CYANOPHYCOTA-CYANOPHYCEAE

The name of the class Cyanophyceae was first proposed by Eichler in 1886. He placed it as one of the five groups with Diatomeae, Chlorophyceae, Phaeophhceae and Rhodophyceae. Later Pascher (1914) treated this group in a separate division Cyanophyta with one class: Myxophyceae. Smith (1933, 1951, 1955) also followed the same. Fritsch (1945) again reduced this group in to a class Cyanophyceae. Papenfuss (1946) treated Cyanophyceae with bacteria and placed both under the Phylum Schizophyta. The later authors such as Prescott (1969) and Round (1973) treated this group in a separate division Cyanophyta, where as Bold and Wynne (1978) following Papenfuss (1946) called this group as Cyanophycophyta incorporating the word Phykos in the divisional name. Recently Rippka and his co-workers (1979) treated this group with bacteria based on the evidence in pure cultures and divided in to five sections. Parker (1982) placed the members of this group under the kingdom Prokaryotae and the division Cyanophycota with one class, Cyanophyceae.

Characteristics of the cyanophycean cells:

Members of this group are photosynthetic monera with an alga like biology and a bacterium like cell organization. The cells show a low state of cellular organization. Cells lack a well defined nucleus and cell division takes place by the division of protoplast by an ingrowth of the septum. The following are the chief pigments present in the cyanophycean cells: Chlorophyll a; β-carotene, c-phycoerythrin, c-phycocyanin and allophycocyanin. Chlorophyll a consists of four linked pyrrole rings with a magnesium atom chelated at the centre; they are conjugated with proteins. It also has a long phytol chain. Acetone extracts show two absorption peaks, in the blue part of the spectrum at 430 nm and red at 660 nm.

Biliproteins contain the linearly arranged tetrapyrrolic bilin pigments phycoerythrobilin and phycocyanobilin. These are strongly covalently bonded to a protein component.

Carotenoids consist of the hydrocarbon carotenes and their dihydroxy derivatives, xanthophylls. They are usually red, brown or yellow in colour. Carotenoid is photo protective and they screen out harmful blue and near UV radiation.

Reserved food is stored in the form of Cyanophycean starch (Cyanophycin granules-arginine and aspartic acid). These granules distributed peripherally in ***Nostoc*** and on either side of the septa in ***Phormidium***. Glycogen (Polyglucan) or α-granules as well as lipid droplets are located between thylakoids.

Photosynthetic apparatus:

Members of this group are aerobic autotrophs with some are facultatively non-oxygenic photosynthesis with H_2S as electron donor. Chlorophyll-a and β-carotene are present in thylakoids, which are freely distributed in the cyanophycean cells. Each thylakoid is around 20 nm thick. It consists of closely appressed unit membranes separated from one another by a space of 3-6 nm. Thylakoid membranes are made up of a lipid bimolecular layer in which proteins are inserted. The thylakoids are not only the sites for photosynthesis but also for respiration. Even these thylakoids are absent in ***Gloeobacter violaceus***. In this organism photosynthesis and respiration are associated with plasma membrane. In this organism photosynthesis and respiration are associated with plasma membrane.

Cell wall is four layered with a sheath covering it externally. The sheath is made up of fibrils arranged reticulately in a homogenous matrix. The main constituents of these fibrils are pectic acids and mucopolysaccharides. The sheath prevents desiccation and helps in gliding in many filamentous forms. Cell wall consists of two layers. The outer layer is 16 nm thick and appears as a double track structure. This layer is mainly made of lipopolysaccharides and proteins. The inner layer is 12 nm thick and contains major constituent of peptidioglycan (up to 50% dry weight). Peptidoglycan contains alanine, glucosamine, muramic acid, glutamic acid and α-diaminopimelic acid. Cell membrane is made of phospholipids with protein units.

Cytokinesis takes place by three ways. In the constrictive types, simultaneous invagination of walls occurs. In the septum type a septum is formed by invagination of the cytoplasmic membrane and the peptidoglycan layer. Before invagination of the outer membrane commences, the thylakoids are pushed towards the centre and are cut across as the septum is completed. Septum formation occurs independently of a specific replication cycle. In the budding type cytoplasm abstracts with cell membrane when it is exposed due to rupture of the cell wall at the terminal region as in ***Chamaesiphon***.

