स्वाध्याय स्वमन्थन स्वावलम्बन

उत्तर प्रदेश राजर्षि टण्डन मुक्त विश्वविद्यालय, प्रयागराज

उत्तर प्रदेश सरकार का एकमात्र मुक्त विश्वविद्यालय

।। सरस्वती नः सुभगा मयस्करत् ।।

PGBY-101(N)

Phycology

शान्तिपुरम् (सेक्टर-एफ), फाफामऊ, प्रयागराज - 211013

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संदेश

प्रयागराज की पवित्र भूमि पर भारत रत्न राजर्षि पुरुषोत्तम दास टण्डन के नाम पर वर्ष 1999 में स्थापित उत्तर प्रदेश राजर्षि टण्डन मुक्त विश्वविद्यालय, प्रयागराज उ0प्र0 का एकमात्र मुक्त विश्वविद्यालय है। यह विश्वविद्यालय उ0प्र0 जैसे विशाल जनसंख्या वाले राज्य में उच्च शिक्षा के प्रत्येक आकांक्षी तक गुणात्मक तथा रोजगारपरक उच्च शिक्षा के अवसर उपलब्ध कराने में निरन्तर अग्रसर एवं प्रयत्नशील है। तत्कालीन देश की सामाजिक एवं आर्थिक परिस्थितियों में एक वैकल्पिक व नवाचारी शिक्षा व्यवस्था के रूप में भारत में मुक्त एवं दूरस्थ शिक्षा प्रणाली का पदार्पण हुआ था, परन्तु वर्तमान परिस्थितियों तथा तकनीकी का सार्थक प्रयोग करते हुये मुक्त एवं दूरस्थ शिक्षा आज की सर्वोत्तम पूरक शिक्षा व्यवस्था के रूप में स्थापित हो चुकी है।

वर्तमान शिक्षा प्रणाली के सामने व्याप्त पाँच मुख्य चुनौतियों - (i) पहुँच (Access), (ii) समानता (Equity), (iii) गुणवत्ता (Quality), (iv) वहनीयता (Affordability) तथा (v) जवाबदेही (Accountability) को केन्द्र में रखकर घोषित देश की राष्ट्रीय शिक्षा नीति (NEP-2020) के प्रस्तावों को क्रियान्वित करने में उत्तर प्रदेश राजर्षि टण्डन मुक्त विश्वविद्यालय कृत संकल्पित है। उ0प्र0 की माननीय राज्यपाल एवं कुलाधिपति की सद्इच्छाओं के अनुरूप उत्तर प्रदेश राजर्षि टण्डन मुक्त विश्वविद्यालय, शैक्षिक दायित्वों के साथ-साथ सामाजिक दायित्वों के निर्वहन में भी लगातार नवप्रयास कर रहा है। चाहे वह गाँवों को गोद लेकर उनके समग्र विकास का प्रयास हो या ग्रामीण महिलाओं, ट्रान्सजेन्डर व सजायाफ्ता कैदियों को शुल्क में छूट प्रदान कर उनमें आत्मविश्वास जागृति व उच्च शिक्षा के प्रति अलख जगाने का प्रयास हो।

राष्ट्रीय विकास को बढ़ावा देने के लिए शिक्षा एक मूलभूत जरूरत है। ज्ञान-विज्ञान एवं तकनीकी के क्षेत्रों में हो रहे तीव्र परिवर्तनों व वैश्विक स्तर पर रोजगार की परिस्थितियों में आ रहे परिवर्तनों के कारण भारतीय युवाओं को विभिन्न क्षेत्रों में गुणवत्तापूर्ण शैक्षिक अवसर उपलब्ध कराने पर ही भारत का भविष्य निर्भर करेगा। इसीलिए विभिन्न क्षेत्रों में सफलता हेतु शिक्षा को सर्वसुलभ, समावेशी तथा गुणवत्तापरक बनाना समसामयिक अपरिहार्य आवश्यकता है। वर्तमान परिस्थितियों ने परम्परागत शिक्षा को और भी सीमित कर दिया है जिसके कारण मुक्त एवं दूरस्थ शिक्षा व्यवस्था ही एकमात्र पूरक एवं प्रभावी शिक्षा व्यवस्था के रूप में सार्थक सिद्ध हो चुकी है। ऐसी स्थिति में विश्वविद्यालय का दायित्व और भी बढ़ जाता है। इस दायित्व को एक चुनौती स्वीकार करते हुए विश्वविद्यालय ने प्राचीन तथा सनातन भारतीय ज्ञान, परम्परा तथा सांस्कृतिक दर्शन व मूल्यों की समृद्ध विरासत के आलोक में सभी के लिए समावेशी व समान गुणवत्तायुक्त शिक्षा सुनिश्चित करने तथा जीवन पर्यन्त शिक्षा के अवसरों को बढ़ावा देने के लिए अपने शैक्षिक कार्यक्रमों में जागरूकता में प्रमाणपत्र, डिप्लोमा, परास्नातक डिप्लोमा, स्नातक, परास्नातक तथा शोध उपाधि के समसामयिक शैक्षिक कार्यक्रमों की संख्या तथा गुणात्मकता में वृद्धि की है।

शैक्षिक कार्यक्रमों में संख्यात्मक वृद्धि, गुणात्मक वृद्धि तथा रोजगारपरक बनाने के साथ-साथ प्रत्येक उच्च शिक्षा आकांक्षी तक पहुँच सुनिश्चित करने के लिए अध्ययन केन्द्रों व क्षेत्रीय केन्द्रों के विस्तार के साथ-साथ प्रवेश परीक्षा, प्रशासन तथा परामर्श (शिक्षण) में आनलाइन व्यवस्थाओं को सुनिश्चित किया गया है। विश्वविद्यालय कार्यप्रणाली में पारदर्शिता तथा जवाबदेही सुनिश्चियन की दृष्टि से तकनीकी के प्रयोग को बढ़ाया गया है। 'चुनौती मूल्यांकन' की व्यवस्था सुनिश्चित करने का कार्य किया गया है, तो शिक्षार्थी सहायता सेवाओं में भी वृद्धि की जा रही है। शिक्षार्थियों की समस्याओं के त्वरित निस्तारण हेतु शिकायत निवारण प्रकोष्ठ को सुदृढ़ करने के साथ-साथ पुरातन छात्र परिषद को गतिशील किया गया है।

"गुरुकुल से छात्रकुल" के सूक्त वाक्य को आत्मसात करते हुए विश्वविद्यालय ने शिक्षार्थियों को विश्वविद्यालय द्वारा तैयार किये गये गुणवत्तापूर्ण स्वअध्ययन सामग्री उपलब्ध कराने के साथ-साथ विश्वविद्यालय की वेबसाइट पर भी उपलब्ध कराया गया है। छात्रहित को ध्यान में रखते हुए शिक्षकों द्वारा तैयार व्याख्यान को भी ऑनलाईन उपलब्ध कराया गया है।

शोध और नवाचार के क्षेत्र में अग्रसर होते हुए विश्वविद्यालय अनुदान आयोग (UGC) नई दिल्ली तथा माननीय राज्यपाल एवं कुलाधिपति, उ0प्र0 की अनुमति से विश्वविद्यालय में शोध कार्यक्रम पुनः प्रारम्भ किया गया है तथा वर्ष पर्यन्त समसामयिक विषयों पर व्याख्यान, सेमिनार, वेबिनार तथा आनलाइन संगोष्ठियों आदि की श्रृंखला भी प्रारम्भ की गयी है। विभिन्न क्षेत्रों में रिसर्च प्रोजेक्ट सम्पादन पर भी ध्यान केन्द्रित किया गया है। पुस्तकालय को अत्याधुनिक तथा सुदृढ़ बनाने हेतु कदम उठाये गये हैं। शिक्षकों व कर्मचारियों के स्वास्थ्य तथा कल्याण की योजनायें क्रियान्वित की गयी हैं।

प्रो0 सत्यकाम
कुलपति

Uttar Pradesh Rajarshi Tandon
Open University

PGBY-101(N)
Phycology

Block - 1

The block-I is organized into following six units as under :

Block-2

The block-II is further organized into next following six units as under:

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Block - Introduction

This is the first block (Introduction, Cyanophyceae –I, Cyanophyceae- II, Chlorophyceae-I, Chlorophyceae-II, Chlorophyceae-III of Phycology. It consists of six units. The objective of this block deals basic introduction to Cyanophyceae and Chlorophyceae in concern to their occurrence, habitat, characteristics properties, classification, cellular organization and reproduction respectively. Algae are photosynthetic organisms that possess photosynthetic pigments such as chlorophyll. However, they lack true roots, stems, and leaves characteristic of vascular plants. Some of them are unicellular whereas others are multicellular. They may also form colonies. Most algae are aquatic. Others are terrestrial and may be found on moist soil, trees, and rocks. Some algal species form symbiosis with other organisms. For example, a lichen is a symbiotic association between fungi and green (and occasionally blue-green) algae. Algae belong to a polyphyletic group.

This means that the organisms in this group are not necessarily closely related and do not have a common ancestor. However, they share a common feature; they are eukaryotes capable of photosynthesis with chlorophyll as their primary pigment but they lack other morphoanatomical features common among vascular plants. The scientific study of algae is called phycology. Some references include blue-green algae. However, they are prokaryotes, and as such, other authorities do not consider them as algae. Green algae shows all three types of life cycle: haplontic, diplontic and haplodiplontic. In haplontic, the haploid gametophyte is the dominant generation. Sporophytic generation is represented only by the diploid zygote which undergoes meiosis to form haploid spores. Examples include *Chlamydomonas*, *Ulothrix*, *Spirogyra* etc. In diplontic, The diploid phase is the dominant generation. Gametes produced by meiosis represent the haploid phase. Examples include *Caulerpa*. Inhaplodiplontic, the haploid and diploid phases are well developed. The haploid gametophyte produces haploid gametes. Fusion of gametes results in the formation of the zygote (2n). Zygote develops into a sporophyte which produces haploid spores through meiosis. Spores then develop into the gametophyte. Examples include *Cladophora*.

Cyanobacterium are marine blue-green photosynthetic algae which belong to family Cyanophyceae These slow-growing prokaryotes play a crucial role via producing atmospheric oxygen and several active secondary metabolites(i.e., rifamycin, lovastatin, vancomycin, and bleomycin) with different therapeutic properties such as antiinflammatory, antibacterial, antidiabetic, and anticancer activities.They form a component of the base of the aquatic food chain, and their photosynthetic activity aerates the habitat. Hence, they are of great importance in aquaculture. Spirulina and Nostoc commune are sources of single cell proteins, edible to man.

Nitrogen fixing forms (Anabaena, Nostoc, etc) increase the nitrogen content of the habitat and supply nitrates in symbiotic relationships where they enhance the nutritive quality of the host plant, which could be used as green manure, fodder, and fish feed. Some act as bio-fertilizers, a fact that can be utilized effectively in improving plant nutrition, especially in rice and wheat production. As producers of growth hormones, they improve yield of rice (e.g. Phormidium tenue). Consequently they are essential in rice based economies. Some are capable of producing antibiotics (Microcystis, Nostoc and Scytonema). Cyanobacteria prevent soil erosion; help in soil water retention, sodium removal and act as the first colonizers in land reclamation

UNIT 1 : INTRODUCTION

Structure

1.1 Introduction

Algae (singular: alga) are organisms that belong to Domain Eucarya and are distinct from animals by being photosynthetic. However, they differ from the vascular plants by lacking true roots, stems, and leaves. They are the members of a group of predominantly aquatic photosynthetic organisms of the kingdom **Protista**. Algae have many types of **life cycles**, and they range in size from microscopic *Micromonas* **species** to giant **kelps** that reach 60 metres (200 feet) in length.

Their photosynthetic pigments are more varied than those of **plants**, and their cells have features not found among plants and **animals**. In addition to their ecological roles as **oxygen** producers and as the food base for almost all aquatic life, algae are economically important as a source of **crude oil** and as sources of food and a number of pharmaceutical and industrial products for humans. The **taxonomy** of algae is **contentious** and subject to rapid change as new molecular information is discovered. The study of algae is called **phycology**, and a person who studies algae is a phycologist.

