warm dry weather checks the disease while cool wet weather favores the development of symptoms in severe form. In case of early infection huge yield losses may occur.

12.21.3 Disease cycle:

Early blight	**Late blight**
Pathogen (*Alternaria solani*) survives in the infected plant parts. Primary and secondary infection takes place by means of conidia. The favorable temperature is 25-30 °C along with high humidity and rainfall.	Pathogen survives in the form of oospores which remain in the soil. At 18-22°C and 91% relative humidity. The fungus sporulates rapidly and conidia cause infection. Following four criteria have been established to forecast the disease: a. Night temperature below the dew point for about 4 hours. b. Night temperature not more than 10 °C c. Mean cloudiness not below 0.8 on the following day d. Rainfall at least 0.1 mm the following day.

12.21.4 Management: Use healthy seed for sowing. Potato seed should be taken from reliable seed companies. Resistant/tolerant varieties i.e. Kiran, FSD-white, FSD-Red, SH-20, Cardinal, Diamont or Desiree should be cultivated. General sanitary measures (crop sanitation, rogueing) should be followed. Foliar spraying gives satisfactory control of early and late blight. In this regard, Mancozeb, Acrobit, Ridomil Gold have given very good results. Folair spraying is effective only if sprayed at accurate time. When the environmental conditions are much favorable for disease, spraying may not give good results and in some cases it becomes very difficult to control late blight. If the crop is near to maturity it is advisable to destroy the vines earlier than the normal time to prevent the attack of disease.

Early blight of potato



Late blight of potato

12.22 Scab, anthracnose and wither tip

These are diseases of foliage and caused by sexual or asexual ascomycetous fungi. Under favorable conditions of disease development, the pathogenic fungi induce heavy losses to crop yield. Unfortunately exact data regarding incidence and losses due to scabs, anthracnose wither tip and diebacks in Pakistan are not available. Frequent surveys are required to monitor the disease development and losses induced by them.

12.22.1 **APPLE SCAB:** It is a serious disease in apple growing regions of Pakistan. The apple orchards having trees that belong to the genus '*Malus*' are more susceptible to scab. About 20% losses have been estimated due to this disease.

a. **Symptoms:** First symptoms appear in the form of olive colored scabby spots on the leaves and sepals. These spots turn into velvety grayish dark spots that are more or less circular in outline. Later the velvety surfaces disappear and lesions obtain a metallic black color. The lesions may be slightly raised. Lesions of scab on fruits are velvety and olive green in the beginning but later on become dark scabby and sometimes cracked. The cuticle of the fruit is ruptured at the margins and the fruit is misshapen, thus the cracked fruits may drop prematurely.

b. **Disease cycle:** The pathogen (*Venturia inaequalis*) overwinters on dead leaves, twigs and fruits fallen on the ground as pseudothecia. These fruiting bodies develop in winter and continue to grow in early spring and liberate ascospores. When the apple tree is in bloom these ascopsores fall on the young emerging buds and cause infection. The discharge may continue for 3-5 weeks after petals formation. Ascospores can germinate over a certain period of time and temperature ranging roughly between 6-26 ºC. The fungus establishes in the host and produces enormous conidia which push outwards, rupture the cuticle and within eight to 15 days after inoculation scabby lesions are formed. Rain splashes may spread the disease in epidemic form as secondary infection takes place through conidia (*Spocaea pomi*). Cool wet weather of spring and early summer favors the disease while dry warm weather of summer checks it.

c. **Management:** A good spraying programme is needed to control the disease. A dormant spray especially, when the ascospores are still in the overwintering pseudothecia is required to reduce the chances of initial inoculum. Fungicides such as captan, captafol, folpet, glyodine, glyodex (mixture of dodine and glyodine) phygon, thiram and lime sulfur are useful for the control of apple scab.

12.22.2 **Mango anthracnose and citrus wither tip:** Anthracnose of mango and die-back of citrus are caused by the same fungus, *Colletotrichum gloeosporiodes*. This fungus is a weak parasite on citrus but exhibits aggressive parasitic action on mango. Both the diseases are of moderate economic importance in Pakistan.

a. Symptoms

Anthracnose of mango	**Wither tip of citrus**
Anthracnose means a blemish blotch-type spot that is	Drying of branches from the tip downwards is first

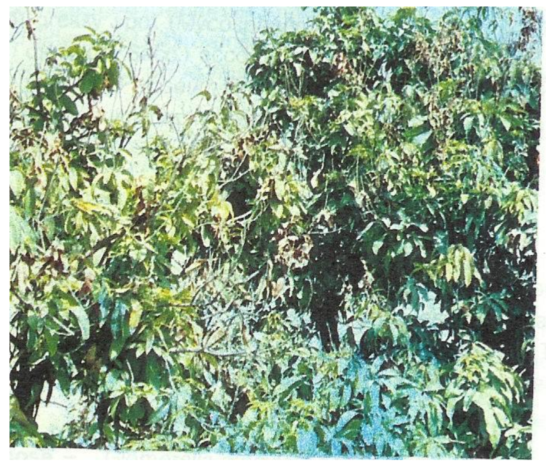
irregular in shape. It appears on the upper portion of mango fruit. The fungus is aggressive on the mango tree by producing brownish irregular black necrotic areas. The tips of very young branches are attacked first and go on drying from top downwards.	prominent symptom. Black dots (acervuli) of the fungus are seen on the infected branches covered sometime with silvery whitish membrane. The fruits on such branches are dried, shrivelled and mumified which may remain clinging to the stem or may fall prematurely.

b. **Disease cycle:** *Colletotrichum gloeosporiodes* survives in the infected plant parts and on dead fallen leaves, branches and fruits. *Glomerella cingulata* is the perfect stage which can face the adverse weather. Primary and secondary infection takes place by means of conidia. In both the diseases humid and moist weather is favorable. The fungus has the capability to grow as facultative parasite on citrus trees which are poorly managed. However, it attacks mango as a strong parasite by entering through the pores or lenticels while the fruit is still green and develops further in the flesh during the ripening period.

c. **Management:** Pruning of infected plant parts. Destruction of dead fallen leaves, branches and fruits. Spray with Perenox or Mancozeb at the initial appearance of disease symptoms and repeat the spray after 15 days interval. Follow recommended agronomic practices to keep the citrus orchard in good healthy condition.

Apple scab

Citrus wither tip



Anthracnose of mango

12.23 Citrus, shisham, guava and mango decline

12.23.1 **Occurrence:** During recent years, due to change in the climatic pattern and mismanagement practices adopted by citrus, guava and mango growers some new pathogens have started appearing in not only fruit orchards but also on the shisham trees grown on road sides, canal banks and in forests of Pakistan. The increased levels of inoculum and abiotic stresses have induced significant losses to the fruit and timber industry of Pakistan. The situation is alarming and poses potential threat to the national economy.

Name of the host	Fungi/nematodes isolated	Abiotic stresses/malpractices
1. Citrus	*Tylenchulus semipenetrans* *Fusarium solani* *Phytophthora* sp.	Imbalance fertilization and irrigation. Lack of plant health advisory service and disease free certified nursery.
2. Shisham	*Botrydiplodia theobromae* *Phytophthora* sp. *Fusarium solani* *Ganoderma* sp.	Extremes in drought and moist conditions. Mismanagement practices in raising nursery.
3. Guava	*Fusarium solani* *Phytophthora* sp.	Same as above
4. Mango	*Fusarium solani* *Botrydiplodia* sp.	Same as above

12.23.1 Symptoms

a. Yellowing of the foliage.
b. Withering and drying of branches.
c. Shredding and cracking of the bark.
d. Partial wilting of the tree in case of shisham.
e. Sudden wilting and drying particularly in case of mango.
f. Slow decline of citrus.
g. Poor fruit development.
h. Sudden collapse of tree.

12.23.3 Management
12.23.4

a. Use disease free healthy nursery plants to establish new orchard.
b. Seed treatment with Topsin-M @ 2.0 g/litre of water.
c. Balanced fertilization and proper irrigation.
d. Pruning of dried/withered branches.
e. For the control of nematodes apply Furadan or Rugby.

Suggested readings

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SECTION VII
BRYOLOGY

Chapter 13
General Account of Bryophytes

13.1 General characters

Study or knowledge of bryophytes is called bryology (Bryo-moss; logy-knowledge). The term bryophyte is used as a collective name to represent a group of plant that includes liverworts, hornworts and mosses growing, predominantly in moist environments. They are called amphibians of the plant kingdom due to the following reasons:

a. Mainly confined to moist habitats.
b. Not fully adapted on land, because their sperm must swim through water to reach the egg.
c. They lack conducting tissues e-g xylem and phloem and rely on surrounding water to conduct necessary fluids and salts during times of growth.

Vegetative plant body in bryophytes is gametophyte, which is green, well-developed and nutritionally independent. True roots, stems and leaves are lacking and the thallus attaches to the substratum by means of rhizoids. It may be homo- or heterothallic as far as reproduction is concerned. Sporophyte, on the other hand, is physically and nutritionally dependent upon gametophyte as it is attached and developed on it in the archegonium. The plant body ranges in size from conspicuously small to about 70 cm long. Because of their relatively small size, they do not need, or have specialized conduction systems.

13.2 Classification

According to International Code of Botanical Nomenclature, the division bryophyte is divided into three classes.

13.2.1 HEPATICOPSIDA: Earlier called hepaticae to include liverworts. In this class, the plants are dorsiventrally flattened, thalloid or differentiated into axes and leaves. The leaves, if present, are without midrib and are arranged into two or three rows on the axis. Sex organs usually develop from superficial cells situated on the dorsal side of thallus. Sporophytes are simple or may be differentiated into foot, seta and capsule, or foot and capsule only. Spore forming cells develop form the endothecium zone of the sporophyte. Capsule wall is one to several layers thick; stomata are not present on the capsule wall. This class comprises of three orders.

a. Sphaerocarpales: The thallus is without air-chambers and pores; sex organs are enclosed in a single cup-shaped involucre; neck of the archegonium is composed of six vertical rows of cells; sporophyte is differentiated into foot, seta and capsule.

b. Marchantiales: Thallus has pores in the epidermis and air chambers in the assimilatory region; simple and tuberculated rhizoids anchor the thallus to the substratum; sporophyte differentiated into foot, seta and capsule; capsule wall is composed of single layer of cells.

c. Jungermanniales: Thallus may be simple or foliose and differentiated into axis and leaves; neck of archegonium consists of five vertical rows of cells; antheridiophore is long enough; capsule wall is composed of many layers of cells.

All the three orders have 9 families and 8500 species.