Cytoplasmic inclusions:
Nucleoplasm: It contains DNA fibrils in a ring-like configuration, in the centre of the cell and not contained within a membrane system. DNA base composition (Guanine+Cytocine ratio) ranges from 35-71 mol %. Plasmids are also reported to occur in blue-green algae. These are circular, double stranded, autonomously replicating DNA molecules. Eg., ***Anacystis, Agmenellum, Oscillatoria, Anabaena, Pseudoanabaena*** and ***Nostoc***.

Cyanophycin granules: (arginene and aspartic acid); Carboxysomes (occur in the central region of the cell and contain Ribulose biphosphate carboxylase oxygenase); Ribosomes (dense granules 100-150 nm in diameter, dispersed throughout the cells). Gas vesicles (these are spindle shaped vesicles surrounded by a 2 nm thick protein envelope arranged linearly in the planktonic species. These vesicles vanish under pressure. Presence of gas vesicles makes the cell buoyant and disappearance of these makes the organisms to sink down. This process is said to be controlled by light intensity).
Polyphosphate bodies; lipid droplets and poly-β-hydroxybutyrate particles or volutin granules.

Thallus organization in Cyanophyceae

Members of the Cyanophyceae range from unicellular to colonial and filamentous forms.

Unicellular organization: Coccoid forms:

The non-motile cyanophycean unicells are referred as coccoid forms. Eg. members of Chroococcaceae-***Aphanothece, Aphanocapsa***. Sometimes two cells which are the products of binary fission, held together in a common gelatinous matrix. Eg. ***Chroococcus*** and ***Gloeocapsa***.

Colonial organization:

Tabular colonies are formed by ***Merismopedia*** and ***Halopedia*** where cells are arranged in two planes in a common matrix.

Cubical colonies are formed by ***Eucapsis***. Here cells are arranged in three planes into cubical masses.

Colonies of indefinite shape (such as simple, linear, elongate, large and reticulate) are formed by ***Microcystis*** were numerous cells are seen in a common matrix.

A spherical colony is formed by the cells of ***Coelosphaerium*** where cells are distributed in the rim of hollow spherical colony.

In certain forms mucilage production is restricted to the base of the cells. This results in the apical placement of the cells on a mucilaginous stalk. This type of colonies is called as dendroid colonies eg. ***Cyanostylon***.

Filamentous organization: Simple filaments:

Simple consists of a single row of cells firmly attached to one another, with no branching. A simple filament in this group is a trichome with very small cells. The trichome is free of any sheath in ***Oscillatoria*** and it is covered by a sheath as in ***Lyngbya***, etc. The trichome may be of equal, width throughout its length as in ***Oscillatoria***, or markedly tapered from base to apex, with the terminal portion hair-like as in ***Rivularia***, with a basal cell a heterocyst. Tapered trichomes may be grouped to form branched aggregates as in ***Rivularia*** or they may radiate from a central point of a mucilaginous colony as in ***Gloeotrichia***. In Nostoc short trichomes are found in a common gelatinous matrix. In the planktonic species of ***Spirulina*** the trichomes are helically twisted. Simple filamentous trichomes show gliding movement. This may be smooth, jerky or bending in nature. These movements are effected by the secretion of mucilage through pores in their cell walls.

Branched filaments:

In the Cyanophyceae, two modes of branching occur. False branching results from interruptions in the filament (eg. By an heterocyst or separation disc), one (***Tolypothrix***) or both (***Scytonema***) portions of the Trichome push out of the sheath as branches.

True branching results from a second plane of division (eg. ***Stigonema***, ***Mastigocladus*** and ***Haplosiphon***).

The filaments may be homocystous or heterocystous. Homocystous filaments are the ones that lack heterocysts. Heterocystous filaments posses heterocysts. Heterocysts occur in many of the members of Nostocales and all members of Stigonematales. (Unicellular Cyanophyceae, such as ***Gloeocapsa***, ***Gloeothece*** and ***Aphanothece*** fix atmospheric nitrogen under aerobic condition without heterocysts).