Objectives

This is the first unit on Introduction of block first (Algae-I). Under first unit, we have following objectives. These are as under:

- To know about **unique features/principle of algae**
- To know about classification, characteristics and distribution of algae
- To know about pigments composition and significance of algal pigments
- To discussalgal reproduction and life cycle of algae and applications of photobioreactor

These are the simple living organisms that have chlorophyll. They are the simplest forms of producers in a food chain. They can be single-celled or multicellular. Known to be largely aquatic, algae have a thalloid structure, without much differentiation. You can find algae in a variety of habitats such as freshwater, marine, moist stones, wood, and even soil. A mutual association is found in between fungi and algae, leading to an entirely new organism called the lichens. What is more interesting about algae is that they are economically very important. They are a source of crude oil and also for many pharmaceutical and industrial products that are used by humans.

1.2 UNIQUE FEATURES/PRINCIPLE OF ALGAE

Algae can be microscopic or even as large as 60 meters in length. They can exist singly or in colonies like the Volvox or may be unicellular like Chlamydomonas or may even have a filamentous structure like Spirogyra and Ulothrix. The unique feature of algae is the ability to perform photosynthesis. This is what differentiates them from other organisms and is also the main reason for their inclusion in the plant kingdom. The mode of nutrition is naturally autotrophic mode.They are subdivided into two parts: Microalgae and the other is Macroalgae.

1. **Microalgae:** It is the unicellular form of algae.
2. **Macroalgae:** It is the multicellular form of algae.

Microalgae are photosynthetic, heterotrophic organisms that have an extraordinary potential for cultivation as energy crops. Algae has its nature that it can grow or can be cultivated under any difficult climatic conditions. Algae produce various commercial by-products such as fats, oils, sugars, and other useful bioactive compounds. The term also includes some members of the red, brown, and green algae. They are photosynthetic in nature and "simple" because they don’t possess the bunch of complicated organs as found in land plants. Hence they are excluded from being considered as plants.

The mode of reproduction that is found in algae is either by vegetative mode or asexual mode or sexual mode. Vegetative reproduction occurs by fragmentation wherein each fragment develops into a thallus. Asexual reproduction occurs by the production of spores, called the zoospores. These zoospores have flagella that make them motile. On germination, they give rise to new plants. Through the fusion of gametes, sexual mode of reproduction occurs in some algae. Depending on the size of the gametes fusing, sexual reproduction could be of isogamous(similar size), or anisogamous (dissimilar size) or oogamous, when a large female gamete and a smaller male gamete fuse.Algae are mostly aquatic organisms. They are present in both fresh and marine water. Algae may also be:

- **Epiphytes:** These algae grow on the surface of other plants. (Ulothric)
- **Endophytes:** These algae live inside the other plants. (Ulvellaleptochaete)

- **Phytoplankton:** The free floating algae are phytoplankton. (diatoms)
- **Sessile:** Some algae are attached to the substratum by holdfast. (Chara)
- **Lithophytic:** Algae growing on surface of rocks and stones are lithophytic (polysiphonia)
- **Halophytic:** Algae growing in water of concentration of salts as in salt lakesare halophytic algae e.g., Chlamydomonas ehrenbergii, Ulothrix
- **Thermophytic:** The thermophytic algae grow in water of high temperature where other plant forms cannot grow. (Cyanobacteria- Hyperthermae above 70°C)
- **Cryophytic:** Algae occurring in snow and ice are cryophyticalgae.(Chlamydomonas nivalis)
- **Epizoic:** on other animals, e.g., Cladophora crisposa grows on snails
- **Endozoic:** Inside the body of animals e.g., Zoochlorellae is found in Hydra.
- **Parasitic:** Some algae can be found as parasites on plants and animals e.g., Cephaleuros is found on leaves of tea, coffee.
-

1.3 CLASSIFICATION

Taxonomic classification of algae is based upon the same rules that are used for the classification of land plants. Microscopic research has shown differences in the features of algae which contributes to another method of their classification. Various features that differentiate various types of algae are: organelle structure, flagellar apparatus, and cell division process. Division-level classification (kingdom-level classification) is negligible for algae. Some scientists place classes like Xanthophyceae, Bacillariophyceae, in division Chromophyta, whereas some scientists place each class in the division: xanthophyll, Bacillariophyceae. In general and widely accepted terms, the classification of algae is done based on the following six types:

1. **Nuclear Organization** – prokaryotic or eukaryotic
2. **Nature of Cell Wall** – cellulosic or non-cellulosic (protein, acid, polysaccharide)
3. **Pigmentation and Photosynthetic Apparatus** – 3 pigments (chlorophylls, carotenoids, and lipoproteins)
4. **Nature of Reserve Food** – Starch, oil, mannitol, leucosis, etc. is the various types of reserve food in various classes.
5. **Flagellation** – Type, number, and position of flagella determine the class.
6. **Type of Life Cycle** – complete absence or presence and the complexity of cycle.

In the 5-kingdom scheme of classification, the algae, together with the protozoa, belong to Kingdom Protista. They are distinct from the protozoa by being photosynthetic. The algae are further grouped into various phyla and the suffix *O–phyta* is used in the classification of algae: Euglenophyta (euglenids), Chrysophyta (diatoms),Pyrrophyta(dinoflagellates), Chlorophyta (g reen algae), Phaeophyta (brown algae), and Rhodophyta (red algae). The Cyanophyta or blue-green algae, which are prokaryotic organisms, are traditionally included in this group but in modern classification, they are now grouped together with bacteria under Kingdom Monera. It should be noted, however, that the taxonomic classification of organisms is bound to change as further studies of the species would lead to a newer system of classification, such as that in The NCBI taxonomy database.

1.4 CHARACTERISTICS OF ALGAE

Morphology

The basic feature characterizing the algae is being aquatic and photoautotrophic eukaryotes. All species are photosynthetic and they have relatively simple anatomy compared with the other phototrophic eukaryotes. Nevertheless, their body plan could range from single-celled to colonial, to multicellular. Most of the algal species are unicellular. Some of them are non-motile whereas others are motile (flagellated). Some of them live independently while others form colonies or filaments. Multicellular forms have a somewhat complex structure that is organized into parts performing distinct functions. However, the body parts are organ-like and are not specialized into true leaves, stems, and roots as seen in bryophytes and tracheophytes. Nevertheless, algae have a cell wall similarly made up largely of cellulose. However, their cell wall also contains pectin, which renders algae somewhat *slimy*.

Nutrition

Although most algae are phototrophic (relying on energy derivation from photosynthesis), some of them are mixotrophic, and others, heterotrophic. Mixotrophic algae obtain energy both via photosynthesis and organic carbon uptake (e.g. by osmotrophy, phagotrophy, and mixotrophy). Others lack the pigments and thereby became colorless and heterotrophic.

Reproduction

The mode of reproduction may also vary. Some of them reproduce asexually whereas others, by sexual reproduction. Algal groups such as red algae and green algae have both in their life cycle. The asexual phase is when the organism is in a diploid condition whereas the sexual phase is when it is in a haploid condition. Two haploid organisms fuse forming a diploid zygote.

Ecology

Algae are abundant and diversely distributed. They live especially in moist and aquatic habitats. Thus, they are found to thrive in freshwater, marine water, and moist terrestrial habitats. Nutrients and light largely influence Their abundance. Thus, there are instances when nutrients abound, their number could also become large enough to cause the so-called *algal blooms* or *red tides*.

Algal groups

The photosynthetic pigments are used as a basis to classify algae into major groups, particularly green algae, red algae, brown algae, and golden algae. Blue-green algae (Cyanophyta) are not considered by others as algae but rather include them together with bacteria under Kingdom Monera.

Green algae

Green algae refer to any of the photosynthetic algae characterized by containing the pigments, *chlorophyll a* and *chlorophyll b*. They store food as starch within plastids. They have diverse forms: unicellular (e.g. *Micrasterias* sp.), multicellular, or colonial. Multicellular forms are those that appear filamentous or form leaf-like thallus (e.g. *Ulva* sp.). Some of them form colonies, such as *Volvox* sp. Green algae include charophytes (mostly in freshwater habitats) and chlorophytes (mostly marine). There are also green algae that live in terrestrial habitats (e.g. soil, rocks, and trees). Certain green algal species have been found to form symbiosis on land. For instance, *Chlorella* sp. forms a symbiosis with *Hydra* sp.

Red algae

Red algae are those belonging to the phylum Rhodophyta. They are characterized by their reddish color due to the presence of accessory pigments, such as phycoerythrin, phycocyanin, and allophycocyanins in phycobilisomes, aside from the chlorophyll. Examples of red algae are *Rhodella*, *Compsopogon*, *Stylonema*, *Bangia*, *Porphyra*, *Porphyridiumcruentum*, *Hildenbrandia*, *Nemalion*, *Corallina officinalis*, *Ahnfeltia*, *Gelidium*, etc.

Brown algae

Brown algae include those of the phylum Phaeophyta. They are characterized by their brown or greenish-brown color due to the presence of brown pigments, such as fucoxanthin, in addition to chlorophyll. Apart from Phaeophyta, other phyla that have predominant brown pigment apart from chlorophyll are Dinoflagellata (dinoflagellates) and olive-brown Bacillariophyta (diatoms).

Golden algae

Golden algae are those belonging to the phylum Chrysophyceae. They are distinguished mainly by the presence of two specialized flagella wherein one has mastigonemes and the other is smooth. *Prymnesium parvum* is one of the well-known golden algae due to its association with fish kills.

Bluegreen algae

The blue-green algae include the members of the Cyanophyta. They are not considered by other references as algae since they are prokaryotes. Nevertheless, they are similar to other algal species in being photosynthetic due to the presence of chlorophyll. Aside from this pigment, the blue-green algal cell also has phycobiliproteins that make them blue-green in color.

Occurrence of Algae

Algae are commonly presumed to be occurring in water and moist places but algae are found in a variety of habitats.The common places of occurrence of algae are as follows:

(i) Aquatic Algae:

Aquatic algae can be:

(a) Fresh water forms

(b) Marine forms.

(a) Fresh water forms:

Fresh water forms are found in water of low salinity such as in ponds, lakes, rivers, ditches etc. Cladophora, Vaucheria, Chara and some algae found in slow running water while Spirogyra, Chlamydomonas, Hydrodictyon and Volvox are found in stagnant water.

(b) Marine forms:

The algae found in sea water are called marine algae. Such algae grow in water of high salinity. Marine algae can be macroscopic and very large in size e.g., Macrocystis (70 meters) and Nereocystis (100 meters). Some other examples of marine algae are: Enteromorpha, Sargassum, Fucus, Polysiplionia, Gelidium and Gracilaria etc.

(ii) Terrestrial Algae:

Algae growing on moist soil surface, stones and rocks are terrestrial algae. The algae growing on surface of soil are called saprophytes and the algae growing under the surface of soil are called cryptophytes. Some terrestrial algae grow on moist walls and barks of trees. These algae absorb CO_2 and water from atmosphere. Some common terrestrial algae are:Fritschiella, Vaucheria, Chlorella, and Oscillatoria.

(iii) Lithophytic Algae:

Algae growing on surface of rocks and stones are lithophytic e.g., Nostoc, Gloeocapsa.

(iv) Halophytic Algae:

Algae growing in water of high concentration of salts as in salt lakes are halophytic algae e.g., Chlamydomonas ehrenbergii and Dunaliella.

(v) Thermophytic Algae:

The thermophytic algae grow in water of high temperature where other plant forms cannot grow. Some blue green algae are capable of growing at very high temperature because of unorganized nucleus. The thermal algae found in hot water springs are Oscillatoria terebriformis, Heterohormogonium, Synechococcus, Scytonema etc.