13.2.2 ANTHOCEROPSIDA: Plants are dorsiventrally flattened and thalloid and attached to the substratum by unicellular smooth walled rhizoid. Thallus is homogenous internally, each cell of the thallus provided with a chloroplast, a nucleus and a pyrenoid. Sex organs are embedded in gametophytic tissue. Archegonia develop form superficial cells while antheridia from hypodermal cells of dorsal side of thallus. Sporophyte is differentiated into foot and capsule only. Capsule wall is 4-6 layers thick and have stomata. Basal portion of capsule is meristemetic. This class comprises of one order, **Anthocerotales**

13.2.3 BRYOPSIDA: Plants have well differentiated plant body, consisting of axis, leaves and multicellular rhizoid. The leaves are arranged in 3-8 rows on the axis and each leaf has a midrib. Sex organs develop on the apical portion of axis. Sporophyte is divided into foot, seta and capsule. The wall of the capsule consists of several layers of chlorophyllous cells and contains stomata. This class has three orders.

a. Sphagnobryales: The plant body consists of one cell thick protonema, which develops into a single gametophore. Gametophore has leaves without midrib; antheridia develop on lateral braches while the archegonia are terminal; sprorophyte is projecting out.

b. Funariales: Plant body has broad rosette leaves; capsule is wide and without a beak-like structure; sporophyte has peristome teeth arranged in two rows, the outer one exostome and inner one endostome.

c. **Polytrichales:** The leaves are narrow; capsule usually erect; calyptra has hairs; peristome leaves arranged in a single row

All the three orders have 28 families and 660 genera and 14500 species.

13.3 Thallus structure

a. External Morphology: There are two morphologically and cytologically different generations; gametophyte and sporophyte are met in all bryophytic lineages. Gametophyte forms dominant phase of life cycle, which is green, autotrophic, well developed and forms vegetative structure. Cytologically it is haploid. The sporophyte is diploid, physically attached to the gametophyte and nourishes from it (Fig. 13.1).

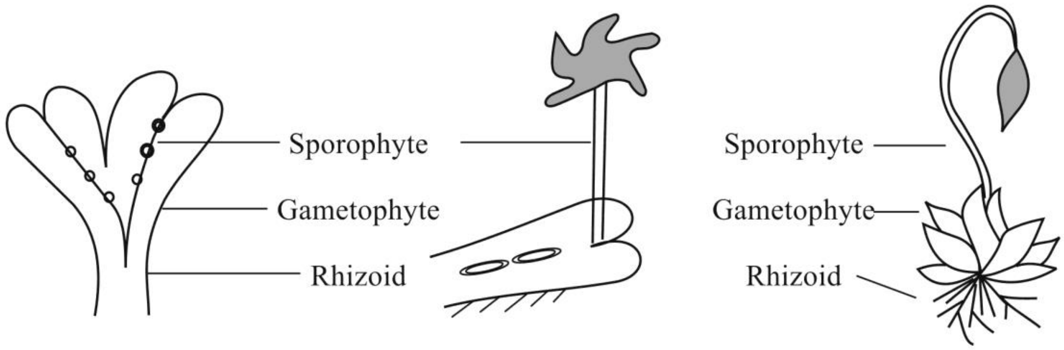

Fig. 13.1. Thalli met in bryophytes

The plant body of primitive thalloid forms like *Riccia* and *Marchantia* are found attached to the substratum by unicellular unbranched rhizoids but in higher forms as in mosses, the rhizoids are multicellular and branched.

b. Anatomy: Internally the plant body consists of simple parenchymatous cells, xylum and phloem and lignified cells are completely absent. The parenchymatous cells may be differentiated into several types e.g. chlorphyllous cells storage cells and rhizoid, where they perform various functions. A vertical section shows that thallus has two main regions, the apper assimilatory region and the lower storage region. The assimilatory region has a large number of air space, surrounded by septa. The pore in the upper epidermis which may almost of 15-40 cells, arranged in a ring. The pores at middle are narrow at both the ends. From the base of air chamber arise several filaments, which are photosynthetic in nature and contain chloroplasts (Fig. 13.2).

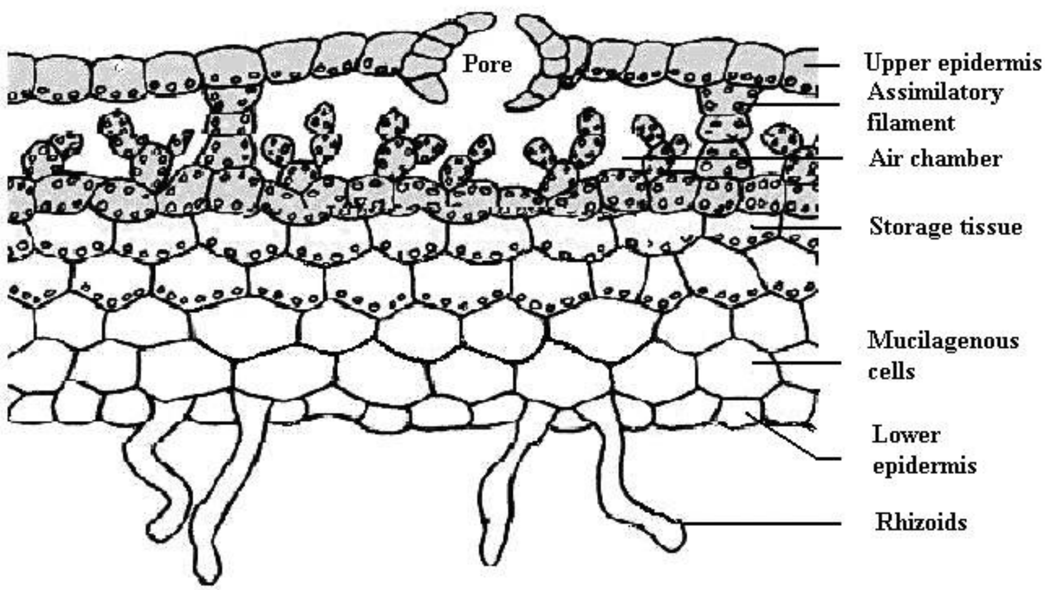

Fig. 13.2. Generalized anatomy of typical thallus of bryophytes

Below the assimilatory region there is a well developed and much differentiated storage region. It consists of compactly arranged cells interspersed with few mucilage cells. The lower most layer of storage region makes up the lower epidermis of which many cells get elongated to form simple or tubereculate rhizoids and few rows of scales which look as beaded structure.

13.4 Habitats, distribution and ecological factors

These plants are mainly confined to moist and shady habitat for growth and reproduction, only some forms like *Riccia*, *Ricciocarpos* etc, are aquatic. Some of the mosses including *Polytrichum* can withstand dry land conditions. Some other forms like *Buxbaumia, Cryptothallus* etc. can grow on rocks without water for several months by holding substantial amounts of water in dead cells of the leaves (e.g. *Sphagnum*). So the habitat is quite diverse, but mostly species are amphibious in nature. Although much less significant, bryophytes dominate particular habitats and *Sphagnum* itself is said to occupy 1% of the earth's surface (half the area of the USA).

The distribution of bryophytes is determined by factors such as availability of sufficient moisture, suitable substrata and favorable environment. Air and soil pollution have been taken as other devastating factors affecting their growth. Many bryophytes have become extinct in the urban areas and polluted environment has been identified as a major driving force behind it. Transplantation experiments have shown that bryophytes die within a short period of time when grown in polluted environment. Gaseous pollutants such as sulfur dioxide, hydrogen fluoride and ozone have been identified as the major ones affecting their growth.

13.5 Reproduction

13.5.1 Vegetative reproduction: This type of reproduction is of common occurrence, and takes place by means of structures such as tubers and gammae etc.

a. Formation of gammae: They are formed in the epidermis. During their development, one of the epidermal cells acts as gammae initial and protrudes out into the papillate outgrowth. It divides by two transverse divisions to form a basal cell or stalk cell and primary body cell called gammae proper. The stalk cell does not divide further, while the body cell undergoes a series of transverse divisions to a form 4-5 celled filament. The filament undergoes further transverse and vertical divisions to form a one cell thick discoid body. The gammae ultimately becomes an oval disc-like structure, the body of which marks the growing region. Majority of the cells contain chloroplasts. Few cells on both the surface are filled with dense protoplast called rhizoidal cells. Some cells contain oil bodies and are called oil cells (Fig. 13.3).

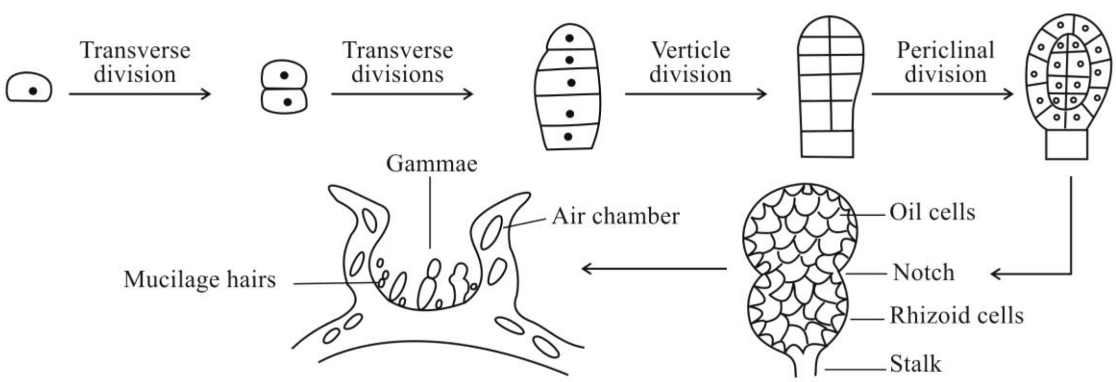

Fig. 13.3. Formation of gammae as a means of asexual reproduction

Gammae disperse with the absorption of water by the mucilage, which swells and exert a pressure upward that causes gammae cups to break their walls. The gammae are dispersed on the suitable substratum under favorable conditions and begin to germinate. The rhizoidal cells anchor in the soil, which carry out absorption work. Each apical cell in the notch becomes active and forms independent thallus.

b. Tubers: The formation of a variety of tubers is of wide occurrence in *Riccia* species, where they may be hair-like structures near the apex of rhizoids. In other species e.g. *Dicranella varia*, they are narrow, few-celled and comma shaped. They store food material and remain alive while rest of thallus has dried away.