Heterocysts are morphologically distinct and functionally specialized cells, which fix atmospheric nitrogen when the filaments containing these structures are grown aerobically in a nitrogen free environment. Heterocysts are modified vegetative cells found with thick envelope formed external to the cell wall. The envelope is three layered: the outermost layer is fibrous whose constituent is unknown; the middle layer is homogenous, made of oligosaccharides and polysaccharides; the innermost layer is laminated with glycolipids which show differential permeability. The heterocysts have one (***Gloeotrichia***, ***Cylindrocapsa***) or two (***Nostoc, Anabaena, Scytonema***) or three pores (***Brachytrichia***). Heterocysts lack accessory pigments and they do not perform oxygenic photosynthesis. They depend on a supply of carbohydrates from adjacent vegetative cells. Energy required for fixing atmospheric nitrogen is supplied by cyclic photophosphorylation. The thick envelopes of the heterocysts prevent the diffusion of oxygen into heterocysts. Thus a local anaerobic condition is maintained inside the heterocysts. Otherwise the oxygen which might get in to the heterocyst may form hydrogen peroxide by the reducing agents present there. Hydrogen peroxide is toxic, in the sense it inactivates the enzymes-Nitrogenase and hydrogenase-which are the key enzymes in the atmospheric nitrogen fixation. Heterocysts are found to contain super oxide dismutase and catalase enzymes which prevent toxic effects of super oxide and peroxide. Small amount of oxygen, which may enter into heterocysts, is used in the respiratory activities. Nitrogenase activity requires ATP and reduced ferredoxin. These are produced by cyclic photophosphorylation. But most of the ferredoxins are appearing to be reduced by NADPH obtained from the hexose monophosphate shunt pathway using carbohydrates imported from adjacent cells. Nitrogen is reduced to NH_4^+ which is converted to glutamine before sent from the heterocyst to adjacent cells of the filament. Nitrogen fixation is always coupled with hydrogen evolution.

Reproduction:

Members of Cyanophyceae reproduce by binary fission and fragmentation. They also reproduce by the formation of the following structures. Hormogone, Planococcus, Akinete, Hormocysts, Expospore and Endospore.

Hormogone: It is a short trichome with rounded ends and without differentiation of cells, covered by a delicate mucilage envelope. Hormogones are formed either by breaking of the trichomes as in ***Oscillatoria*** and ***Anabaena*** or they are set free from the ends of the filaments or their branches as in ***Scytonema*** and ***Stigonema***.

Planococcus: It is a single celled hormogone produced by simple filament of Nostocales.

Akinites: These are unicellular structures with thickened walls, larger than vegetative cells and possess a lot of nitrogen reserves. Akinete formation is said to be associated with nutrient deficiencies. During germination the cell may divide prior to emergence through a pore in the cell wall. In ***Cylindrospermum*** and in Rivulariaceae, akinetes are always formed next to the terminal heterocysts. In ***Anabaena*** akinetes are formed adjacent to the heterocysts. In ***Nostoc insulare*** the heterocysts transforms in to an akinete.

Hormocysts: These are few celled structures, where the cells are stocked with food-reserves and enveloped by a thick sheath which closes round at both ends. These are found among the members of Scytonemataceae and Stigonemataceae.

Exospores: These are produced in ***Chamaesiphon***. At maturity the cell wall of ***Chamaesiphon*** ruptures at tips. This exposes cytoplasm with its membrane and they abstract to form spores continuously.
Endospores: These are formed byh the repeated divisions of the cytoplasm to form numerous spores amitotically (Eg. ***Dermocarpa***). Sometimes these spores are formed by heterocysts when they become old or often after desiccation. Eg. ***Anabaena cycadeae*** and ***Tolypothrix***. The endospores formed by blue-green algae are also called as baeocytes.