(vi) Cryophytic Algae:

Algae occurring in snow and ice are cryophytic algae. These algae impart special colours to snow due to their pigments. Red snow is caused by Haematococcus nivalis and Chlamydomonas nivalis. Green snow is caused by Chlamydomonas yellowstonensis. Purple brown snow is caused by Ancyclonemanordensklioldii. Black snow is caused by Raphidonema.

(vii) Epiphytic Algae:

Algae growing on other algae and plants are called epiphytic algae e.g., Polysiphonia, Oedogonium are found growing on other algae, bryophytes and aquatic angiosperms.

(viii) Epizoic Algae:

Algae growing on other animals are called epizoic algae e.g., Cladophora crisposa grows on snails, Stigeoclonium grows on gills of fishes.

(ix) Endophytic Algae:

Algae growing inside other plants are called endophytic algae e.g., Nostoc is found in thallus of Anthoceros, Anabaena cycadearum is found in coralloid root of Cycas, Anabaena azollae is found in Azolla.

(x) Endozoic Alga:

Algae found inside the body of animals are endozoic algae e.g., Zoo chlorella is found in Hydra and sponges. Some blue green algae are found in respiratory and digestive tracts of animals.

(xi) Parasitic Algae:

Some algae can be found as parasites on plants and animals e.g., Cephaleuros is found on leaves of tea, coffee and mango plants and causes red rust. Polysiphonia fastigiate is semi-parasitic on algae Ascophyllum.

(xii) Symbiotic Algae:

Some algae of Chlorophyceae and Cyanophyceae are found in symbiotic association with other plants. Nostoc and Anabaena make symbiotic association with Anthoceros and coralloid roots of Cycas. Lichens are symbiotic association of algae and fungi.

(xiii) Planktons:

Algae growing on surface of water and found as free floating on surface of water are called planktons. Planktonic algae are mainly members of Chlorophyceae, Cyanophyceae and Bacillariophyceae. When planktonic algae grow fast and increase enormously in number, these algae form water blooms.

Flagella in Algae:

The motile members of algae, zoospores and gametes have one or more flagella which are organs of motion. Flagella are absent in members of Cyanophyceae and Rhodophyceae. Flagella are uniform or thread-like protoplasmic appendages. All flagella are uniform in their internal structure. Each flagellum is made of two central tubules surrounded by nine peripheral tubules. The structure of 9 + 2 is surrounded by a membrane. In different algal groups flagella differ in number, size, location and types.

1.5 DISTRIBUTION OF ALGAE

Algae can be aquatic or subaerial, when they are exposed to the atmosphere rather than being submerged in water. Aquatic algae are found almost anywhere from freshwater spring to salt lakes, with tolerance for a broad range of pH, temperature, turbidity, and O2 and CO2 concentration. They can be planktonic, like most unicellular species, living suspended throughout the lighted regions of all water bodies including under ice in polar areas. They can be also benthic, attached to the bottom or living within sediments, limited to shallow areas because of the rapid attenuation of light with depth. Benthic algae can grow attached on stones (epilithic), on mud or sand (epipelic), on other algae or plants (epiphytic), or on animals (epizoic).

In the case of marine algae, various terms can be used to describe their growth habits, such as supralittoral, when they grow above the high-tide level, within the reach of waves and spray; intertidal, when they grow on shores exposed to tidal cycles: or sublittoral, when they grow in the benthic environment from the extreme low-water level to around 200 m deep, in the case of very clear water.Oceans covering about 71% of earth's surface contain more than 5000 species of planktonic microscopic algae, the phytoplankton, which forms the base of the marine food chain and produces roughly 50% of the oxygen we inhale.

However, phytoplankton is not only a cause of life but also a cause of death sometimes. When the population becomes too large in response to pollution with nutrients such as nitrogen and phosphate, these blooms can reduce the water transparency, causing the death of other photosynthetic organisms. They are often responsible for massive fish and bird kills, producing poisons and toxins. The temperate pelagic marine environment is also the realm of giant algae, the kelp. These algae have thalli up to 60 m long, and the community can be so crowded that it forms a real submerged forest; they are not limited to temperate waters, as they also form luxuriant thickets beneath polar ice sheets and can survive at very low depth.

The depth record for algae is held by dark purple red algae collected at a depth of 268 m, where the faint light is blue-green and its intensity is only 0.0005% of surface light. At this depth the red part of the sunlight spectrum is filtered out from the water and sufficient energy is not available for photosynthesis. These algae can survive in the dark blue sea as they possess accessory pigments that absorb light in spectral regions different from those of the green chlorophylls a and b and channel this absorbed light energy to chlorophyll a, which is the only molecule that converts sunlight energy into chemical energy.

1.6 ALGAL PIGMENTS

Three major classes of photosynthetic pigments occur among the algae: chlorophylls, carotenoids (carotenes and xanthophylls) and phycobilins. The pigments are characteristic of certain algal groups as indicated below. Chlorophylls and carotenes are generally fat soluble molecules and can be extracted from thylakoid membranes with organic solvents such as acetone, methanol or DMSO. The phycobilins and peridinin, in contrast, are water soluble and can be extracted from algal tissues after the organic solvent extraction of chlorophyll in those tissues. The rationale behind the extraction techniques is to disrupt cell integrity as much as possible, thereby removing pigment molecules from intrinsic membrane proteins. Freezing the tissue with liquid nitrogen, and grinding the still frozen tissue in with a mortar and pestle or blender, overcomes some of the problems of working with material that produces large amounts of viscous polysaccharides. “Freeze-thawing” tissue also breaks down cellular membranes, but may liberate more polysaccharides.

Finely ground tissue can be then homogenized in organic solvent to further disrupt cellular membranes, and to liberate pigment molecules from the light harvesting pigment protein complexes. Once the pigments are extracted into appropriate solvents they can be separated chromatographically by TLC or HPLC for spectral analysis and identification. Pigment concentrations in hydrocarbon solvents can be estimated; however, these formulas are predictive, and may overestimate some pigment concentrations. Uncoupling pigments from the pigment binding proteins can change the absorption patterns of the pigments, resulting in shifts in maxima from 10 to 50 nm, when compared with spectra measured for intact tissues.

1.7 PIGMENTS COMPOSITION

The colour of the algal thallus which varies in different classes of algae is due to the presence of definite chemical compounds in their cells. These are called pigments. Each pigment has its own characteristic colour. The particular colour that a thallus has is due to the predominance of one pigment in combination with several others. For example brown algae have predominance of Fucoxanthin and phycophenin while red algae and blue green algae have phycoerythrin and phycocyanin respectively. Each group of algae has its own particular combination of pigments and characteristic colour which is not found in other group.

The photosynthetic pigments of algae are of three kinds – Chlorophylls, Carotenoids and Phycobillins or Billoproteins. Chlorophyll pigments are fat soluble compounds and are of five different types, i.e., chlorophyll a, b, c, d and e. Out of these, chlorophyll a is universally present in all the groups of algae whereas chlorophyll b, c, d and e have restricted distribution. Carotenoids are fat soluble yellow coloured pigments and are subdivided into carotene, xanthophylls and carotenoid acids. Phycobillins are water soluble blue (phycocyanin) and red (phycoerythrin) coloured pigments and are present in Cyanophyceae and Rhodophyceae.

Divison	**Common name**	**Major accessary pigments**
Chlorophyta	Green algae	Chlorophyll b
Charophyta	Charophytes	Chlorophyll b

Euglenophyta	Euglenoids	Chlorophyll b
Phaeophyta	Brown algae	Chlorophyll c1 + c2, fucoxanthin
Chrysophyta	Yellow-brown or golden-brown algae	Chlorophyll c1 + c2, fucoxanthin
Pyrrophyta	Dinoflagellates	Chlorophyll c2, peridinin
Cryptophyta	Cryptomonads	Chlorophyll c2, phycobilins
Rhodophyta	Red algae	Phycoerythrin, phycocyanin
Cyanophyta	Blue-green algae	Phycocyanin, phycoerythrin

Table: Pigment composition of several algal groups

1.8 SIGNIFICANCE OF ALGAL PIGMENTS

The Chlorophyceae contain chlorophyll *a* and *b*, zeaxanthin and lutein, together with a minor proportion of less typical carotenoids. In general the quantities and proportions do not diverge greatly from those found in higher plants; green algae cultured under abnormal or artificial conditions often develop unusual pigmentation though experience is here rather limited. In view of what has become known of the role played by carotenoids in the sexual reproduction of *Chlamydomonas eugametos*, particular interest is attached to the differential pigmentation of gametes, antheridia and oogonia of many of the Chlorophyceae.

Quantitative and qualitative examination of Xanthophyceae, Chrysophyceae, Dinophyceae, Cryptophyceae, Chloromonadineae and Euglenineae is less complete, but it is certain that chlorophyll *a*, carotenes, and xanthophylls are still the main pigments though other carotenoids which have hitherto appeared to be characteristic of other algal classes (e.g. fucoxanthin) or higher plants (e.g. flavoxanthin and taraxanthin) are occasionally encountered. Some of the algae of these classes contain characteristic carotenoids (diato- and diadinoxanthin in diatoms, peridinin and dinoxanthin in dinoflagellates) though their general distribution has yet to be examined; the detailed chemical nature of these materials remains obscure, and its elucidation is complicated by the pigments assuming labile forms which may be present in the algae or formed by chemical treatment.

The diatoms are distinguished also by chlorophyll *c* which has been found as well in some of the Phaeophyceae. The brown algae have long been thought to contain no more than traces of chlorophyll *b*, a view substantiated by modem analyses, so that the new chlorophyll may replace chlorophyll *b* of other algae and higher plants, and is perhaps to be correlated with photosynthetic activity as indicated by typical reserve materials. The Phaeophyceae, in addition to carotenoids common to most algae, are characterized by fucoxanthin and nearly related pigments which assume a degree of photo-synthetic activity: quantitatively, however, the brown algae are not richer in carotenoids when compared with other algae, for an excess of fucoxanthin is balanced by a deficiency in other polyene pigments.

The Rhodophyceae contain no chlorophyll *b*, but here the deficiency is to some extent made good by a recently discovered pigment, chlorophyll *d*. The total chlorophyll content is nevertheless low compared with that of the green algae, part of the photosynthetic activity being due to phycobilins which occur also in the Cyanophyceae. The blue-green algae are in turn outstanding in exhibiting a series of new carotenoids, perhaps of photosynthetic value; of these myxoxanthin and myxoxanthophyll seem to be as characteristic of the Cyanophyceae as, for example, fucoxanthin is of the Phaeophyceae.

1.9 ALGAL REPRODUCTION AND LIFE CYCLE

Algae regenerate by sexual reproduction, involving male and female gametes (sex cells), by asexual reproduction, or by both ways. Asexual reproduction is the production of progeny without the union of cells or nuclear material. Many small algae reproduce asexually by ordinary cell division or by fragmentation, whereas larger algae reproduce by spores. Some red algae produce monospores (walled, nonflagellate, spherical cells) that are carried by water currents and upon germination produce a new organism. Some green algae produce nonmotile spores called aplanospores, while others produce zoospores, which lack true cell walls and bear one or more flagella. These flagella allow zoospores to swim to a favourable environment, whereas monospores and aplanospores have to rely on passive transport by water currents.

Sexual reproduction is characterized by the process of meiosis, in which progeny cells receive half of their genetic information from each parent cell. Sexual reproduction is usually regulated by environmental events. In many species, when temperature, salinity, inorganic nutrients (e.g., phosphorus, nitrogen, and magnesium), or day length become unfavourable, sexual reproduction is induced. A sexually reproducing organism typically has two phases in its life cycle. In the first stage, each cell has a single set of chromosomes and is called haploid, whereas in the second stage each cell has two sets of chromosomes and is called diploid. When one haploid gamete fuses with another haploid gamete during fertilization, the resulting combination, with two sets of chromosomes, is called a zygote.