13.5.2 Sexual reproduction: It is of advanced oogamous type male gametes are called anthrozoids and biflagellate, small in size and are produced in antheridia, while female gametes, the eggs, are large in size, non-motile and produced in archegonia. Fertilization takes place in water. An antherozoids or spermatozoids swim to the neck of arhcegonium and passes through the canal formed in it goes into the base where it fuses with egg and forms zygote. The zygote undergoes repeated divisions immediately after fusion and an embryo is formed. Embryo is not liberated but is retained in the archegonium where it develops into a sporophyte. Sporophyte is normally comprised of foot, seta and capsule; the capsule attaches to gametophyte by foot, where as seta bears it.

a. Development of antheridium: It takes place on the male gametophytic thallus and involves the following steps (Fig. 13.4):

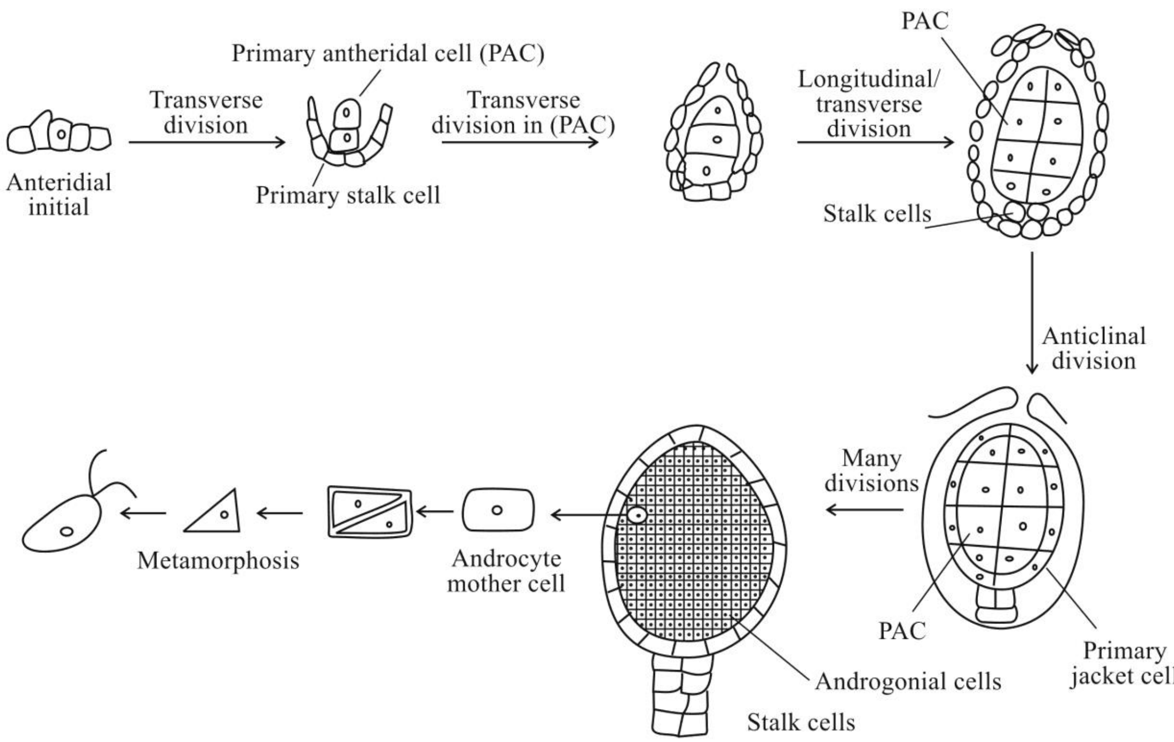

Fig. 13.4. Stages in the development of antheridium

- ***i.*** During the development of antheridium, the superficial cell near the growing apex of a lobe becomes conical and functions as antheridial initial
- ***ii.*** The antheridial initial divides and forms upper primary antheridial cell (PAC) and a lower primary stalk cell
- ***iii.*** The primary antheridial cell divides and forms two upper PACs
- ***iv.*** The PACs divides by transverse and longitudinal divisions to distinguish into PACs of lower cell form cell filament and stalk cell
- ***v.*** The PACs divide by anticlinal divisions to cut off primary jacket cells on the outside and primary androgonial cells on the inside
- ***vi.*** This structure grows by further divisions to form one cells thick jacket of cells and archegonial cells inside
- ***vii.*** The androgonial cells finally give rise to androcyte mother cell

viii. A diagonal wall is laid down in each androcyte mother cell so as to produce two triangular androcytes, or spermatias which metamorphose to form antherozoids or spermatozoids

ix. Each antherozoid is a small, coiled or rod-shaped uninucleate and biflagellaed structure.

b. **Dehicence of antheridium:** Water on the upper surface of the antheridial disc disintegrates the wall of the antheridium and reptures it. The mass of androcytes emerges out containing antherozoid, which are set free in water.

c. **Development of archegonium:** The archegonium is born on archigoniophore, which is similar to the antheridial branch with regard to origin and structure of the stalk. It also originates from the lobes of thallus. The disc of the archegonium is multilobed. Until the fertilization is complete, the neck of the first formed archegonim diverts upwards. At this stage, the stalk is very short and the disc appears sub-sessile (Fig. 13.5).

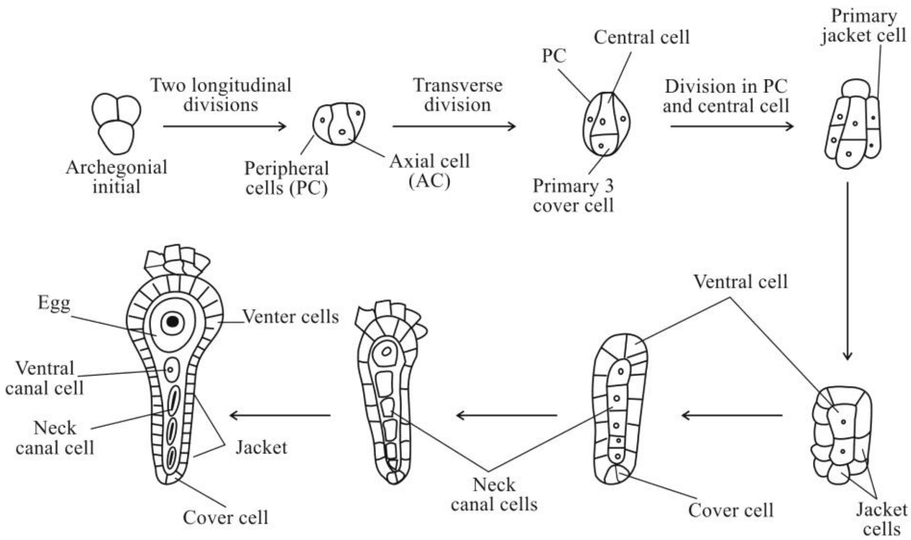

Fig. 13.5. Stages in the development of archegonium

i. During the development of archegonium, a superficial cell near the apex of lobe becomes conspicuous by its conical shape, dense cytoplasm and prominent nucleus. It is called archegonial initial. It divides longitudinally to form two peripheral cells and one axial cell.

ii. Axial cell undergoes a transverse division and forms an upper central cell or primary archegonial cell and a lower cell or primary cover cell.

iii. The central cell undergoes anticlinal division to form primary jacket cell or jacket initials.

iv. The central cell, primary cover cell and jacket cells undergo a number of transverse, longitudinal and anticlinal divisions to form a filament comprising of venter and neck of archegonium. At the neck of archegonium there is a cover cell, which gives rise to neck canal cell. The jacket cells enclose the venter and neck canal cell.

v. The neck canal cell by two successive transverse divisions forms four neck canal cells, while the venter cell enlarge in size. The two distinct cover cells lie at the neck of archegonia. The ventral cell divides into a ventral canal cell and an egg cell.

vi. The development of archegonum completes with the formation of a basal egg cell, a venter canal cell, neck canal cells and two cover cells at the apex.

c. **Fertilization:** Water in close vicinity of male and female thalli is needed for fertilization. When the atmosphere is moistened either with rain or dew, anthrozoids reach the archegonia. Of a number of anthrozoids reaching the archegoniophore, finally one antherozoid attached the neck of the archegonium. This attachement is governed by some sort of chemical.

d. **Post-fertilization changes-the development of sporophyte:** After fertilization, the zygote is formed which gives rise to embryo immediately after division. The embryo remains in the archegonium, where it differentiates into an elaborated structure called sporophyte.

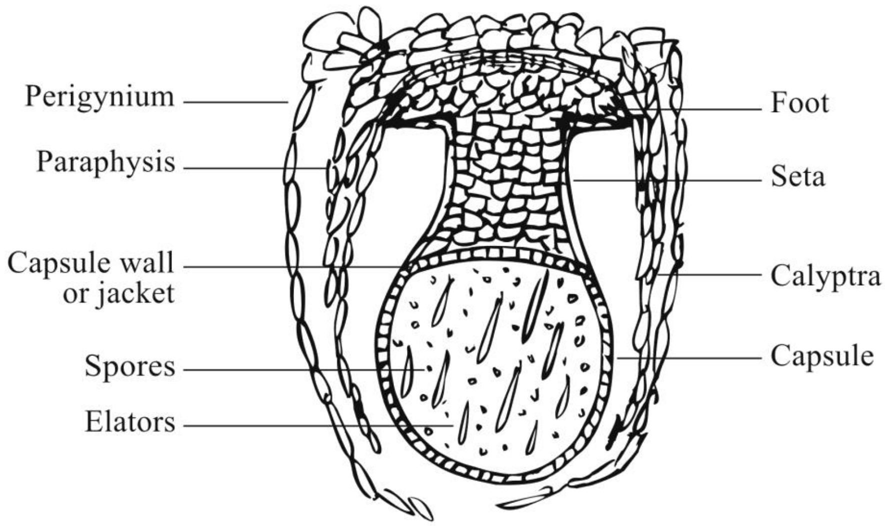

Fig. 13.6. A mature sporophyte showing foot, seta and capsule

- ***i.*** **Parts of capsule:** Mature capsule has three parts; **foot** is a basal broad and bulbous structure made up of paranchymatous cells. It absorbs the nutrients and water and anchors the developing sporophyte to the disc of archegonium. **Seta** is short and constricted structure, before the spores are formed. As the spores mature, it elongates, pushes the mature capsule and ruptures the calyptra and the covering sheath, the perigynium. **Capsule** is yellowish spherical structure. It forms the distal part of sporophyte and consists of a single layer of thick wall called jacket. It encloses spores and elators in it.
- ***ii.*** **Dehiscence of capsule:** It is accompanied with the elongation of seta and rupture of calaptra and perigynium. In capsule the spore are formed after meiosis, which are of one kind and are non-motile. They are spherical and ranging from 13-20 µm in diameter. Spores are comprised of three walls; the outer exine, middle intine and the inner one is perisporium. Each spore is provided with a small amount of granular substance and a distinct nucleus. They are formed as a tetrad after meiotic division. Elators are narrow, long spindle-shaped cells and are tapering at their inner walls. They are hygroscopic, and as a result of their coiling and uncoiling under moist conditions the spores are dispersed. They are liberated from the capsule by wind, fall on a substratum and germinate into a new gametophytic plant in case of *Riccia* and *Marchantia*. However, in mosses, the spores germinate into filamentous protonema, which provide bed that give rise to new plant.

e. **Germination of spores-the development of gametophyte:** Upon dispersal, the spores remain viable for about one year. Out of four spores produced in a tetrad, usually two develop into male and two into female thalli. The spores absorb moisture, enlarge considerably in size and divide repeatedly in transverse, longitudinal and anticlinal fashion to give rise to a mass of cells. Further differentiation takes place by more divisions in different plans to form above ground structures and rhizoids.

13.5 Life cycle

Two generations i.e. Sporophyte with gametophyte alternate with each other. Sex organs antheridia and archegonia develop on gametophyte (Fig. 13.7).