Sexual Reproduction:
This is absent and genes are transferred by transformation or by conjugation. Bazin (1968) reported transfer of genes by transformation in ***Anacystis nidulans***. He showed that strains of ***Anacystis nidulans*** resistant to either of the antibiotics polymyxin or Streptomycin produced a double-resistant strain when grown together. This is by transformation where DNA freed in to the medium was taken up by the recipient cell. Conjugation is also reported in the species of ***Anabaena*** and ***Nostoc.***

CLASSIFICATION
Ripka and his co-workers (1979) grouped the members of this group with bacteria, under prokaryotae and classified in to five sections. According to them each section is characterized as follows:

Section I: Unicellular; reproduction by binary fission or by budding (corresponds to Chroococcales and exospores forming Pleurocapsales of the botanical system).

Section II: Unicellular; Reproduction by multiple fission, producing baeocytes and in several genera also by binary fission (corresponds to endospore forming Pleurocapsales).

Section III: Filamentous, without heterocysts and not true branchings (corresponds to non-heterocystous members of Nostocales).

Section IV: Filamentous with heterocysts and no true branching (corresponds to heterocystous Nostocales).

Section V: Filamentous with heterocysts and true branchings (corresponds to Stigonematales).

In the botanical system of classification, five orders are placed under this class by Desikachary (1959). Recently, Silva (in Parker, 1982) placed four orders, viz., Chroococcales, Pleurocapsales, Nostocales and Stigonematales. Characteristic features of these four orders and the names of families with their important genera are given below.

Chroococcales:

Members of this order are important primary producers; several species from noxious water blooms (*Microcystsi*) [eutrophication]; and some are known to produce toxins that affect animals. Chroococcales do not fix nitrogen under ordinary conditions.
Distribution: Widespread in freshwater, in marine habitats, in soil, on rocks and as symbionts in lichens or more rarely in animals.

Families: Chroococcaceae (*Microcystis, Coelosphaeria, Merismopedia*); Tubiellaceae and Entrophysalidaceae.

Pleurocapsales:Members of this order are unicellular, with or without binary fission, or they are Multicellular, forming cell aggregates or filaments. The filaments when present, are of simple construction and lack the close connection between cells that is characteristic of orders in which hormogonia are formed. Cell polarity is absent or present. Reproduction takes place by motile or immotile endospores (Baeocytes) produced by the multiple division of a cell and released through the rupture of the outer-wall layer (endosporangium) or by exospores, small cells produced in basipetal order by an unequal division of the mother cell and released through an apical opening of the outer layer of cell wall.
Families: Pleurodapsaceae (*Pleurocapsa*); Scopulonemataceae; Siphononemataceae; Pascherinemataceae; Cyanophanaceae; Dermocarpaceae (*Dermocarpa*); Chamaesipnonaceae (*Chamaesiphon*).

Nostocales:
Filaments are unbranched or have false branchings. When false branchings are present, the filaments (sheath with trichome) are branched but the trichomes themselves, within the sheath are not. This type of branching occurs when cell divisions take place in a trichome segment without the sheath increasing in length. The growing trichome forms a bulging loop breaking. The newly formed trichome ends continue to grow as a lateral branch is formed when the continuity of a trichome is interrupted and only one of the newly create trichome ends grow out of the sheath. In such cases, the other newly formed end cell that 4remains inside the sheath usually develops into a heterocysts.

Heterocysts are prevent or absent; reproduction is by motile hormogonia, and akintets, endospores; hormocysts are also present.

Families: Microchaetaceae (*Microchaete*); Rivulariaceae (*Rivularia*); Nostocaceae (*Nostoc, Anabaena*); Oscillatoriaceae (*Oscillatoria, Spirulina, Lyngbya*); Gomontiellaceae; Scytonemataceae (*Scytonema, Tolypothrix*).

Order **Stigonematales**:
Uniseriate or multiseriate filamentous forms characterized by hormogonalean organization and true branching. In Stigonematales, pit like protoplasmic connections are present between the cells of the trichome. In true branching the trichome itself is branched. True branchings are dichotomous, lateral or of the V or Y type. The filament is often differentiated into a main axis and branches. Heterocysts are usually present. Reproduction takes place by the formation of hormogonia, hormocysts or akinites.

Families: Stigonemaytaceae (*Stigonema*); Capsosiraceae; Nostochopsidaceae (*Nostochopsis*); Borzinemataceae; Mastigocladaceae (*Mastigocladus*, *Brachytrichia*); Mastigocladopsidaceae (*Mastigocladopsis*).