Either immediately or at some later time, a diploid cell directly or indirectly undergoes a special reductive cell-division process (meiosis). Diploid cells in this stage are called sporophytes because they produce spores. During meiosis the chromosome number of a diploid sporophyte is halved, and the resulting daughter cells are haploid. At some time, immediately or later, haploid cells act directly as gametes. In algae, as in plants, haploid cells in this stage are called gametophytes because they produce gametes. The life cycles of sexually reproducing algae vary; in some, the dominant stage is the sporophyte, in others it is the gametophyte. For example, *Sargassum* (class Phaeophyceae) has a diploid (sporophyte) body, and the haploid phase is represented by gametes. *Ectocarpus* (class Phaeophyceae) has alternating diploid and haploid vegetative stages, whereas *Spirogyra* (class Charophyceae) has a haploid vegetative stage, and the zygote is the only diploid cell.

In freshwater species especially, the fertilized egg, or zygote, often passes into a dormant state called a zygospore. Zygospores generally have a large store of food reserves and a thick, resistant cell wall. Following an appropriate environmental stimulus, such as a change in light, temperature, or nutrients, the zygospores are induced to germinate and start another period of growth. Most algae can live for days, weeks, or months. Small algae are sometimes found in abundance during a short period of the year and remain dormant during the rest of the year. In some species, the dormant form is a resistant cyst, whereas other species remain in the vegetative state but at very low population numbers. Some large, attached species are true perennials. They may lose the main body at the end of the growing season, but the attachment part, the holdfast, produces new growth only at the beginning of the next growing season.

1.10 Life Cycle of Algae

The life cycle of algae varies depending on the species, and there are four basic life cycle patterns in algae. There is an alternation of generations in all four patterns, indicating different haploid and diploid stages. In all life cycles, the haploid stage indicates gametophyte, while the diploid stage indicates saporophyte.

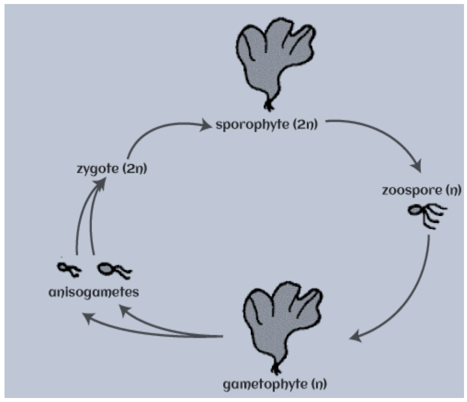

Fig. 1.1 Life cycle of algae

Haploid refers to a cell or organism that contains a single set of chromosomes. Moreover, the organisms that reproduce asexually are called haploids. On the other hand, the organisms that reproduce sexually are called diploids, having two sets of chromosomes. Similarly, one such example can be seen in humans where only eggs and sperm cells are haploid cells, which produce diploid cell (zygote) after fertilization.

1.11 TYPES OF LIFE CYCLE IN ALGAE

Four major types of life cycles in Algae are described below:

1. Haplontic Life Cycle:

In the Haplontic life cycle, the plant body is called gametophyte (haploid). In contrast, the sporophyte (diploid) stage is exclusively represented by the zygote. In the gametangium, the gametophytic plant produces haploid gametes. The fusion of gametes culminates in the development of the zygote, which is the sole diploid stage of this life cycle, i.e. the sporophytic phase.The zygote divides into four meiospores during meiosis. These meiospores become haploid plants as they mature. The number of chromosomes can be used to interpret the alternation of generations.

The ***monogenic life cycle*** is another name for this life cycle. The majority of Chlorophyceae, such as Chlamydomonas, Ulothrix, Oedogonium, Spirogyra, Chara, and others, as well as all members of the Xanthophyceae, have this type (haplontic) of life cycle.

2. Diplontic Life Cycle:

Diplontic is multicellular sporophyte stage. In this type of life cycle, the sporophyte develops sex organs. Mitosis is the process by which sex organs create gametes. The gamete represents only the gametophytic stage; the gametes are quickly fertilised and form a zygote. The zygote does not go through meiosis and produces sporophytic plant bodies.

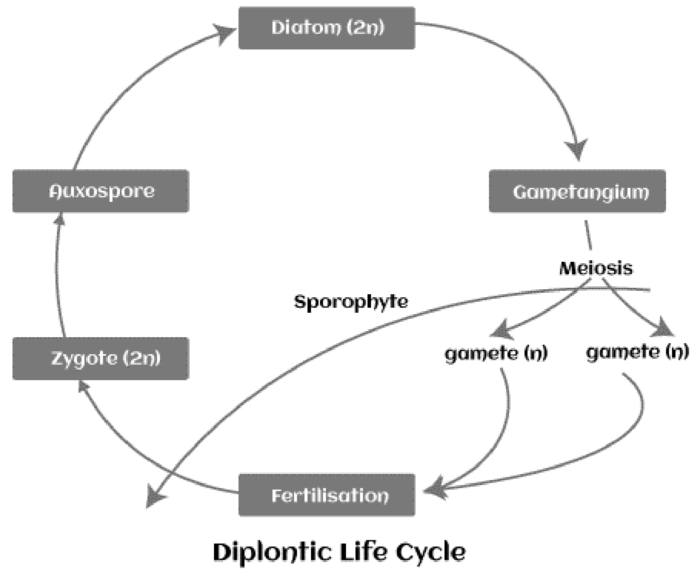

Fig.1.2 Diplontic Life Cycle

The majority of Bacillariophyceae members and some Chlorophyceae members like Cladophora glomerata show this type of life cycle. Furthermore, the diplontic life cycle can also be found in Phaeophyceae plants such as Fucus and Sargassum.

3. Diplohaplontic Life Cycle:

The haploid and diploid phases are equally dominant in this life cycle, which two vegetative individuals represent. Only the number and function of their chromosomes differ.

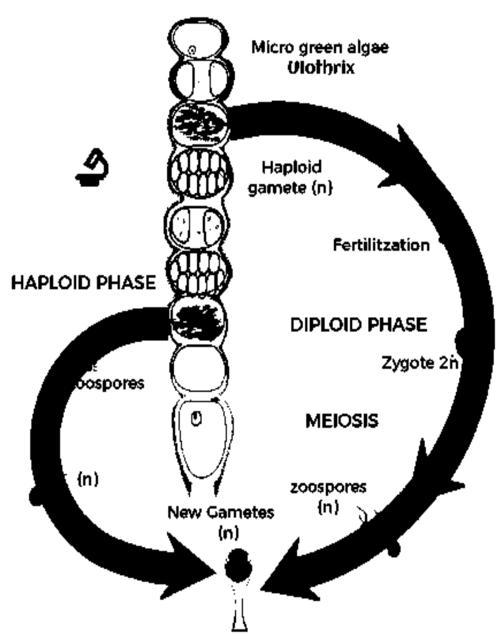

Fig.1.2

The haploid gametophytic plant reproduces sexually, whereas the diploid sporophytic plant reproduces asexually. The two different vegetative individuals alternate with each other or sporogenic meiosis alternates with gametes fusion in this life cycle.

1.12 ECONOMIC IMPORTANCE OF ALGAE

According to some scientists, algae produce half of the earth's **oxygen**. And this production of oxygen is by far the most important contribution of algae. As mentioned in the beginning they are a source of crude oil. These algal biofuels could well be a replacement for the **fossil fuels**. Algae also play an effective role in keeping the atmospheric carbon dioxide stable and also using it efficiently. The food industry also uses some algae. Agar is obtained from Gelidium and Gracilaria and is making ice-creams and jellies. The other food supplements that are algae and which are widely used are Chlorella and Spirulina. Some important economic importances of algae are as given below.

- **Algae as primary producers-** algae provides the base or beginning of most aquatic animals or organisms because of their photosynthetic activities so it is also known as **primary producers** of organic matter.
- **Commercial products from algae-** many products are derived from algal cell wall for economic value. Three of these are: **Agar Alginic Acid**, and **Carrageenan**, are produced from the walls of algae.
- **Carrageenan** is produced from the walls of several red algae. Species of **Chondrus**, **Gigartina** are mostly used.
- Agar is well known as a solidifying agent in the preparation of microbiological media. It is obtained from red algae. Species of **Gelidium** and **Gracilaria** are extensively used.
- **Alginic acid** and its salts are obtained from the wall for brown algae. Species of brown algae producing this compound include- **Macrocystis**, **Laminaria**, **Fucus**.
- **Algae as food-** many species of algae are (mostly red and brown algae) are used as food in the far east.
- Red algae one of the most important is **Porphyra:** it is used as food in Japan where it is called
- Other red algae such as **Chondrus, Nemalion** are locally collected and prepared.

1.13 ENVIRONMENTAL APPLICATIONS OF ALGAE

Algae as a Biofuel

A number of government agencies and companies are funding efforts to minimize operating and capital costs and make algae fuel production commercially viable. Attempts are being made to cultivate algae into large amounts for making bioethanol, biodiesel, biogasoline, biobutanol, biomethanol and other biofuels.Benefits of algal fuels are:

- They can be cultivated with minimal impact on fresh water resources
- Can be produced using waste and ocean water
- Are biodegradable and harmless to the environment even if spilled

Algae for Wastewater Treatment

The use of algae for wastewater treatment is more advantageous than conventional wastewater treatments. Some of the key benefits are:

- **Economical** – It is a cost-effective technique for the removal of phosphorus, nitrogen and pathogens when compared to sludge processes and other secondary treatment procedures.

- **Low Energy Requirements** – Conventional wastewater treatment processes involve aeration, which is energy intensive whereas, algae-based wastewater treatments produce oxygen that is needed for aerobic bacteria. Algae offers an efficient way for nutrient consumption and provide aerobic bacteria with oxygen through photosynthesis.
- **Reductions in Sludge Formation** – In traditional wastewater treatment facilities, the sludge obtained contains hazardous solid waste that finally finds its way to landfills. However, in algal wastewater treatment facilities, the resulting sludge with algal biomass has a large amount of energy that can be processed further to make fertilizers or biofuels. Algal technology does not use chemicals and the whole effluent treatment procedure is simple and results in minimum sludge formation.
- **GHG Emission Reduction** – According to the US EPA, conventional wastewater plants contribute significantly to greenhouse gases. Algae-based wastewater treatments release carbon dioxide but the consumption by algae is greater than what is released, making the whole system carbon negative.
- **Production of Useful Algal Biomass** – The algae biomass obtained is a source of biodiesel.

1.14 PHOTOBIOREACTOR OR ALGAE BIOREACTOR

A photobioreactor or an algae bioreactor is used to cultivate algae to produce biomass or fix carbon dioxide emissions. Algae bioreactors are used for the production of fuels such as bioethanol and biodiesel for the reduction of pollutants such as CO_2 and NOx in flue gases emitted from power plants. These photoreactors are based on the photosynthetic reaction performed by algae containing chlorophyll. With the help of sunlight and dissolved carbon dioxide, CO_2 is made accessible by dispersing it into the reactor.

Other Eco-friendly Applications

Other major environmental applications of algae are:

- Algae can be used for trapping fertilizers present in farm runoff. After harvesting they can be used as fertilizer.
- Since algae can grow in harsh conditions and do not require many nutrients they are cultivated in places that are not suitable for agricultural purposes therefore, they do not compete for arable land as well as use wastewater, not freshwater.
- Unlike row crops, algae do not depend on specific seasons. Algae can thrive wherever there are warm temperatures and plenty of sunlight.
- Algae are grown in seawater as well as in desert ponds. Algae can also grow in waste water and water containing phosphates, nitrates and other contaminants.
- Since algae are carbon neutral, it can help the environment by taking CO_2 from the air. Algae farms can be located near carbon producing refineries or power plants.

1.15 OTHER APPLICATIONS OF ALGAE

Algae are used in a number of other applications that are enumerated below:

- Algae can be cultivated for hydrogen generation. In 1939, German researcher, Hans Griffon discovered that the algae, Chlamydomonas reinhardtii, could be switched from oxygen to hydrogen production.