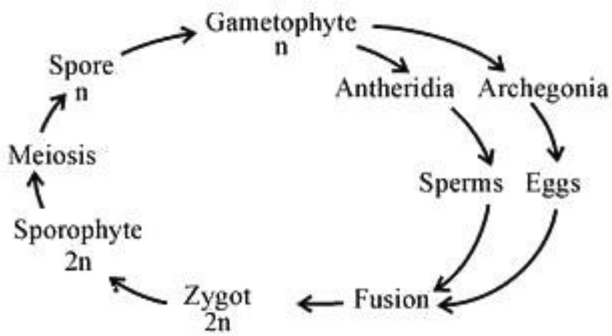

Fig. 13.7: Life cycle of typical bryophyte

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1. Smith, A.J.E. 1982. Bryophyte Ecology. Chapman and Hall, London
2. Margulis, L. and Schwartz, K.V. 1988. Five Kingdoms. Second edition. W.H. Freeman & Co., New York
3. Pandey, S.N., Misra, S.P. and Trivedi, P.S. 1974. A Textbook of Botany. Vikas Publishing House, New Delhi
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Chapter 14
Homologies and Evolutionary Tendencies

The fossil records of bryophytes are scarce. Available palynological evidence indicates that bryophytes may have been some of the earliest plants to colonize the land. Nevertheless, to trace their origin the comparisons of the living forms is based on their morphology, anatomy and ontogenetic changes that take place during their development.

14.1 Homology of sex organs

The gametophyte in bryophytes shows the appearance of sex organs. In bryophytes, the male and female gametophytes are antheridia and archegonia which show uniformity in basic structure. In higher forms they are ordinarily protected by sterile layer of cells.

14.1.1 Antheridium: The antheridium, borne on antheridiophore, is a saclike structure, which encloses the antherozoids and ultimately produces the male gametes. The antheridium normally develops from a single superficial cell in most forms, but in Anthocerose it originates from a hypodermal cell. Initially a primary stalk cell is cut off and later by periclinal divisions; a wall is separated from the interior mass of antherozoid mother cells. In the meanwhile, the antheridiophore elongates. Antheredia show a variety of structures, depending upon their location within the thallus. In Marchantiales, which show the sunken sex organs in a chamber, the antheridium is oval shaped with a short stalk. In Jungermanniales, it is borne in the axils of concave leaves and the stalk is quite lengthy. In higher forms, the antheridia show much variation in size. For instance in *Funaria hygrometrica*, it attains a length of 0.25 mm while in *Polytrichum commune* it is 1.5 mm long. However, the basic ontogenetic events are much alike in various forms.

14.1.2 Archegonium: Archegonium, borne on archegoniophore, is quite often flask shaped and composed of two parts. The basal portion is a wide rounded venter, which contains the non-motile egg (famel gamete), venter canal cell and a long narrow neck. Neck is a tube and is composed of highly protoplasmic neck canal cells. These structures dislodge when the fertilization takes place. Like the antheridium, the archgonium also develops from single superficial cell, with the exception of *Anthocerose*, which show sub-apical development and is quite small in structure. The neck canal also varies in number and form. In *Riccia* they are four in number and in Anthocerose are four to six. Ten or more neck canal cells may be found in typical moss archegonia, while there may be exceptionally up to 40 cells in some liverworts. As seen in antheridium, separation of wall from central part of archegonium is a feature in early development. The venter shows quite enlargement in size to accommodate the big egg cell and at the same time the neck lengthens sharply. Furthermore, the densely protoplasmic canal cells are quite less in number than the antherozoid cells.

14.2 Origin and evolutionary tendencies

As the fossil record of bryophytes is much scarce as compared to other plants, it is difficult to precisely find the course of evolution. However, based on the available information regarding the morphological details of living forms and their similarities with algae and pteridophytes, two theories have been put forward regarding the evolution of bryophytes:

a. Progressive evolution: This hypothesis takes support from the following similarities of bryophytes with green algae including Chlorophyta and Charophyta.

- ***i.*** Presence of flagellated spermatozoids and necessity of water for fertilization.
- ***ii.*** Amphibious nature of living bryophytic forms.
- ***iii.*** Presence of chloroplast containing chlorophyll a, b; α, β carotene, lutein, violaxanthin and zeaxanthin. Reserve material as starch.
- ***iv.*** Presence of pyrenoids in lower bryophytes e.g. in order Anthocerotales.
- ***v.*** Cell wall composed of cellulose and pectic substances.
- ***vi.*** Presence of protonema at juvenile stage of development. It is believed that juvenile stage of an organism shows similarities with its ancestral forms

Fritsch (1945) accepted that probable origin of bryophytes is from heterotrichous Chaetophorales and more elaborated parenchymatous phaeophytes. Based on these affinities it is presumed that their course of evolution is through green and brown algae. There are certain reasons to establish the validity of this hypothesis:

- Heterotrichous habit is the beginning point, which is due to the presence of both prostrate and erect branching systems in Chaetophorales.
- Establishment of parenchymatous thallus, dichotomous branching and apical growth.
- Development of tissue differentiation and formation of sex organs in a close cavity, as in some members of Phaeophyta.

b. **Retrogressive evolution:** This is the second school of thought, which states that the bryophytes have evolved as a result of degenerate evolutionary trend or decedents of pteridophytes. This hypothesis takes support from the following affinities of bryophytes with the pteridophytes: The proponents of this hypothesis take support from the absence of assimilatory filaments in the air-chambers of the thallus and the structure of pore in the upper epidermis of the thallus.

i. Similarities between capsules of Anthocerotales with the sporangia of Psilotales.
ii. Psilotales have leafless, colorless and dichotomously branched sporophyte, as seen in Anthocerotales.

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1. Mauseth, J.D. 1998. Botany-An introduction to Plant Biology. James and Bartlett Publishers, Massachusetts
2. Pandey, S.N., Misra, S.P. and Trivedi, P.S. 1974. A Textbook of Botany. Vikas Publishing House, New Delhi
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SECTION VIII
ECONOMIC IMPORTANCE OF VIRUSES, BACTERIA AND THALLOID ORGANISMS

Chapter 15
Importance to Agriculture and Industry

15.1 Economically important species

Plants are the primary producers in the food chain due to photosynthesis they perform by harnessing sunlight. The seaweeds are an exclusive source of photosynthesis, as they account for greater than 90% of the photosynthesis. Other organisms, including various non-photosynthetic bacteria and fungi are largely heterotrophic to saprobes and parasites in their mode of nutrition and some of them act as pathogens. They have been successfully employed for the beneficial purposes in genetic engineering, biotechnology, agriculture, industry, medicine etc. An account of beneficial aspects of viruses, bacteria and thalloid organisms is given below:

15.2 Economic importance of viruses

Although the viruses have harmful effects on plants in general, they have also been utilized for some beneficial purposes mainly in genetic studies, as indicated below:

a. Cauliflower mosaic virus (CaMV) is the plant virus with double stranded DNA genome. As it has a DNA genome, it is used as a possible vector in introducing foreign genes into plant. It is possible to insert a non-viral gene into CaMV genome and obtain expression of the gene in the infected plant. The viral promotor region from CaMV is effective for obtaining expression of other genes in plant cells. The genes to be expressed are now fused to a promoter element from CaMV and a gene of *Agrobacterium tumefaciens*. They are then introduced into the plants using *A. tumefaciens* Ti-DNA transformations.

b. Messenger RNA is extracted and exposed to an enzyme reverse transcriptase which synthesizes a complementary single stranded DNA (cDNA). The complimentary DNA is exposed to another enzyme, DNA polymerase, which produces the double stranded cDNA. The cDNAs are inserted into the plasmids of *A. tumefaciens.*

c. A chimeric gene containing a cloned cDNA of the coat protein gene of tobacco mosaic virus (TMV) was constructed. This chimeric gene was introduced into tobacco cells on a Ti plasmid of *A. tumefaciens*. Then the cells were grown on nutrient media and the tobacco plants were regenerated from the transformed cells (tissue culture). The plants synthesized through genetic engineering expressed TMV mRNA and coat protein as a nuclear trait. The transgenic plants did not develop mosaic symptoms when inoculated with virulent strains of TMV. By this method transgenic tobacco plants showing resistance to alfalfa mosaic virus and tobacco rattle virus have also been developed.

d. Satellite RNAs are associated with several viruses. They are packaged into virus particles along with the genomic RNAs of the helper virus. They are not part of the viral genome and have no obvious sequence relationships with the helper virus. The presence of the satellite RNA suppresses the disease severity in many hosts. Hence transgenic plants which express satellite RNA have been produced to manage virus diseases. Examples are transgenic plants against tobacco ring spot virus, cucumber mosaic virus and tomato aspermy virus.

e. A DNA copy is made of one or more sections of the viral genome that include the initiation codon for the proteins vital to virus replication. The DNA copy is inserted into the host cell genome. Cells then produce an 'antisera RNA' called mic RNA (mRNA interfering complementary to 5' end of the gene). The mic RNA hybridizes in vivo with the viral mRNA blocking translation. The mic RNA is inserted into the plants using the Ti plasmid of *A. tumefaciens*. Plants regenerated from the transformed cells will be resistant to the particular virus. This possibility is being exploited for the control of some virus diseases.

f. The single-stranded DNA geminiviruses, the single stranded RNA tobacco mosaic virus some other virus systems are being developed as plant gene vectors.

g. When a virus mild strain (or avirulent strain) of an aggressive pathogenic strain (virulent) is introduced into the disease affected plant, the activity of aggressive strain is suppressed and the disease is controlled. This phenomenon is called cross-protection.

h. The contagious hypovirulence is caused by double stranded RNA being transmitted by virus infection to virulent strains. Chestnut canker caused by *Endothia parasitica* is controlled by hypovirulent strains of the pathogen.

i. When bacteriophages are sprayed marked protection against various bacterial diseases has been reported. However, application of phage simultaneously with the pathogen or after inoculation of the plant with the pathogen is ineffective.

15.3 Importance of bacteria

15.3.1 Vectors for genetic transformations:

a. Plasmids of *Agrobacterium tumefaciens* are used as vectors of genetic material into plants.

b. Bacteriocins are non-replicating bactericidal protein-containing substances which are produced by certain strains of bacteria and are active against some other strains of the same or closely related species. *A. tumefaciens* causes crown gall in many crops. *A. radiobactor* is a non-pathogenic bacterium and it produces bacteriocin. Bacteriocins produced by *Agrobacterium* spp. are called agrocins. When seeds or roots of peaches were inoculated with *A. radiobactor*, crown gall of peaches was effectively controlled. Similarly when non-pathogenic *A. tumefaciens* strain 84 was inoculated to tomato the crown gall disease caused by virulent strain of *A. tumefaciens* was controlled.

15.3.2 Antibiotics production: Many soil-borne microorganisms produce antibiotics in culture. But in soil antibiotic production is negligible. Large addition of organic matter may be needed to induce antibiotic production in soil. The antibiotic, pyrrolnitrin produced by *Pseudomonas fluorescens* obtained from the rhizosphere of cotton plants, reduces cotton root rot caused by *Rhizoctonia solani* when used as seed treatment.

15.3.3 Predation: Predatory bacteria such as *Bdellovibrio bacteriovorus* found on phylloplane parasitize other bacteria. It controls *Pseudomonas syringae* pv. *glycinea* infection on soybean leaves.

15.3.4 Disease control: Many bacteria produce sidrophores. The siderophores are low molecular weight substances that form complex with iron due to high affinity and thus supply iron to bacterial cell. In fact with the help of siderophore iron is sequestered from the soil and made unavailable to other microorganisms including pathogenic fungi such as *Fusarium* sp. and *Gaeumannomyces* sp. *Pseudomonas fluorescens* and *P. putida* produce siderophores called pseudobactin, which can control all disease of wheat and barley caused by *Gaeumannomyces tritici* and flax wilt disease caused by *Fusarium oxysporum*.

15.4 Economic importance of fungi

Although the fungi are primarily known for pathogenic action, they have been exploited for some beneficial purposes, as given below:

15.4.1 Biological fermenters: The yeasts i.e., *Saccharomyces cerevisiae* used in brewing and baking industry, for conversion of glucose to ethyl alcohol and CO_2. Different organic acids, such as lactic acid, succinic acid, fumaric acid etc. are obtained from different fungi. The citric acid and gluconic acid are obtained from *Aspergillus ni*ger, *Rhizopus stolonifer* is a source of fumaric acid and lactic acid while oxalic acid, succinic acid and gallic acid are obtained from *Rhizopus* and *Mucor*.

15.4.2 Decomposers of organic matter: Fungi decompose dead organic matter. *Serpula lacrimans* causing dry rot of wood is an important decomposer. Cellulose decomposing fungi are called cellulolytic, while lignin decomposing fungi are called lignolytic.

15.4.3 Antibiotics and growth substances: Fungi are an important source of antibiotics. Examples are penicillin from *Penicillium chrysogenum* and *P. notatum* and gibberellins from *Gibberella fujikuroi*. Digestin and polyzime from *Aspergillus flavus*, B-complex, riboflavin from *Sacchromyces cerevisiae*

15.4.4 Food stuff: Fungi are consumed as food. *Agaricus brunnescens* meadow mushroom, *Lentinus edodes*, Shiitake mushroom, *Volvariella volvacea* Chinese mushroom, morels and truffles have antitumor to hypocholesterolemic effects. These are aphrodisiacs and fend off old age. Fungi are also used as mycoprotein. These include galls on an ear of corn infected by *Ustilago maydis*, mushroom in Mexico *Rhizopus, Mucor, Actinomucor* from rice in Japan, "Temph" and "Sufu" from soybean in Indonesia and China.

15.4.5 Biological reaserch models: Examples are *Neurospora tetrasperma, N. crassa* have been extensively used in genetic modeling studies

15.4.6 Biocontrol agents: Fungi used as mycoherbicides and for biocontrol of plant pathogens and insects. *Colletotrichum gloeosporioides* is available with trade name "Collego" used to control joint vetch. *Trichoderma harzianum* and *Arachniotus* spp. control *Rhizoctonia solani* causing root rot of cotton. *Rhizoctonia lecani, Beauvera bassiana* and *Metarrhizium anisopliae* can control *Bemisia tabaci* vector of cotton leaf curl virus. *Darluca filum* can parasitize *Puccinia graminis tritici.*

15.5 Economic importance of algae:

In addition of their role as primary producers in aquatic communities, the algae have a variety of economic benefits to the mankind:

15.5.1 Symbiosis: A fairly large number of algae live in association with other organisms for mutual benefits. Common examples are the presence of *Nostoc* in *Anthoceros* thallus, *Anaabaena cycadae* with the roots of *Cycus, Anabaena azollae* in *Azolla* leaves etc. Lichens are the best examples of symbiosis where the association lies in between algae and fungi. Some 30 genera are known to behave as phycobionts (algal components of lichens) e.g. *Trebauxia*, *Calolthrix*, *Chlorella*, *Gleocapsa*, *Nostoc* etc. There are instances of symbiosis between algae and animals e.g. the occurrence of *Cladophora* on snails. The symbiotism has advantages like protection, facilitated nutrition, increased gas supply etc.

15.5.2 Extracellular products: The production of a great variety of extracelllular substances by algae is well established. These are the substances which after synthesis are released to the medium. They play a role in algal growth, physiology and ecosystem. Widely occurring extracellular substances include carbohydrates, nitrogenous substances, organic acids, vitamins, phenolics volatiles etc. They have the following ecological implications:

a. They are directly used by bacteria and some animals as carbon source.

b. Some of them have the property of forming complexes with other ions or chelating inorganic ions. This is important in two ways: Firstly, the ions and other trace elements can be maintained in a state available and algae and secondly the level of toxic elements e.g. copper can be reduced in the medium. Otherwise, the presence of which in free state may put disastrous effect on the growth of plants and animals.

15.5.3 Use as fodder: Seaweeds especially the brown algae are used as fodder in many countries, where factories have been set up for the production of feed for cattle, poultry and piggery. This is due to the reason that certain known algae and kelps are rich in vitamins and they therefore enhance the production of meat and milk.

15.5.4 Use as human food: Both marine and freshwater algae are used as human food. In Japan and Korea, red algae among marine and green algae among many freshwater ones are commonly used as special dish, side dish, salad or to garnish the dishes. This is due to the reason that algae yield handsome amount of proteins, carbohydrates, oils, minerals and many types of vitamins.

15.5.5 Industrial uses: A number of commercial and industrial uses are:

a. **Alginic acid and derivatives:** It is extracted form the members of Phaeophyta. It is similar to cellulose and pectins in composition. Alginates are used as thickness in food industries for filling creams, in cosmetics as hand creams, in textile industries for printing paste, in rubber industry for latex production, as emulsifiers in ice creams, synthetic creams, pharmaceutical and emulsions paints. Important alginate yielding algae are *Dictyota*, *Laminaria*, *Ascophyllum*, *Turbinaria* etc.

b. **Carragenan:** It is most famous carbohydrate mucilage. Such carbohydrates are variously used with puddings, eaten with milk or mixed with fruit and even in ice cream. They are also used in a number of other industries including food, textile, pharmaceutical, leather and brewing industry.

c. **Agar:** It is dried gel like non-nitrogenous extract from red algae. Agar is used as a medium in the cultures of bacteria, fungi and algae and also in numerous industrial processes. Dried agar is insoluble in cold water but soluble in hot water. In addition to this, agar has also been used in food, bakery, cosmetics, pharmaceutical, leather, textile industries, confectionary and dental impression etc.

d. **Iodine and other compounds:** Brown algae like *Laminaria* and red algae are largely known for the extraction of iodine (0.02%), while chlorophytes also show lower amount of this element (0.003%). In addition some other micronutrients useful for human consumption have also been noted in the algae. Some algae have vitamin C which is slightly higher than juice of lime fruit.

e. **Funori:** This is sizing agent and glue for textiles that was prepared by Japanese form *Gleopeltis*. The composition of Funori is similar to agar but misses in sulfate ester group.

f. **Diatomite:** Diatomaceous earth is quite useful in industries in infiltration processes, sugar refining and brewing industry. It is also used as filter in paint and plastic industry and to remove fungal mycelia in the preparation of antibiotics in pharmaceutical industry.

g. **Lens paper industry:** Japaness use *Spirogyra* in the manufacture of lens or tissue papers used for cleaning optical articles.

h. **Pharmaceutical industry:**

- ***i.*** **Medicine:** Because of high iodine content, the brown algae are used in various goiter medicine either mixed or directly as powder.
- ***ii.*** **Agar:** Agar is used in several kinds of pharmaceutical products such as pills and ointments and various laxatives.
- ***iii.*** **Fucoidin:** These are used as anticoagulants but carrageenan acts as blood coagulant.
- ***iv.*** **Laminarian stipes:** This is used as surgical tool in the opening of wound due to its property of gentle swelling exposed to moisture.
- ***v.*** **Mannitol:** This is a supplement for sugar requirements of diabetic patients without harmful affects.
- ***vi.*** **Antibiotics:** Chlorellin is extracted form *Chlorella*, which inhibits growth of certain bacteria. *Rhodomela larix* produces bromophenol, which has antibiotic activity against certain microorganisms. *Microcystis* is particularly known for its inhibitory action on the growth of *Staphycoccus* and *Closteridium*.

i. **Water Purification:** In water reservoirs luxurious growth of algae creates nuisance, but lesser growth of algae acts as biological filter by forming a microzone on the sand surface, which together with bacteria and fungi forms a mucilage layer. This microzone traps harmful bacteria and water also gets aerated.

j. **Sewage disposal:** The presence of algae such as *Chlorella*, *Chlamydomonas* etc. facilitates oxygenation of sewage to a large extent. They form a surface filter on the sewage disposal which supplies oxygen and utilize nutrients to breakdown sewage.

k. **Uptake of radioactive wastes:** Uptake of radioactive elements by certain algae is also known. For example *Porphyra* can take up ^{106}Rb, *Chlorella* ^{87}Cs, *Cladophora* ^{60}Co etc.

15.5.6 Improvement of soil properties: It is brought about in following ways using algae:

a. Algae reduce the pH of alkaline soil from 9 to 7 and increase the WHC by 40%.

b. Sometimes acting as binding agent, algae reduces the danger of erosion of disturbed or burnt soil by rapid growth.

c. They add to the nitrogen and carbon status of soil.

15.5.7 Alage as growth stimulants: By virtue of the presence of growth promoting substances, the algae stimulate the growth of rice. Presowing seed treatment by Phormidium results in intensely green plants, profuse tillering, increased height and multiple rice yield.

15.6 Economic importance of mycorrhizae

Plants that are involved in ectomycorrhizae are always trees and are found only in a few families. They include the Betulaceae, Beeches and Alders, Casuarinaceae, Ironwood, Fagaceae Oaks, Myrtaceae Eucalyptus and Pinaceae Pines, Douglas Firs, Firs, etc. Most of these are utilized as a source of lumber, and in the case of the Pine family, millions of trees are used annually as Christmas trees. Planting these trees is a routine practice, in forestry, to inoculate the seedling with a mycorrhizal fungus. This group of mycorrhiza has also been tested as a means of resisting fungal root pathogens. It was reasoned that if the fungal sheath of the ectomycorrhizal fungus is covering the root tips, fungal root pathogens would be unable to gain entry into the root system of the host.

15.6.1 Availability of nutriets to plants: This is brought about by the following ways:

a. Mycorrhizae may be of particular value in the areas where our tap water is alkaline. Iron, one of the essential nutrients, reacts with certain organic components in the soil to form complex chemical structures. The roots can not absorb the iron from these structures when the conditions are alkaline. In essence, the iron is "locked up" within the chemical structure and is no longer available to the root. The mycorrhizae, however, seem to be able to absorb this "locked up" iron.

b. Mycorrhizae are a group of fungi which grow in association with plant roots in a symbiotic relationship. A large volume of the soil is penetrated by fine, highly branched fungal hyphae which are "extensions" of the tree's own root system. As the fungal hyphae are very absorptive, and more efficient than the plant's roots themselves, they take up mineral nutrients from the soil and then pass some of these minerals to the plant. In return, the fungi receive sugars and other nutrients from the plant's photosynthetic processes. Hence the symbiotic relationship.

c. Mycorrhizae also contain nitrogen fixing bacteria which fix atmospheric nitrogen. Nitrogen, in a usable form is one of the plant's most important requirements. However, plants are dependant upon the activity of soil microorganisms which incorporate nitrogen through this form of nitrogen fixation. After, nitrogen fixation has occurred usable nitrogen compounds, N02 and NH3 are available for both the micro-organism and the plants.

15.6.2 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. In addition, a mycorrhizal infection is beneficial to plant in situation where nutrients are deficient or the plant faces strong competition from other organisms. This results in an increased surface area available for mineral and water uptake.