- Algaeis a complete protein containing important amino acids that are involved in metabolic processes such as enzyme and energy production. It has large amounts of complex and simple carbohydrates that provide the body with an additional fuel source. Specifically speaking, sulfated complex carbohydrates improve the regulatory response of the immune system. It also contains Omega 3 and Omega 6.
- Chondrus crispus or "carrageen"is a good stabilizer in milk products and reacts with casein, a milk protein that alginates in lotions and can be absorbed through the skin.
- Can be used as soil conditioners, fertilizers and as a livestock feed source. Since a number of species are microscopic and aquatic they are placed in ponds or clear tanks and harvested for the treatment of effluents pumped through ponds.
- Algae can also be used as sugar. Algae produce natural pigments that can be used instead of coloring agents and chemical dyes.
- Currently manufactured paper products are not easily recycled due to the chemical inks used. According to recyclers, algae inks are very easy to break down.
- The food sector is also attempting to replace the coloring agents presently used with coloring obtained from algal pigments.
- Algae can be used for medicine manufacture, sewage treatment and cosmetic manufacture.
- A green algae species grown in water tanks and exposed to sunlight and heat becomes bright red in color. This can be harvested and used as a natural pigment for foods such as Salmon.

1.16 SUMMARY

Under this unit we have summarized**unique features/principle of algae, classification & characteristics of algae, life cycle of algae and importance of algae etc.** In general algae can be referred to as plant-like organisms that are usually photosynthetic and aquatic, but do not have true roots, stems, leaves, vascular tissue and have simple reproductive structures. They are distributed worldwide in the sea, in freshwater and in moist situations on land. Algae are considered to be the most efficient biological system for harvesting solar energy and for the production of organic compounds via the photosynthetic process.

The life cycle of algae depends on the type of algae, and there are four main patterns of life cycles in algae. All four patterns exhibit an alternation of generations, which means that there are distinct haploid and diploid stages. In all cases, the haploid stage is referred to as the *gametophyte*, and the diploid stage is called the *sporophyte*.The gametophytic plant produces haploid gametes. The gametes fuse to form a zygote, which is diploid. Thus, diploid represents the sporophytic phase (diploid phase) of their lifecycle. This lifecycle is also known as the monogenic lifecycle and is found to be active in a majority of classes.*Haploid* means that the organism has only one set of chromosomes, and is often noted as "n." In contrast, *diploid* organisms have two sets of chromosomes, one from each parent, and the shorthand "2n" is used for this stage. The four main types of life cycles in algae are haplontic, diplontic, diplohaplontic and triphasic. Algae provide much of Earth's oxygen, serve as the food base for almost all aquatic life, and provide foods and industrial products, including petroleum products. Their photosynthetic pigments are more varied than those of plants, and their cells have features not found among plants and animals.

1.17 TERMINAL QUESTIONS

Q.1. What do you mean byunique features of algae? Explain it.

Answer:--
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Q. 2 Describe the algal pigments and pigment composition in algae.

Answer:--
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Q.3 Describe the environmental applications of algae.

Answer:--
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Q.4 Write short notes on the following.

(a) Photobioreactor

(b) Algal pigments

Answer:--
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Q.5 Write short notes on the pigments composition in algae.

Answer:--
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Q.6 Describe the life cycle of algae.

Answer:--
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Further readings

- Biochemistry- Lehninger A.L.
- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry and molecular biology- Wilson Walker

UNIT 2 : CYANOPHYCEAE I

Structure

2.1 INTRODUCTION

It is a primitive group of algae, consists of 150 genera and about 2,500 species. In India, the division is represented by 98 genera and about 833 species. Members of the class Myxophyceae (Cyanophyceae) are commonly known as blue green algae. The name blue green algae is given because of the presence of a dominant pigment c-phycocyanin, the blue green pigment. In addition, other pigments like chlorophyll a (green), c-phycoerythrin (red), β-carotene and different xanthophylls are also present. The members of this class are the simplest living autotrophic prokaryotes. They have the following important characteristics:

- Nucleus is of prokaryotic nature i.e., devoid of nuclear membrane and nucleolus,
- Absence of well-organised cell organelles, and
- Pigments are distributed throughout the chromoplasm (the outer part of protoplasm).

Depending on the above prokaryotic characteristics many microbiologists consider the members of Cyanophyceae as bacteria. Based on prokaryotic cell structure like bacteria, Christensen (1962) placed both Cyanophyta and bacteria under a common phylum Prokaryota. Cyanophyta or blue green algae have also been named as cyanobacteria.

Objectives

This is the second unit (Cyanophyceae-I) of Algae-I. Under second unit, we have following objectives. These are as under:

- To know about characteristics and occurrence of cyanophyceae
- To know about thallus organisation in cyanophyceae
- To discuss classification and characteristics of cyanobacteria
- To discuss reproduction in cyanophyceae

2.2 IMPORTANT CHARACTERISTICS OF CYANOPHYCEAE

The important characteristics of the division are as follows:

- The individual cells are prokaryotic in nature. The nucleus is incipient type and they lack membrane bound organelles.
- Both vegetative and reproductive cells are non-flagellate.
- Cell wall is made up of microfibrils and is differentiated into four (4) layers. The cell wall composed of mucopeptide, along with carbohydrates, amino acids and fatty acids.
- Locomotion is generally absent, but when occurs, it is of gliding or jerky type.
- The principal pigments are chlorophylls a (green), c-phycocyanin (blue) and c-phycoerythrin (red). In addition, other pigments like β-carotene and different xanthophylls like myxoxanthin and myxoxanthophyll are also present.
- Membrane bound chromatophore are absent. Pigments are found embedded in thylakoids.
- The reserve foods are cyanophycean starch and cyanophycean granules (protein).
- Many filamentous members possess specialized cells of disputed function (supposed to be the centre of N_2 fixation) known as heterocysts.
- Reproduction takes place by vegetative and asexual methods. Vegetative reproduction takes place by cell division, fragmentation etc. Asexual reproduction takes place by endospores, exospores, akinetes, nannospores etc.
- Sexual reproduction is completely absent. Genetic recombination is reported in 2 cases.

2.3 OCCURRENCE OF CYANOPHYCEAE

Members of Cyanophyceae are available in different habitats. Most of the species are fresh water (e.g., Oscillatoria, Rivularia), a few are marine (e.g., Trichodesmium, Darmocarpa), and some species of Oscillatoria and Nostoc are grown on terrestrial habitat. Species of some members like Anabaena grow as endophytes in thallus of Anthoceros (Bryophyta) and in leaves of Azolla (Pteridophyta) and Nostoc in the root of Cycas (Gymnosperm). Species of Nostoc, Scytonema, Gloeocapsa, and Chroococcus grow symbiotically with different fungi and form lichen. Some members like Nostoc, Anabaena etc. can fix atmospheric nitrogen and increase soil fertility.

2.4 THALLUS ORGANISATION IN CYANOPHYCEAE

Plants of this group show much variation in their thallus organisation. The thallus may be of unicellular or colonial forms:

1. Unicellular Form:

In unicellular form, the cells may be oval or spherical. Common members are Gloeocapsa, Chroococcus and Synechococcus.

2. Colonial Form:

In most of the members the cells after division remain attached by their cell wall or remain together in a common gelatinous matrix, called a colony. **The colonies may be of two types:**

- Non- filamentous, and
- Filamentous.

a. Non-Filamentous Type

The cells of this type divide either alternately or in three planes, thereby they form spherical (Gomphosphaera, Coelosphaerum), cubical, squarish (Merismopedia) or irregular colony.

b. Filamentous Type:

By the repeated cell division in one plane, single row of cells are formed, known as trichome. e.g., Oscillatoria, Spirulina, Arthosporia etc. The trichome when covered by mucilaginous sheath is called a filament. The filament may contain single trichome (Oscillatoria, Lyngbya) or several trichomes. The trichomes may be unbranched (Oscillatoria, Lyngbya), branched and falsely branched.

2.5 REPRODUCTION IN CYANOPHYCEAE

Members of Cyanophyceae reproduce by simple and primitive methods, i.e. by vegetative means and asexually. Sexual reproduction is completely absent in the cyanobacteria. - Cyanobacteria usually reproduce by vegetative methods like fragmentation when the condition is favourable and water is available. - When the methods are not unfavourable or water is not available, the cyanobacteria reproduce by spore formation such as akinetes, and endospores, and exospores. - These akinetes and spores lay dormant until favourable conditions and germinate as soon as the water is available to form the filament. Vegetative reproduction is generally in four ways:

(i) **Binary fission**: A cell divides into two in roughly equal halves. Each grows to original form. Here nucleus divides mitotically first and then the cytoplasm. This is the most common type.

(ii) **Fragmentation:**Filaments break into small pieces. Each piece grows into new filament. Mostly occurs in colonial forms.

(iii) **Hormogonia:**Trichomes break up within the sheath into short segments called hormogonia or hormogones. Hormogones can be 2-3 cells to several cells long. Any portion of the trichome may get abstracted as a hormogone (e.g. in Nostoc and Oscillatoria). Stigonema forms hormogonia on special branches. Sometimes these are motile and move away from parent filament.

(iv) **Hormocytes:** These multicellular structures have a thick and massive sheath. They are intercalary or terminal. They can germinate from either end or both ends thereby forming new filaments.

2.6 VEGETATIVE REPRODUCTION

It continues within the colony until such time as the moisture disappears. Then many of the cells form **spores.** These spores form the blackish mass seen in dry weather. These spores are capable of surviving drought and ultra violet radiation in the summer. These spores grown in spring and form new colonies.

2. **Hormogones formation:** It is the most common method of asexual reproduction in Nostoc. Hormogones are short length filaments. They develop into larger lengths by vegetative reproduction. Heterocysts are the point at which the filament breaks into hormogones. Hormogones may also formed by the breaking of filament or decay of filament at some other points. Hormogones may retain gelatinous envelope. But in some cases, hormogone come out of the gelatinous envelope and develop into new colony. In some cases, hormogone do not come out of the colony and grow to form new trichome within the parent colony. Thus a large number of trichomes are developed in the same colony.

3. **Akinetes or Anthrospores formation:**Akinetes are formed during unfavorable conditions. Akinetes are thick walled spores with a large amount of reserved food material. Their wall is two to three layers thick. They have granular protoplasm. Akinetes have reserved food material in the form of **cyanophycin starch grains.** Akinetcs are capable of forming new filaments. The Akinetes can survive dry conditions. These ultimately start new colonies elsewhere where rain comes.

4. **Ileterocysts:** Heterocysts are not common means of -eproduction in Nostoc. But in *Nostoc commune* heterocysts germinate to form new colony'. The contents of the heterocysts divide into two and then four cell germiling. The wall of heterocyst ruptures or dissolve and genniling cells come out. They germinate to develop new plant.

5. **Endospore formation:** Endospores may form in N. commune and *N. tnicroscpicum.* Endospores are formed by the division of content of heterocyst. They come out and develop new plant.

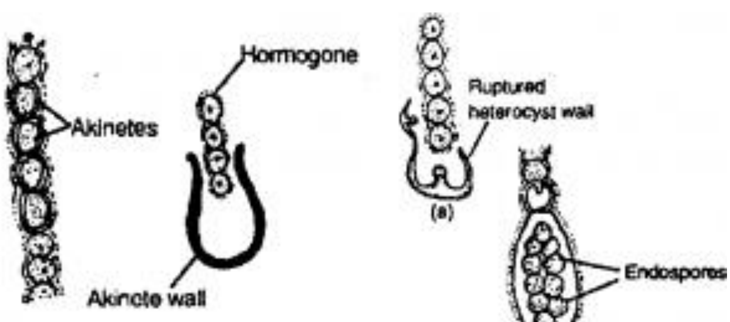

Fig. Akinete germination

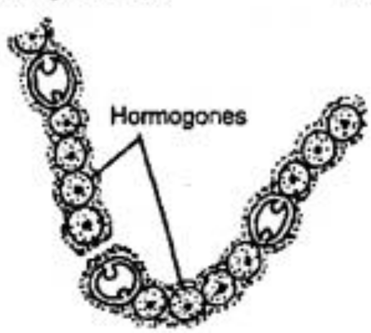

Fig. Hormogones

Fig.2.1 : Nostoc filament and nostoc colony

2.7 ECONOMIC IMPORTANCE OF NOSTOC

1. Nostoc contains protein and vitamin C.
2. Nostoc species are cultivated and consumed as a foodstuff, primarily in Asia. The *N. flagelliforme* and *N commune* varieties are consumed in 'China, Japan and Java, N. commune is also consumed in the Andes. The preferred variety in Central Asia is *N. ellipsosporunt.*
3. Fat choy (Nostoc flagelliforme) are abundantly consumed in china. But it has no nutritional value. It also contains Betamethylamino L-alanine (BMAA). a toxic amino acid. This amino acid can affect the normal functions of nerve cells. It may cause degenerative diseases such as Alzheimer's, Parkinson's, and dementia.