15.7 Economic Importance of Lichens

Economically, lichens have little significance. Perhaps this is why there is so little interest in this group of organisms. However, some importance has been realized of this relatively less studied group of organisms:

15.7.1 **Industrial use:** Lichens have been utilized in the extraction of blue, red, brown or yellow dyes in the garment industry. Also, the indicator pigments used in litmus paper is also derived from lichens.

15.7.2 **Cosmetic industry:** They are the source of some pharmaceutical compounds. You can include some "folk" remedies in this category as well. They are also used in the cosmetic industry, in the making of perfumes and essential. Finally, some species have been used as food. One species, *Lecanora esculenta*, is a species that grows in the mountains near Israel and are typically blown free from their substrate. Desert tribes grind up the lichen, dry it and mix it with dry meal to form flour. It is postulated that this is the species lichen that is referred to as "Manna from Heaven" when Moses led the Hebrews across the desert during biblical time. One species, *Cladonia rangiferina* (reindeer moss), is fed upon by reindeers and cattle. This has led to the discovery that lichens readily absorb radioactive elements. After open-air, atomic testing, both Alaskan Eskimos and Scandinavian Laplanders were found to have high levels of radioactive contamination, which they had absorbed from eating reindeer, which in turn ate lichens.

15.7.3 **Other significant uses for lichens:** Lichens are conspicuously absent in and surrounding cities because many species are sensitive to pollution, especially to common pollutants like sulfur dioxide and flourine. For this reason, they have been commonly used as indicators of pollutants. In urban areas, where lichen surveys have been carried out, the absence of certain indicator species is used as early warnings of decrease in air quality. Lichens also play a very significant role in nature. They are the pioneers in rocky substrates, where there is no soil. Lichens break down the rocky substrate into soil and their decomposing thallus fertilize the newly produced soil, making it possible for the plant habitation.

15.8 Economic importance of Bryophytes

Although bryophytes form an important group in the lower plants, their ecomonic importance of has been meagerly studied. Nevertheless, the bryophytes have the follwing significant uses:

15.8.1 **Genetic studies:** Scientifically, bryophytes are the classic organisms for studying the relationships between chromosome complement (ploidy) and morphology, the effects of maternal environment on the phenotypic expression of genotype, and the nature of totipotency. Bryophytes, more than any other plants with the possible exception of fungi, are able to reproduce entire plants of complex morphology from single cells, not just in laboratory culture but in nature. They are therefore of great significance in the study of regeneration and wound repair. Moreover, bryophytes are a source of drought-resistant genes, as certain species are resurrection plants

15.8.2 **Medical use:** The genus *Sphagnum* is of some economic importance both as an antiseptic absorbent-much used until about 1950 and recently re-introduced commercially-and as a horticultural medium. Both uses depend on the unique anatomical structure, which has a very high water-holding capacity; as much as 20-25 times the dry weight. Because of its ability to soak up blood and its relative freedom from bacterial contamination *Sphagnum* was used in dressings.

15.8.3 **Pollution indicator:** Although less sensitive to sulphur dioxide than lichens, bryophytes have been used as monitors of environmental pollutants, particularly the heavy metals

15.8.4 **Source of antibiotics:** Recent work has shown the existence of antibiotics in bryophytes although none has yet reached the stage of commercial production

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GLOSSARY

Accessory pigments: photosynthetic pigments that absorb light energy and transfer it to a reaction center of chlorophyll a.
Acervulus: a saucer shaped asexual fruiting body in Deuteromycetes producing conidia on conidiophores.
Achlorophyllous: without chlorophyll.
Acquired resistance: non-inherited or adapted resistance.
Acropetal arrangement: development of spores from the base upward, with the youngest at the apex.
Actinomycetes: group of bacteria forming branched filaments mostly Gram positive and anaerobic.
Aeciospores: dikaryotic rust spores produced in an aecium.
Aecium: a cup shaped fruiting body of the rust fungi producing aeciospores.
Agar: a polysaccharide in the walls of some red algae, polymer of galactose subunits.
Air-borne: organisms transported from place to place through air.
Akinite: thich walled resting spore.
Algae: protoctists comprising several groups that are simple in form, producing energy through photosynthesis and lack true tissue differentiation of the body.
Alternate host: host other than parent host to complete life cycle of the parasite.
Alternation of generation: occurrence of two or more distinct forms or generations in the life cycle of an organism.
Ameboid: having a cell form with ever-changing cytoplasmic protrusions.
Amylose: starch of green algae and higher plants.
Anisogametes: motile gametes similar in structure or morphology but differing in size.
Anisogamy: sexual fusion between flagellated gametes of different sizes.
Antagonism: interference or inhibition of growth of one organism in the presence of another.
Anterior: towards the front or head end of cell of an organism.
Antheridium: male sexual structure in algae, fungi and bryophytes.
Antheriodiophore: stalk bearing the antheridia.
Antherozoid: male gamete in Charophyta.
Anthracnose: a blotched appearance on the upper portion of fruit; irregular withering of leaves.
Antibiotic: a substance produced by one microorganism that has inhibitory or killing effect on the other.
Antibody: a protein produced by certain white blood cells (lymphocytes) in response to a foreign body (antigen).
Anticlinal division: division of cells perpendicular to the circumference of surface.
Antiserum: the serum containing monoclonal or polyclonal antibodies.
Antisporulant: a substance inhibiting spore germination without affecting the vegetative growth.
Aplanetic: non-motile.
Aplanospore: a non-motile spore.
Apoplast: the cell wall and intercellular spaces of an organism through which solutes can be transported.
Apoplastic movement: movement of material in the apoplast.
Apothecium: an open saucer shaped ascocarp in Discomycetes, bearing asci and ascospores.
Appresorium: the swollen flattened tip of hypha that helps in the attachment to host surface and later penetration by the fungus.
Archegoniophore: stalk bearing the archegonia.
Archegonium: female sexual structure in algae and bryophytes.
Arthrospore: a spore resulting from the fragmentation of a hypha at the septum.
Ascigerous: the ascal stage of Ascomycetes.
Ascocarp: fruiting body in Ascomycetes containing or bearing asci.
Ascogenous hypha: a specialized hypha which gives rise to asci.
Ascogonium: the female gametangium or sexual organ in Ascomycetes.
Ascoma: the ascus containing structure.
Ascomycetes: fungi producing sexual spores (ascospores) within asci.
Ascostroma: a stromatic ascocarp bearing asci strictly in locules within stroma.
Ascus mother cell: a binucleate crook cell in the Ascomycetes in which karyogamy occurs and develops into an ascus.
Ascus: an elongated sac-like structure usually containing eight ascospores produced by free cell formation.
Asexual reproduction: a type of reproduction not involving union of gametes or meiosis.
Atrophy: degeneration or under development of a plant part or an organ (reduction in size).

Autoecious: an organism completing its entire cycle on the same host.
Autogamy: union of two nuclei both derived from a single parent.
Autolysis: deterioration and spoilage by enzymatic activity arising from chemical and biochemical reactions from within the system.
Autotroph: an organism that does not require organic compounds from an external source but can synthesize them from light or inorganic chemical substances.
Auxospore: a diatomaceous spore that has been released from the rigid frustule, often the result of fertilization.
Avirulent: not able to cause disease.
Azygospore: a zygospore formed parthenogenetically without gametangial fusion.
Bacteria: unicellular prokaryotic organisms (with ribosomes and both DNA and RNA) usually lack chlorophyll and multiply by fission.
Bactericide: chemical that kills bacteria.
Bacteriocin: substance produced by certain bacteria and active against one or more strains of the same or closely related species.
Bacteriophage: a virus that is parasitic within bacterium.
Basal body: basal part of the flagellum where they are inserted.
Basidiocarp: the entire fructification of Basidiomycetes bearing basidia.
Basidiospore: a spore produced by meiosis in basidium.
Basidium: a structure bearing on its surface a definite number of basidiospores (typically four) those are usually formed following karyogamy and meiosis.
Benthos: organisms living on or attached to the bottom of aquatic habitat.
Bilateral symmetry: symmetrical about a line.
Binary fission: transverse splitting of a cell into two.
Binomial nomenclature: system of classification introduced by Linnaeous, composed of two names; the first as genus and second the species.
Bioassay: quantitative determination of the strength of a substance using an organism with that of a standard preparation.
Biochemical resistance: resistance against pathogenic attack based on substances produced in the host cells before or after infection.
Biocide: a chemical toxic to a living organism.
Biological control: management of plant diseases through bio-control agents.
Biological pesticide: a pesticide, the active ingredient of which consists of a living organism or from a living source.
Bioluminescence: production of light by living organisms.
Biotroph: an organism that can live and multiply only on another living organism.
Bleaching: destruction of all pigments.
Blight: general and rapid killing of leaves, flowers or stems.
Blister: a raised lesion on the leaf surface, which opens to expose spores.
Blotch: a disease characterized by large irregular spots on leaves, shoots or stems.
Bromoviruses: viruses having rounded particles.
Brown rot: when hemicellulose and celluloses in the wood are decomposed except lignin, giving brown colour.
Bryology: study of bryophytes.
Budding: a bubble-like structure protruding from the hypha and separated by constriction of wall from the parent hypha.
Bunt: a fungal disease resulting in dried shriveled grains.
Callus: mass of undifferentiated developing cells.
Canker: a necrotic often sunken lesion on any part of the plant arising from destruction of epidermal or cortical tissues.
Capsid: the protein coat covering nucleic acid in case of viruses.
Capsomer: the aggregated protein subunits in virus protein coat.
Capsule: external mucilage in algae; swollen spore containing part of sporophyte in bryophytes; a layer of polysaccharides around bacterial cell for protection from adverse environment.
Carotenoid: yellow, orange or red pigments soluble in organic solvents.
Carpogonia: female gametophyte in red algae.
Carpospore: diploid spore produced in carposporangium in red algae.
Carrageenan: polysaccharide produced by red algae, similar in structure to agar of brown algae.