2.8 CLASSIFICATION OF CYANOBACTERIA

Cyanobacteria were previously known as Cyanophyta in the five-kingdom classification scheme and are one of the phyla of the Kingdom Protista. Euglenophyta, Chrysophyta, Pyrrophyta, Chlorophyta, Phaeophyta, and Rhodophyta are the other phyla.

- Because of their photosynthetic ability, these phyla are groups of plant-like protists.
- Cyanophyta (also known as blue-green algae) is now known as Cyanobacteria, a phylum of bacteria.
- This is due to the fact that this clade is made up of prokaryotic species.
- Blue-green algae are the only prokaryotic algae in phycology; the rest are eukaryotes.
- As a result, they are now classified as bacteria of the Phylum Cyanobacteria.
- Unlike embryophytes, they lack true roots, stems, and leaves.

The specific classification of cyanobacteria is as following;

- Kingdom - Monera
- Division - Eubacteria
- Class - Cyanobacteria
- Order -Nostocaceae
- Genus - Nostoc
- Common Name - Star Jelly

Sub-groups of Cyanobacteria

Based on morphology, cyanobacterial subgroups are classified as follows:

- Chroococcales
- Pleurocapsales
- Oscillatoriales
- Nostocales
- Stigonematales

2.9 CHARACTERISTICS OF CYANOBACTERIA

Cyanobacteria characteristics are as following;

- There is an immature nucleus present.
- The presence of a ribosome of the 70s type
- There is a gas vacuole present.
- They are autotrophic, and photosynthesis is accomplished through oxygenic photosynthesis.
- Double membrane-bound cell organelles such as the ER, Golgi body, and plastids are not present.
- There are no locomotory organelles present.
- Sexual reproduction is not present.
- Reproduction is completed through the asexual method.Unlike embryophytes, they lack true roots, stems, and leaves.
- a major concern for societies all over the world. Cyanobacteria can seriously compromise the safety of drinking water, as well as the value of fishing, irrigation, and recreational activities.
- Cyanobacteria deplete the oxygen in the water, cause toxins to be released, and degrade water quality.
- Cyanobacterial blooms cause fish and plants to suffocate and die.
- They endanger the water's quality and safety for animals and humans by releasing cyanotoxins into it.
- When the cyanobacteria in the bloom begin to decompose, they emit unpleasant tastes and odors.

2.10 CYANOBACTERIA ANDNUTRIENT POLLUTION

Cyanobacteria are actively exploiting human-caused water pollution. Nutrient pollution and eutrophication are beneficial to them.

- Nutrient contamination, salinization, and eutrophication of streams are all exacerbated by urban, agricultural, and industrial activity.
- Organisms become more common and chronic as a result of this.
- Cyanobacterial blooms are becoming more common as a result of climate change.
- More frequent and extensive cyanoHABs are induced by rising temperatures and changing precipitation patterns.
- Thermal stratification occurs early and lasts longer at higher temperatures, making them buoyant cyano bacillus more buoyant.

2.11 PHYLOGENY OF CYANOBACTERIA

Cyanobacteria are the oldest microorganisms performing oxygenic photosynthesis. Despite their morphological diversity, establishing a taxonomy that reflects evolutionary relationships has always been challenging.Cyanobacteria are known as architects of Earth's atmosphere. The global importance of cyanobacteria is well established because of their worldwide distribution and abundance in the myriad possible niche as well as their contribution to atmospheric oxygen. In spite of a long evolutionary history of cyanobacteria, only a fraction of their diversity has been addressed in recent times through molecular methods.

The classical taxonomy emphasized on the morphological identification of cyanobacteria. Although it provides critical information such as accurate taxonomic identification and quantitative data, the process is relatively time-consuming and requires experienced taxonomists. Also, certain noteworthy phenotypic changes, which may occur in natural assemblages as well as in laboratory environments,make the morphological identification often more challenging even to experienced taxonomists. In recent years, several valuable phenotypic, especially ultramorphological, features, such as cell wall perforations, have been confirmed to be stable and reliable taxonomic characters.

To reconstruct evolutionary relationships among cyanobacterial species, a specific set of marker genes usually 16S rDNA, rpoB, phycocyanin locus, internal transcribed spacer region, and nif genes, have been used widely in cyanobacteria. These specific target sequences represent variations and allow identification of similarities or dissimilarities in organisms. Therefore the molecular approaches applied, with classical single and multilocus phylogenetic taxonomy methods, on the one hand, and the rapid identification of cyanobacterial diversity within environmental samples, on the other, have been investigated with high-throughput next-generation sequencing methods, without considering their taxonomic status in depth.

Moreover, the molecular techniques, such as DNA barcoding, metagenomic analysis, and quantitative polymerase chain reaction (PCR), have also been applied for the identification and quantification of cyanobacteria. In the present scenario, completely sequenced genomes of several cyanobacterial species have uncut information about the cell. Therefore taxonomists have suggested that phylogenetic reconstructions should be considered more reliable to resolve phylogenetic interest, provided they are based on entire genomes. A multitude of taxonomists have used a varied number of genes for analysis, but very few have tried to combine data into a unified data set for a comprehensive analysis. In this context, combined analysis (analysis of extensive concatenated data set from several single-gene data sets) has been suggested in cyanobacteria, which up until recently has been applied only intermittently.

2.12 CHROOCOCCIA/CHROOCOCCUS

Chroococcus (Gr. chroo, **color**. coccus, **berry**) are predominantly freshwater alga. It is found in damp places such as moist soil, tree trunks, moist walls, and rocks. This genus is represented by 250 species. They are either free-floating or form a thin layer on the soil. Chroococcus is a genus of cyanobacteria belonging to the family Chroococcaceae. As a result of recent genetic analyses, several new genera were erected from this genus: e.g., Limnococcus. The genus has a cosmopolitan distribution.

Species:

The important species of Chroococcus are as given below.

- *Chroococcusbatavus*
- *Chroococcuscimneticus*
- *Chroococcuscohaerens*
- *Chroococcusyellowstonensis*

- *Chroococcus minor*
- *Chroococcushansgirgi*

Scientific classification

Domain:	Bacteria
Phylum:	Cyanobacteria
Class:	Cyanophyceae
Order:	Chroococcales
Family:	Chroococcaceae
Genus:	*Chroococcus* Nägeli, 1849

Chroococcus Characteristics

There are many marine and brackish species (with salinity less than in the marine environment; generally, less than two percent). They often form blooms, especially duringwarm months of the year. The cells are single or united into spherical colonies, each containing a small number of cells. Some common species are *C. limneticus*, *C. turgidus*.

Chroococcus Classification

- **Class:** Cyanophyceae
- **Order:** Chroococcales
- **Family:** Chroococcaceae
- **Genus:** *Chroococcus*

ChroococcusSp Plant Body

The genus *Chroococcus* consists of many algae species with rounded or spherical cells. Some species may contain solitary cells, but families of 4 to 16 individual cells are mostly found. Each cell of the colony is independent and is enveloped in a gelatinous mass. Reserve food material is a glycogen-like substance along with some oil drops. Mitochondria, endoplasmic reticulum, and Golgi bodies are also absent.

Reproduction in Chroococcus Algae

- The reproduction takes place by cell fission only.
- The newly formed cells do not separate immediately but remain held together in mucilaginous covering forming non-filamentous colonies of 2-4 cells.
- A cell may divide in three different directions. Cells grow in size and become independent. Only in rare cases, nannocytes have also been found.

- The characteristic feature of this class is the absence of Sexual reproduction and motile reproductive structures.

2.13 GLOEOTRICHIA

Gloeotrichia is a large (~2 mm) colonial genus of Cyanobacteria, belonging to the order Nostocales.The name Gloeotrichia is derived from its appearance of filamentous body with mucilage matrix. Found in lakes across the globe, gloeotrichia are notable for the important roles that they play in the nitrogen and phosphorus cycles. Gloeotrichia are also a species of concern for lake managers, as they have been shown to push lakes towards eutrophication and produce deadly toxins.

Morphology

Spherical colonies of radiating straight trichomes (filaments without sheaths). Each trichome has an akinete as the basal cell near the center of the colony. Akinetes if present are adjacent the heterocyst. The primary morphology is trichomous (filamentous without sheaths), the secondary is colonial. The mucilaginous sheath is top short at the apex. Heterocysts are usually spherical in appearance. Trichomes are tapered at the apical region. Vegetetive cells are shorter and barrel shaped. The sheaths are firmly attached at the basal region. Sex organs are absent.

Scientific classification

Domain:	Bacteria
Phylum:	Cyanobacteria
Class:	Cyanophyceae
Order:	Nostocales
Family:	Gloeotrichiaceae
Genus:	*Gloeotrichia*

Species

- *Gloeotrichiaechinulata*
- *Gloeotrichia intermedia*
- *Gloeotrichianatans*
- *Gloeotrichiapisum*

Similar genera

Rivularia is reported to form a morphologically similar colony when they are attached with the substratum and reported to radiating, tapered filaments with basal heterocysts.

Habitat

It is freshwater Cyanobacteria. In North America Gloeotrichia appears unexpectedly in many remote oligotrophic lakes during late summer and fall. It is also reported from several remote and pristine lakes in the undisturbed boreal forest watershed. Recently Gloeotrichia was also found in 26 of 27 'low nutrient' lakes in New England USA. Likely the colonies develop in the bottom waters where sediment mineralization releases a portion of its phosphate, then adjust their buoyancy with displacement of bacterioplasm by elongating gas vesicles and rise to the surface where they can be distributed horizontally by wind-driven water currents. Blooms form in mid to late summer due to this 'recruitment' from the sediments, as the benthic colonies rise relatively in synchrony, measured in inverted funnel traps at up to 104 colonies m-2 day-1 in Lake Sunapee, NH USA.

Evidence that Gloeotrichia is meroplanktonic, spending part or most of the year in sediments, comes from mesocosm growth experiments at Lake Erken. While open-water (pelagic) colonies were increasing during July 2000 – 2001, colonies in mesocosms (41 L and 300 L volume) were decreasing, even with additions of various combinations of nutrients (exception: addition of N, P and Fe). The conclusion is that P-rich sediments enable colony growth and that increasing colony buoyancy during July brings them into the pelagic zone Gloeotrichia is also reported from some remote nutrient rich lakes surrounded by paddy field in West Bengal of India. Though this newly found paper which states about the presence of them in Bengal is not widely verified.

Phosphorus Cycling

Lakes have several sources of P, but a large source is found in the bottom sediments or benthos. The P in the benthos is generally found in organic matter or bound to metals, like iron. However, summer stratification in the water column keeps the P from circulating to the epilimnion, or upper layers. Gloeotrichia have been linked to the phosphorus (P) cycle in lakes due to the fact that they transport P from the benthos to the epilimnion when they migrate. Over the winter Gloeotrichia forms dormant cells called akinetes that germinate and begin to form colonies when temperatures begin to increase.