Caulimovirus: virus containing circular double stranded DNA.
Cellulose: polysaccharide composed of β-1, 4 linked molecule forming the main skeletal framework of cell wall of majority of algal organisms.
Centrum: totality of structures within ascocarp.
Chemotherapeutant: fungicides those act on the pathogen by entering into plant system.
Chemotherapy: control of diseases with such chemicals that can translocate within the plant.
Chitin: a polymer in fungal wall composed in part of amino sugars.
Chlamydospore: thick walled fungus spores capable of surviving under adverse conditions.
Chlorophyll: green porphyrin ring type pigment soluble in organic solvents.
Chlorosis: yellowing of normally green tissues due to destruction of chlorophyll.
Clamp connection: outgrowth of hyphae those form bridges around septa, thus connecting two cells.
Cleistothecium: a completely closed ascocarp.
Clone: a group of genetically identical individuals produced asexually from one individual.
Coccoid: spherical.
Coenobium: colony of algal cells in a specific arrangement and number that does not increase once mature.
Coenocytic: multinucleate condition of the filament without cross walls.
Collar rot: rotting of stem or main axis at or about the level of soil.
Collateral host: host other than the parent.
Colony: a group of related individuals living together growing on a substrate.
Columella: a sterile structure, the extension of stalk within a sporangium.
Commensalism: a type of symbiosis in which two partners live in close association when one member benefits but with no harm to the partner.
Compost: substrate on which mushroom grows.
Concepticle: cavity in a thallus where the gametangia are produced.
Conidiophore: a specialized hypha bearing conidia.
Conidium: an exogenously formed asexual spore on conidiophore.
Conjugation: fusion of two non-flagellated gametes.
Connecting band: part of the girdle in the diatoms.
Consumer: in biological terms, an individual that lives upon the products of a producer.
Contaminant: growth of micro-organism not required during isolation of plant pathogens.
Cultural control: method of pest control by means of skillful combination of agronomic practices.
Culturing: artificial propagation of organisms on nutrient media or living plants or plant parts.
Cuticle: coating on the outside of a cell wall.
Cyst: cell with a thick or silicified wall and resistant to adverse conditions.
Damping off: sudden collapse, death and rotting of seedlings at soil level resulting from the attack of *Pythium* sp.
Deficiency disease: a disease caused by inadequate intake of any essential macro- or micronutrient.
Dehiscence: liberation of seed or spore.
Dendroid: a non-motile colony that produces mucilage usually forming a stalk.
Diatomaceous earth: a mineral consisting of the remains of the silicified frustules of the Bacillariophyta.
Dictyospore: a spore with both cross-wise and longitudinal septa.
Die back: death of shoots from, tip progressing backward towards the main stem.
Differential host: host that shows reactions which distinguish between race specific isolates of a pathogen.
Diffuse growth: type of growth where most of the cells are capable of division.
Dimorphic: an organism that grows and exists in two forms.
Dioecious: a condition where male and female gametes are borne on separate plants.
Diplanetic: refers to a species which produces two types of zoospores (planetic or flagellated condition) and in which two swarming periods occur.
Discomycetes: the apothecia producing fungi.
Disease cycle: the chain of events involved in disease development.
Disease escape: plants not affected by the pathogens due to certain environmental factors or other adjustments (cultural and human).
Disease incidence: number of plant unit infected expressed as percentage of diseased entities within a sampling unit.
Disease rating scale: numerical description of a disease based on disease incidence and damage.

Disease: a dynamic process (in time and space) due to continuous irritation by biotic/abiotic agents resulting in abnormal physiology and morphology and reducing the quantity or quality (or both) of the produce above economic threshold level.
Disinfectant: an agent (mostly a chemical) used to free plant tissues from infection.
Disinfestant: an agent used for eliminating or avoiding surface borne pathogens.
Disjunctor cell: cell or projection connecting spores in a chain.
Downy mildew: plant showing downy growth on the host surface, especially leaves.
Dry rot: a disease in which tissues don't become soft but become dried and wrinkled.
Durable resistance: resistance that remains effective for sufficiently long time (20 years).
Dwarfing: reduction in size, particularly the height.
Economic injury level: the lowest population density of a pest causing economic damage or loss.
Economic threshold level: the density of a pest at which control measure should be initiated to prevent increasing pest population.
Ectoderm: outer protoplasm next to the plasma membrane in Charophyta.
Ectoplasm: outer more or less rigid and granule free layer of cytoplasm.
Elator: hygroscopic cell or band usually attached to the spore e.g. in Bryophyta.
Elicitors: the molecules produced by host or a pathogen that induces response.
Enation: an out growth or tissue malformation on plant surface induced by viral infection.
Encystment: formation of a rigid wall around the naked protoplast of a cell.
Endemic disease: any disease regularly present in a mild or severe form.
Endobiotic: an organism which completes its entire life cycle inside its host.
Endoconidium: conidium formed within a hypha.
Endoderm: inner protoplasm next to the vacuole in Charophyta, capable of cytoplasmic streaming.
Endolithic: living inside a rock.
Endophyte: plant inside another plant.
Endoplasm: inner relatively fluid central portion of cytoplasm.
Endospores: asexual spore formed by internal division of a cell in Cyanophyta
Endozoophyte: a plant living in the body of an animal.
Entomopathogenic fungi: fungi parasitizing and killing the insects.
Enzyme linked immunosorbent assay (ELISA): a serological method in which one antibody is linked to an enzyme to indicate detection of an antigen.
Epibasidium: the upper portion of the basidial apparatus.
Epidemiology: science dealing with the study of factors affecting the outbreak and spread of an infectious disease.
Epilithic: living on the surface of a rock.
Epinasty: more rapid growth of the upper side of an organ.
Epipelic: growing on mud.
Epiphyte: an organism which lives on the surface of plant usually leaves and stem, without any evidence of mutualistic or antagonistic existence.
Epiphytotic or epidemic: irregular appearance of the disease on susceptible host over larger areas.
Epipsemic: living on the sand.
Epizoophyte: plant living on the body of animal.
Eradicant: a chemical that destroys a pathogen at the site of infection.
Estuary: mouth of river showing tidal effects and where fresh water mixes with sea water.
Etiology: science of cause of the disease.
Eucarpic: forming reproductive structures on certain portions of the thallus, the thallus itself continuing to perform its somatic function.
Eukaryotic: a cell with well organized true nucleus.
Eutrophication: a process whereby water receives a large amount of nutrients that results in a large growth of algae.
Exospores: externally borne reproductive structure not necessarily resistant to adverse conditions.
Eye spot (syn **stigma):** a spot in algae composed of lipid droplets and meant for light perception.
Facultative parasite: organism primarily a saprophyte, but also sometimes acting as a parasite.
Facultative saprophyte: organism having no relationship with the living cell and getting nutrient from dead tissues.
Fertilization: fusion of two haploid cells, gametes or gamete nuclei to form a diploid zygote.
Filament: linear arrangement of cells, which may be branched or unbranched.

Floridean starch: typical starch of red algae.
Foot rot: rotting of axis immediately above seed in the seedling.
Foot: basal portion of sporophyte in bryophytes that attached to the gametophyte.
Free cell formation: process by which the ascospores are formed by developing membrane around the ascus nuclei.
Fructification: any fungal structure containing spores.
Fruiting body: any structure bearing fungal spores.
Frustule: cell wall of bacillariophyte cell.
Fumigant: a chemical volatile in nature.
Fungi: non-vascular, heterotrophic microorganisms lacking chlorophyll.
Fungicide: a toxic substance used to kill fungi.
Gall: a swelling or over growth as a result of infection.
Gametangium: organ or cell in which gametes are formed.
Gamete: mature haploid reproductive cell whose nucleus fuses with that of another gamete of an opposite sex to form a zygote.
Gametogenesis: a process whereby gametes are produced.
Gametophyte: a haploid gamete producing generation.
Gammae cups: asexual reproductive structure that can develop into a new individual.
Geminivirus: paired (gemini) virus containing single stranded DNA.
Gene cloning: isolation and multiplication of an individual gene or gene sequence by inserting into a bacterium or yeast cell for replication.
Gene for gene concept: the concept that for each gene that confers resistance in the host there is a corresponding gene that confers avirulence in the pathogen.
Genetic engineering: transfer of a specific gene between organisms.
Germ tube: a thread like structure coming out of the germinating spore.
Globule: male reproductive structure of Charophyta.
Habit: characteristic shape or appearance of an individual.
Habitat: set of conditions in which an organism completes its life cycle.
Haplobiont: a plant having only one vegetative phase either haploid or diploid.
Haustorium: knob-like structures of parasitic plants or fungi, which penetrate the host cells for getting nutrition.
Helicospore: coiled or helical shaped spore.
Heterocysts: a specialized cell formed in filamentous cyanobacteria and is meant for nitrogen fixation
Heteroecious: requiring more than one host to complete the life cycle in a rust fungus.
Heterokaryosis: mycelium containing two genetically different nuclei in a cell.
Heterokont: biflagellated cell in which two flagella are unequal in length.
Heteromorphic: vegetative phases in a life cycle distinctly different from each other.
Heterothallic: fungi in which male and female gametes are produced on distinct mycelia.
Heterotrichy: filamentous thallus showing differentiation into basal and erect more openly branched filaments on the substrate.
Heterotroph: the organism that obtains carbon and energy from the organic compounds produced by autotrophs.
Histone: class of positively charged chromosomal proteins that bind to DNA, tend to be lysine or arginine rich.
Holdfast: a modified basal region for attachment with substrate, may be uni- or multicellular.
Holobasidium: a simple, non-septate and not deeply divided basidium bearing usually four basidiospores on sterigmata.
Homothallic: a fungus producing male and female gamete on the same mycelium.
Hormogonium: a short segment of trichome in cyanobacteria that develops into a new trichome after growth.
Host range: any number of hosts attacked by a pathogen.
Host: on or in the body of which another organism lives to derive its nourishment.
Hyperparasite: one parasite living on another parasite with reference to time and space.
Hyperplasia: overgrowth resulting from an abnormal increase in the number of cells.
Hypersensitivity: extreme degree of incompatibility in which there is a prompt death of the tissues around the point of entry that further prevents the spread of infection.
Hypertrophy: overgrowth resulting from an abnormal increase in the size of cells.
Hypha: the individual thread of the vegetative part of the fungus, collectively known as mycelium.
Hypnospores: aplanospore with a greatly thickened cell wall.
Hypobasidium: the basal portion of the basidial appratus.

Hypoplasia: sub normal cell division.
Hypotrophy: reduction in the size of the cells.
Hypovirulence: greatly reduced ability to cause a disease.
Immunity: condition of host that does not allow the pathogen to develop parasitic relationship.
Imperfect stage: a part of life cycle of a fungus in which no sexual spores are produced.
Incubation period: period between penetration and the appearance of the disease symptoms.
Infection: establishment of the pathogen in the host after penetration.
Inhibitor: a chemical substance preventing any process.
Injury: damage of a plant by any physical or chemical agent.
Inoculation: transfer of a pathogen into host. It can be done by different ways such as spray, injection, smear and pinprick.
Inoculum potential: the capability of the parasite to infect a host.
Inoculum: part or whole of the material capable of causing infection.
Inoperculate: without an operculum or lid.
Integrated pest management: management of plant diseases by using different methods simultaneously instead of dependence on one single method.
Isogamy: formation of zygote by fusion of gametes, which are similar in size and morphology.
Isogeneic lines: a series of plant lines genetically similar but carrying specific genes for resistance to a particular pathogen.
Isokont: flagellated cells having flagella of equal length.
Isolate: any microorganism obtained from an organism or a system.
Karyogamy: fusion of nuclei often in zygote formation.
Karyokinesis: division of the nucleus.
Koch's postulates: procedure used to prove pathogenicity of an organism.
Latent virus: a virus not showing symptoms on the host.
Leaf spot: a self limiting lesion on the leaf.
Lentic: referred to standing water, related to pond or lake.
Lesion: a localized area of discolored diseased tissues.
Lichen: a fungus containing symbiotic algae.
Life cycle: sum of all stages between the appearance and reappearance of same stage of an organism.
Lithotroph: needing only light and inorganic compounds for growth.
Littoral: zone from the water’s edge to a depth of six meter.
Local infection: an infection affecting a limiting part of plant.
Lotic: referred to flowing water, related to streams and rivers.
Malformation: abnormal growth due to disturbed action of growth regulators, or some other reasons.
Masked symptoms: symptoms not expressed or exhibited by the host.
Mastigoneme: lateral hairs on the surface of flagella.
Medulla: inner non-photosynthetic structure of the stipe of algae surrounded by cortex.
Meiosis: one of the nuclear divisions in which the number is reduced to half.
Meristoderm: dividing layer of cells in the thallus of Phaeophyta.
Mesophilic: organism growing at moderate temperature (ranging between 10 to 40°C).
Mesosome: space between membrane and wall of Cyanophyta cell
Metabolism: the sum total of the enzymatic reaction occurring in a cell, organ or an organism.
Mitosis: a cell division in which the chromosome number of the cell is conserved from one offspring to the other.
Mixotroph: photosynthetic organism capable of using organic compounds in the medium.
Molecular biology: qualitative study of molecular structure within cell.
Monoecious: (syn hermaphrodite), the plants in which male and female reproductive structures are produced on the same plant.
Monoplanetic: species in which there is only one type of zoospore and swarming period.
Monospore: a single spore formed from the contents of a cell.
Mosaic: interspersed patches of normal and light green or yellowish color.
Mottling: an irregular pattern of light and dark areas.
Mucilage: a polysaccharide layer formed outside the wall of certain algal cells.
Mycobiont: fungus component of lichen partnership.
Mycology: study of fungi.
Mycoplasma: pleomorphic free-living microorganism lacking rigid cell wall.

Mycorrhizae: association between hyphae of a fungus and root of a plant.
Mycovirus: virus infecting fungi.
Necrosis: death of cells or tissues.
Nucleocapsid: the virus particles consisting of protein coat (capsid) and nucleic acid.
Nucleoprotein: consisting of nucleic acid and protein.
Nucule: female reproductive organ in Charophyta.
Obligate parasite: parasites restricted to only living tissues, usually do not grow on artificial culture media.
Ontogeny: pattern or type of development of an individual.
Oogamy: an advanced type of sexual reproduction involving the fusion of a large non-motile egg with a small motile sperm.
Oogonium: the female gametangium of Oomycetes.
Oospore: a sexual thick walled resting spore developing from an oosphere either through fertilization or parthenogenesis.
Organelle: distinct intracellular structure surrounded by one or more envelops.
Osmotroph: organisms that obtain energy by absorbing and metabolising nutrients.
Overwintering: survival by some means during periods of adverse environmental conditions.
Palmelloid: a habit in algae describing an indefinite number of single non-motile cells in a mucilaginous matrix.
Paramylon (syn **paramylum):** reserve polysaccharide of Euglenophyta and Dinophyta composed of β-1, 3 linked units of glucose.
Parasexual cycle: a nuclear cycle in which plasmogamy, karyogamy and haplodization occur but neither in a specified organ nor at a definite time in the life cycle of the organism.
Parasite: organism that lives on or inside the body of a different organism and obtains nutrients from it.
Parenchymatous thallus: a thallus comprised of unspecialized cells having the ability to grow in all planes.
Partial resistance: resistance expressed by slower development of pustules or lesions.
Pectin: complex carbohydrates found in the cell wall.
Peptidoglycan: polysaccharide composed of sugars and amino acids in the walls of Cyanophyta.
Pericentral cell: a small cell formed around a central axis.
Periclinal division: division of cells parallel to the circumference of the thallus.
Peridium: outer wall of a fruiting body or fructification.
Periphyton: organism attached to the submerged vegetation.
Periplasm: a protoplasmic layer which surrounds the oospore within the oogonium.
Perithecium: flask shaped fruiting body or ascocarp in Pyrenomycetes having an opening or pore called ostiol.
Phaeoplast: brown plastid, the membrane bound photosynthetic structure of Phaeophyta.
Phagotrophy: mode of heterotrophic nutrition involving ingestion of particles.
Photoautotroph: organisms using light as a energy source and CO_2 as principal carbon source.
Photoheterotroph: organisms using light as a energy source and an organic compound as the principal carbon source.
Phototaxis: movement towards the light source.
Phototropic: plants showing movement by getting stimulus from sunlight.
Phycobilin: one of the various blue green or reddish pigments that participate in photosynthesis in the cells of Cyanophyta and Rhodophyta.
Phycobiont: photoautotrophic component of lichen partnership.
Phylloplane: the microhabitat (microorganism) on the leaf surface.
Phylogeny: evolution of a genetically related group of organisms.
Physiologic race: a group of microorganisms similar in morphology but differ genetically.
Physiological specialization: existence of number of races or forms of one species of a pathogen.
Phytopathometry: plant disease assessment or measurement.
Pit connection: protoplasmic connections joining cells into tissues.
Plankton: free floating microscopic organisms.
Plasmogamy: fusion of protoplasts of two cells without fusion of nuclei.
Plastid: cytoplasmic, photosynthetic pigmented organelle (chloroplast) or its non-photosynthetic derivative (e.g. chromoplast, leucoplast, etioplast).
Plurilocular sporangium: a multicellular reproductive structure formed in brown algae.
Polar nodule: wall swelling near the end of a cell in Bacillariophyta.
Polyglucan granule: protoplasmic structure containing the storage product in Cyanophyta.
Polyhedral body: protoplasmic structure containing DNA fibrils and CO_2 fixing enzymes in Cyanophyta.

Polysome: a cluster of ribosomes associated with messenger RNA.
Posterior: pertaining to the rear end.
Prokaryote: cell or organism composed of cells lacking a membrane-bound nucleus, histones and organelles.
Promycelium: a short hypha produced by a teliospore; the basidium of rust and smut fungi.
Propagative virus: a virus that multiplies on insect vector.
Prosorus: a structure which eventually divides and gives rise to a sorus.
Protoctists: eukaryotic organisms that are not members of the kingdoms Fungi, Animalia or Plantae, include eukaryotic algae and many non-pigmented organisms.
Protonema: filamentous or plate-like structure produced by germinating spore.
Pustule: a small blister like elevation of epidermis.
Pycnidium: an asexual fruiting body containing conidiophores and conidia.
Pycnium: a flask shaped structure containing spermatia.
Pyrenoid: proteinaceous structure inside some plastids that serves as a center of starch formation.
Radial symmetry: regular arrangement of parts around one longitudinal axis: any plant through this axis will divide the object or organism into two similar parts.
Raphe: a longitudinal slit along the valve of some pennate Bacillariophyta.
Receptacle: fertile area at the tip of the gametophyte.
Reservoir: vestibule or holding structure e.g. at the base of the flagellum in the protoctists.
Resting cells: cell in Bacillariophyta with same morphology as vegetative cell but with a large amount of lipid and reduced size of organelles.
Resting spore: thick walled spores, which are resistant to extremes of environments.
Retrovirus: RNA virus that uses reverse transcriptase to synthesize DNA.
Rhodoplast: red plastid; the membrane bound photosynthetic structure of Rhodophyta.
Sclerotium: hard compact mass of mycelium having ability to survive under adverse conditions, germinating upon the return of favourable conditions.
Secondary infection: infection caused by inoculum produced as a result of primary infection.
Seta: stalk-like structure between foot and capsule of the sporophyte in Bryophyta.
Silicalemma: membrane of a silica deposition vesicle.
Siphonoxanthin: a carotenoid found in siphonaceous algae.
Soil-borne: microorganisms capable of living and surviving in the soil.
Somatogamy: union of plus and minus mycelia or fusion of somatic cells during plasmogamy.
Sorus: a compact mass of spores or fruiting structures found in rusts and smuts.
Spermatia: male non-flagellated gamete of red algae.
Spermatization: plasmogamy by the union of a spermatium with a receptive structure.
Spiroplasma: a prokaryote with helical shape and lacking cell wall.
Sporangia: hollow unicellular or multicellular structure in which spores are produced and released.
Sporangiophore: hypha bearing sporangium.
Spore: microsporic propagative structures containing at least one genome, often tolerant of adverse conditions.
Sporidium: a basidiospore of a smut or a rust fungus.
Sporodochium: a compact cushion like fruiting structure with short condiophores in cluster.
Sporophyte: spore producing diploid plant.
Statospore: a resistant spore surrounded by a silicified wall formed by the members of Chrysophyta.
Sterigma: a small projection which supports a conidium or a basidiospore.
Stipe: a stem like region of thallus of higher algae.
Stolon: a hypha of the order Mucorales that connects two groups of rhizoids.
Stroma: a compact, matress-like somatic structure, on or in which fructifications usually occurs.
Stylospore: elongated curved spore produced in certain fungi.
Susceptibility: inability of the plant to resist the effect of a pathogen.
Symbiosis: intimate and protracted association between two or more organisms of different species.
Symptom: visible reaction or expression on a plant due to abiotic or biotic factors.
Teleomorph: the sexual (perfect) state.
Telium: a structure in which teliospores are produced.
Tetrasporangium: structure in which tetraspores are formed.
Thallus: simple flat body undifferentiated into organs like leaf, stem or root.
Theca: hard covering enclosing the protoplasm of cell e.g. in Bacillariophyta.
Thermophilic: organisms that can tolerate high temperature (45-65 °C).

Tissue: aggregation of similar cells, which are structurally and functionally organized.
Trichogyne: long colorless part of carpogonium that receives the spermatium in Rhodophyta.
Trichogyne: the receptive neck of an ascogonium.
Trichome: a row of cells without the sheath (in Cyanophyta).
Unilocular sporangium: sporangium composed of a single cell producing zoospore.
Unitunicate: an ascus in which both the inner and outer wall are more or less rigid and do not separate during spore ejection.
Uredinium: a structure containing uredospores.
Uredospore: dikaryotic one celled spores produced in a uredium or uredinium.
Vector: insect able to transmit a pathogen.
Vein banding: retention of bands of green tissues along the veins, while the tissues between the veins becoming chlorotic in certain virus diseases.
Vein clearing: destruction of chlorophyll adjacent or in the vein tissues mostly as a result of virus infection.
Vesicle: a small sac like structure having fluid.
Virion: a virus particle.
Viroid: single stranded small circular naked RNA virus (without protein coat) replicating in host nucleus.
Virology: science dealing with the study of viruses and viral diseases.
Viruliferous: insect vector with virus in its body and being capable of introducing it into a susceptible host.
Virus: submiscrosopic strictly obligate parasite filterable infective entities nucleoprotein in nature.
Virusoid: a subviral circular RNA component of some RNA viruses.
Water soaked: a disease symptom where plant tissue appears wet.
Wilting: drooping down of leaves due to loss of turgor.
Xanthoplast: photosynthetic organelle of Xanthophyta.
Yeast: a single celled fungus that reproduces either by budding or fission.
Yellows: a plant disease showing yellowing and stunting effect on a host plant.
Yield loss: measurable reduction or loss in produce.
Zoosporangium: a sporangium containing zoospore (with flagella).
Zoospore: a flagellated asexual spore.
Zygosporangium: a sporangium producing zygospores.
Zygospore: sexual resting spore of zygomycetes produced by the union of two morphologically similar gametangia.
Zygote: diploid nucleus or cell produced by the fusion of haploid cells and destined to develop into a new individual.

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