As these cells grow, they uptake nutrients like P. However, they generally uptake more nutrients than they need and store it for later use for when they migrate to the nutrient deplete epilimnion. The minimum cellular need for P in Gloeotrichia is approximately 2.3 g P/mg C, but actual uptake is 25-500e-6 g/L/day, compared to algae, which is normally 1-100e-6 g/L/day. Once Gloeotrichia have stored enough P to sustain colonial formation and growth, they begin to form vacuoles filled with gas to increase their buoyancy and bring them up to the epilimnion.

There, the extra nutrients allow for further colonial growth. Colonies generally form from late June through July. As Gloeotrichia migrate, the percentage of P in the epilimnion due to Gloeotrichia increases from 1% to 53%. In fact, the migration of gloeo causes a P flux of 2.25 mg/m day. This increased amount of P allows Gloeotrichia to outcompete other algal species in a nutrient-deplete epilimnion.

2.14 NITROGEN FIXATION

Along with their role in the phosphorus cycle, Gloeotrichia also play an important role in lake nitrogen (N) cycling. Like many other cyanobacteria, Gloeotrichia have the nitrogenase enzyme, which allows them to convert N from its biologically unavailable form (dissolved N_2 gas), into biologically available ammonia (NH_3). This N-fixation allows gloeotrichia to outcompete other phytoplankton and thrive in low-N environments. Cyanobacterial N-fixation also impacts overall phytoplankton community structure by increasing the pool of biologically available N within a lake. This increase often boosts phytoplankton production and favors taxa that do better in nutrient rich environments.

Toxins

While research on toxin production of specific species of Gloeotrichia is limited, some species are potentially harmful. In Lake Sunapee, Gloeotrichiaechinulata have been found to produce microcystin-LR, which could become a risk to the health of humans and aquatic ecosystems. Microcystins are a group of potent heptapeptide hepatotoxins, which contains more than 85 known varieties, produced by different species of aquatic cyanobacteria. Gloeotrichiaechinulata are found in a variety of ecosystems, but tend to form large, potentially dangerous blooms in lakes with eutrophic and poor ecological status.

2.15 NOSTOC

Nostoc is a genus of blue-green algae or cyanobacteria. They are prokaryotic and perform photosynthesis. They are found mainly in freshwater as free-living colonies or attached to rocks or at the bottom of lakes. They are also found on tree trunks. They are also found as an algal component of lichens in certain bryophytes (Anthoceros). They are capable of nitrogen-fixing and perform photosynthesis. They are also present as an endosymbiont to fungus.

Nostoc Classification

Nostoc are prokaryotic and are grouped with bacteria. The cell lacks membrane-bound organelles and genetic material is found dispersed in the cytoplasm. They are kept in cyanobacteria as they are photosynthetic.

Domain	Bacteria
Phylum	Cyanobacteria
Class	Cyanophyceae
Order	Nostocales
Family	Nostocaceae
Genus	*Nostoc*

Some of the commonly found *Nostoc* species are:

- *Nostoc commune* is eaten as a salad
- *Nostoc azollae* forms symbiotic association with water fern
- *Nostoc punctiforme* form symbiotic relationship with Anthceros and other higher plants
- *Nostoc flagelliforme* is known as Fat choy. It is used as a vegetable in China
- *Nostoc pruniforme* forms very big colonies (diameter as large as ~25 cm)

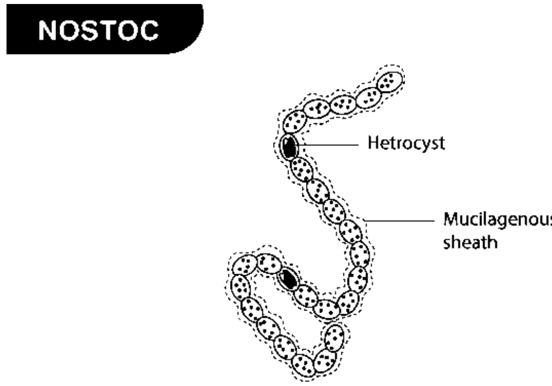

Fig.2.2 Nostoc

Structure of Nostoc

- Nostoc are filamentous and unbranched. Numerous filaments are found in a gelatinous mass as a colony. The colonies may be as big as an egg. The filament consists of a chain of cells, which appear like a bead. They are called trichomes.
- Cells are oval, spherical or cylindrical
- Some of the cells in the filament are differentiated, they are called **heterocyst.** They are sites for nitrogen fixation. Nitrogenase enzyme fixes nitrogen.
- Each filament is covered in a mucilaginous sheath, which is a protective layer. It absorbs and retains water. The gelatinous sheath is made up of polysaccharides and also contains proteins.
- Colonies are of different shapes, sizes and colours. They are mostly greenish or bluish-green in colour and also have red-brown or yellow-green colour.
- Extracellular pigments are also found, e.g. nostocine, scytonemin. These pigments along with some amino acids protect the cells from UV radiation.
- Each cell has a thick cell wall made up of peptidoglycan.
- The cytoplasm of a cell is differentiated into outer coloured due to peripherally arranged chromoplast and inner clear cytoplasm.
- Cells have various pigments. Cells contain chlorophyll (green pigment). Phycocyanin (blue) and phycoerythrin (red) are also present.
- Inner cytoplasm contains incipient nucleus or a nuclear body, DNA is without histones.

Nostoc Reproduction

Nostoc reproduces vegetatively or asexually by spore formation. The vegetative reproduction is by fragmentation. Small colonies can grow attached to a large colony and later form separated colonies. Hormogonia are short and free filaments. They are formed when a filament breaks. It retains the gelatinous sheath. New trichomes are developed inside the colony. Asexual reproduction is by the formation of resting spores known as **akinetes.** Some of the cells become thick-walled due to accumulation of food. They can withstand unfavourable conditions for many years. Under favourable conditions, they germinate to form a new filament. Nostoc also reproduce by heterocysts. Heterocysts separate from the filament. They divide and germinate into a new filament.

Ecological Importance

- *Nostoc* are important for their nitrogen-fixing ability. They are used in paddy fields and are also used to increase the nutrient value of soil
- They are rich in proteins and vitamin C and are used as a delicacy in various Asian countries, e.g. *N. flagelliforme, N. commune, etc.*
- *N. muscorum* has shown to accumulate polyhydroxy butyrate, which is a precursor of plastic. It may have useful application in the industry
- Cyanobacteria can convert CO_2 to biofuels. Nostoc have shown to produce hydrogen
- They can be used for bioremediation of wastewater and degrade environmental pollutants
- Various species, e.g. *N. muscorum, N. commune, N. insulare, etc.* extracts have shown antibacterial or antiviral activity and may be used in future to prepare drugs

Economic Importance of Algae

(i) Food

Most societies around the globe think about green growth as a basic wellspring of sustenance. Residents living in European nations like Scotland, Ireland, France, Germany, Sweden, and Norway just as individuals living in South and North America, and Asian countries like Japan and China are utilizing green growth as a key fixing in various nearby dishes. Such dinners may remember green growth for a serving of mixed greens, following meat in a singed pot, as oats beating, or even as a fluid concentrate in a nutritious smoothie.

Green growth contains various gainful components including sugars, fats, proteins and nutrients A, B, C and E. Green growth isn't just viewed as a minimal effort wellspring of protein by numerous buyers around the globe, it additionally contains various significant minerals, for example, potassium, iron, magnesium, manganese, calcium, and zinc. An assortment of dairy items, for example, milk, frozen yoghurt, cheddar, whipped fixings, just as sugar, icing, organic product squeeze, and even plate of mixed greens dressings, are regularly found in green growth.

(ii) Fodder

Algae are utilised as a feed for a diverse set of farm animals, especially seaweed. For example, cows and chickens, Rhodymenia palmate or alleged "Sheep's weed" is utilized. Green growth is utilized as a grain in different nations, including the northern European nations of Denmark, Sweden, and Norway, just as in Taiwan, Australia, New Zealand and South and North America.

(iii) Reclaiming alkaline

Fields that once generated large quantities of agricultural yields in several countries, like India too, for instance, can no more be used to procure the same yield as a result of high alkalinity levels of the soil. To eventually grow crops in these lands, often referred to as "usar" lands, it is necessary to lower pH level and increase the soil's ability to hold onto water. The blue-green algae can be used to accomplish this cycle.

(iv) Binding agent

Soil can be held together by algae. In protecting against natural processes such as erosion, the effectiveness of algae to help in healthy soil formation is important.

Frequently Asked Questions

Q. 1 Where is nostoc found?

Nostoc is a genus of cyanobacteria (blue-green algae). They are found mainly in freshwater as free-living colonies or attached to rocks, tree trunks or at the bottom of lakes. They are also found in symbiotic association with plants such as water fern and Anthoceros.

Q. 2 Which kingdom does nostoc belong to?

Nostoc is a genus of cyanobacteria (blue-green algae). They belong to the kingdom Monera.

Q. 3 Does nostoc produce oxygen during photosynthesis?

Nostoc is a genus of prokaryotic microorganisms commonly known as blue-green algae. They are capable of nitrogen-fixation and also perform photosynthesis. They are capable of performing oxygenic photosynthesis. They have chlorophyll 'a', just like plants.

Q. 4 Is nostoc eukaryotic or prokaryotic?

Nostoc is a genus of prokaryotic microorganisms commonly known as blue-green algae. They belong to the kingdom Monera and the phylum Cyanobacteria, which contains photosynthetic bacteria.

Q. 5 How nostoc fix atmospheric nitrogen?

Nostoc has the ability to fix atmospheric nitrogen in a specialised cell called heterocyst. Some of the cells in the filament are differentiated, they are called heterocyst. They are sites for nitrogen fixation. The nitrogenase enzyme fixes nitrogen. They are used in paddy fields and are also used to increase the nutrient value of soil. They fix atmospheric nitrogen to ammonia, nitrites and nitrates.

2.16 SUMMARY

Under this unit we have summarized concept of characteristics, classification, thallus organization and reproduction in cyanophyceae, as well as economic importance of Nostoc. etc. Thallus is in the form of colonies. The colonis are free floating and irregularly covered by colourless, mucilaginous sheath. Many members of Cyanophyceae have the capacity to change their colour in relation to the wave length of incident light. Due to variation of the wavelength of incident light they can change their pigment composition. It may appear blue green in yellow light, green in red light and reddish in green light. Sexual reproduction is absent. The vegetative reproduction performs through fission (Synechococcus), fragmentation (Oscillatoria, Cylindrospermummuscicola), hormogonia formation (Oscillatoria, Nostoc), hormospores (Westiella lanosa), planococci and Palmelloid stage.

Nostoc is a genus of blue-green algae or cyanobacteria. They are prokaryotic and perform photosynthesis. They are found mainly in freshwater as free-living colonies or attached to rocks or at the bottom of lakes. They are also found on tree trunks. They are also found as an algal component of lichens in certain bryophytes (Anthoceros). They are capable of nitrogen-fixing and perform photosynthesis. They are also present as an endosymbiont to fungus.

2.17 Terminal Questions

Q.1 What do you mean byimportant characteristics of cyanophyceae**.**

Answer:---

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Q.2 Describe the of thallus organisation in cyanophyceae.

Answer:--

Q 3 Describe the reproduction in cyanophyceae.

Answer:--

Q. 4 Describe the classificationand characteristics of cyanobacteria.

Answer:--

Q.5 Write short notes on the following.

(a) Nitrogen Fixation

(b) Nostoc

Answer:--

Q. 6 Describe the economic importance of Nostoc.

Answer:--

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 3 : CYANOPHYCEAE -II

Structure

3.1 INTRODUCTION

Cyanobacteria, also known as Cyanophyta, are a phylum of Gram-negative bacteria that obtain energy via photosynthesis. The name cyanobacteria refers to their colour, giving them their other name, "blue-green algae", though modern botanists restrict the term algae to eukaryotes and do not apply it to cyanobacteria, which are prokaryotes. They appear to have originated in freshwater or a terrestrial environment. Sericytochromatia, the proposed name of the paraphyletic and most basal group, is the ancestor of both the non-photosynthetic group Melainabacteria and the photosynthetic cyanobacteria, also called Oxyphotobacteria.

It is a primitive group of algae, consists of 150 genera and about 2,500 species. In India, the division is represented by 98 genera and about 833 species. Members of the class Myxophyceae (Cyanophyceae) are commonly known as blue green algae. The name blue green algae is given because of the presence of a dominant pigment c-phycocyanin, the blue green pigment. In addition, other pigments like chlorophyll a (green), c-phycoerythrin (red), β-carotene and different xanthophylls are also present. The members of this class are the simplest living autotrophic prokaryotes.

Objectives

This is the third unit (cyanophyceae-II) of Algae-I. Under third unit, we have following objectives. These are as under:

- To know about important characteristics of cyanophyceae
- To discuss cellular organization of cyanophyceae
- To discuss the classification of cyanobacteria
- To know about *cylindrospermum and*stigonema

Cyanobacteria use photosynthetic pigments, such as carotenoids, phycobilins, and various forms of chlorophyll, which absorb energy from light. Unlike heterotrophic prokaryotes, cyanobacteria have internal membranes. These are flattened sacs called thylakoids where photosynthesis is performed. Phototrophic eukaryotes such as green plants perform photosynthesis in plastids that are thought to have their ancestry in cyanobacteria, acquired long ago via a process called endosymbiosis. These endosymbiotic cyanobacteria in eukaryotes then evolved and differentiated into specialized organelles such as chloroplasts, chromoplasts, elioplasts, and leucoplasts, collectively known as plastids.

Cyanobacteria are the first organisms known to have produced oxygen. By producing and releasing oxygen as a byproduct of photosynthesis, cyanobacteria are thought to have converted the early oxygen-poor, reducing atmosphere into an oxidizing one, causing the Great Oxidation Event and the "rusting of the Earth", which dramatically changed the composition of the Earth's life forms and led to the near-extinction of anaerobic organisms. The cyanobacteria Synechocystis and Cyanothece are important model organisms with potential applications in biotechnology for bioethanol production, food colorings, as a source of human and animal food, dietary supplements and raw materials. Cyanobacteria produce a range of toxins known as cyanotoxins that can pose a danger to humans and animals.

3.2 CHARACTERISTICS OF CYANOPHYCEAE :

They have the following important characteristics:

- Nucleus is of prokaryotic nature i.e., devoid of nuclear membrane and nucleolus.
- Absence of well-organized cell organelles, and
- Pigments are distributed throughout the chromoplasm (the outer part of protoplasm).

Depending on the above prokaryotic characteristics many microbiologists consider the members of Cyanophyceae as bacteria. Based on prokaryotic cell structure like bacteria, Christensen (1962) placed both Cyanophyta and bacteria under a common phylum Prokaryota. Cyanophyta or blue green algae have also been named as cyanobacteria.

3.3 IMPORTANT CHARACTERISTICS OF CYANOPHYCEAE

The important characteristics of the division are as follows:

- The individual cells are prokaryotic in nature. The nucleus is incipient type and they lack membrane bound organelles.

- Both vegetative and reproductive cells are non-flagellate.
- Cell wall is made up of microfibrils and is differentiated into four (4) layers. The cell wall composed of mucopeptide, along with carbohydrates, amino acids and fatty acids.
- Locomotion is generally absent, but when occurs, it is of gliding or jerky type.
- The principal pigments are chlorophylls a (green), c-phycocyanin (blue) and c-phyco-erythrin (red). In addition, other pigments like β-carotene and different xanthophylls like myxoxanthin and myxoxanthophyll are also present.
- Membrane bound chromatophore are absent. Pigments are found embedded in thylakoids.
- The reserve foods are cyanophycean starch and cyanophycean granules (protein).

3.4 OCCURRENCE OF CYANOPHYCEAE:

Members of Cyanophyceae are available in different habitats. Most of the species are fresh water (e.g., Oscillatoria, Rivularia), a few are marine (e.g., Trichodesmium, Darmocarpa), and some species of Oscillatoria and Nostoc are grown on terrestrial habitat. Species of some members like Anabaena grow as endophytes in thallus of Anthoceros (Bryophyta) and in leaves of Azolla (Pteridophyta) and Nostoc in the root of Cycas (Gymnosperm). Species of Nostoc, Scytonema, Gloeocapsa, and Chroococcus grow symbiotically with different fungi and form lichen. Some members like Nostoc, Anabaena etc. can fix atmospheric nitrogen and increase soil fertility.

Cyanobacteria can be found in almost every terrestrial and aquatic habitat – oceans, fresh water, damp soil, temporarily moistened rocks in deserts, bare rock and soil, and even Antarctic rocks. They can occur as planktonic cells or form phototrophic biofilms. They are found inside stones and shells (in endolithic ecosystems). A few are endosymbionts in lichens, plants, various protists, or sponges and provide energy for the host. Some live in the fur of sloths, providing a form of camouflage. Aquatic cyanobacteria are known for their extensive and highly visible blooms that can form in both freshwater and marine environments. The blooms can have the appearance of blue-green paint or scum. These blooms can be toxic, and frequently lead to the closure of recreational waters when spotted. Marine bacteriophages are significant parasites of unicellular marine cyanobacteria.

Cyanobacterial growth is favoured in ponds and lakes where waters are calm and have little turbulent mixing. Their lifecycles are disrupted when the water naturally or artificially mixes from churning currents caused by the flowing water of streams or the churning water of fountains. For this reason blooms of cyanobacteria seldom occur in rivers unless the water is flowing slowly. Growth is also favoured at higher temperatures which enable Microcystis species to outcompete diatoms and green algae, and potentially allow development of toxins.

Based on environmental trends, models and observations suggest cyanobacteria will likely increase their dominance in aquatic environments. This can lead to serious consequences, particularly the contamination of sources of drinking water. Cyanobacteria can interfere with water treatment in various ways, primarily by plugging filters (often large beds of sand and similar media) and by producing cyanotoxins, which have the potential to cause serious illness if consumed. Consequences may also lie within fisheries and waste management practices. Anthropogenic eutrophication, rising temperatures, vertical stratification and increased atmospheric carbon dioxide are contributors to cyanobacteria increasing dominance of aquatic ecosystems.

Cyanobacteria have been found to play an important role in terrestrial habitats. It has been widely reported that cyanobacteria soil crusts help to stabilize soil to prevent erosion and retain water. An example of a cyanobacterial species that does so is *Microcoleusvaginatus*. *M. vaginatus* stabilizes soil using a polysaccharide sheath that binds to sand particles and absorbs water. Some of these organisms contribute significantly to global ecology and the oxygen cycle. The tiny marine cyanobacterium Prochlorococcus was discovered in 1986 and accounts for more than half of the photosynthesis of the open ocean. Circadian rhythms were once thought to only exist in eukaryotic cells but many cyanobacteria display a bacterial circadian rhythm.

"Cyanobacteria are arguably the most successful group of microorganisms on earth. They are the most genetically diverse; they occupy a broad range of habitats across all latitudes, widespread in freshwater, marine, and terrestrial ecosystems, and they are found in the most extreme niches such as hot springs, salt works, and hypersaline bays. Photoautotrophic, oxygen-producing cyanobacteria created the conditions in the planet's early atmosphere that directed the evolution of aerobic metabolism and eukaryotic photosynthesis. Cyanobacteria fulfill vital ecological functions in the world's oceans, being important contributors to global carbon and nitrogen budgets.

3.5 CELLULAR ORGANIZATION OF CYANOPHYCEAE

Cyanobacteria are the most primitive types of organisms (plants) with simple prokaryotic cellular structures. With the help of an electron microscope, **Pankratz** and **Bowen** (1963) studied the structure of cyanobacterial cells. The detailed cell structure of cyanobacteria is as follows:

3.6 CELL SHEATH

The cyanobacterial cell is surrounded by a hygroscopic gelatinous sheath, which is made up of three layers of microfibrils. The microfibrils are composed of pectic acids and mucopolysaccharides. Sheaths are reticulately arranged within a matrix to give a homogeneous appearance.The function of the cell sheath is to absorb and retain water.

3.7 CELL WALL

A multi-layered wall is present below the gelatinous sheath. The cell wall is made up of four layers which are designated numerically as LI, LII, LIII, and LIV. The layers LI and LIII are electron transparent, while LII and LIV are electron-dense.

- **Layer LI:** The innermost layer of the cell wall is LI. It is present next to the plasma membrane. Layer LI is of about 3-10 nm thickness and is enclosed by layer LII.
- **Layer LII:** LII is an electron-dense, thin layer. It is about 10-1000 nm in thickness. The layer LII consists of muramic acid, glutamic acid, alanine, glucosamine, and α-di-amino-pamelic acid.
- **Layer LIII:** The electron transparent Layer III is of about 3-10 nm thickness, just like layer III.
- **Layer LIV:** The outermost layer is LIV which is a thin and again electron-dense layer.

3.8 PLASMA MEMBRANE

Below the cell wall, a thin cytoplasmic bilayer membrane called the plasma membrane is present. The plasma membrane consists of two electron-opaque layers separated by a translucent layer. It has a thickness of 7 nm, is selectively permeable, and maintains the physiological integrity of the cell.

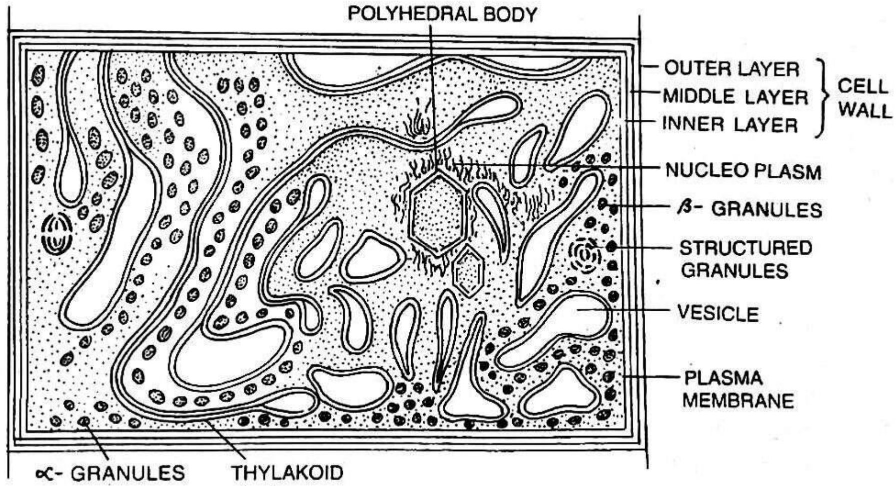


Fig.3.1 : Different parts of a cyanobacterial cell

Cytoplasm

The cytoplasm is differentiated into two regions, the outer colored peripheral region which is called the chromoplasm, and the central colourless region called the centroplasm or central body.

1. **Chromoplasm**

The chromoplasm contains flattened vesicular structures called photosynthetic lamellae or thylakoids.

Lamellae

In the peripheral part of the cyanobacterial cell (in chromoplasm), many lamellae or thylakoids are present. The lamellae are arranged in two or more parallel stacks or scattered irregularly. Each lamella is represented by a flat sac, which is surrounded by a unit membrane. Each unit membrane is about 75 Å in thickness.

These lamellae are separated by a space of 50 μ. This space is occupied by many rows of discoidal phycobilisomes, which contain phycocyanin pigment and, to a lesser extent phycoerythrin pigment.

2. **Centroplasm or Central Body**

The central body, or centroplasm, is colorless and irregular in shape, occupying more or less a quarter or one-third of the total volume of the cell. Some people are of the opinion that the centroplasm is the storehouse of food and according to others, it is an incipient nucleus or nucleoplasm. The nucleoplasm contains numerous fine, randomly oriented DNA fibrils.

3.9 CYTOPLASMIC INCLUSIONS

In a typical cyanobacterial cell, many sub-cellular organelles such as cyanophyceangranules, gas vacuoles, polyglucoside bodies,ribosomes,polyhedral bodies, polyphosphate bodies, etc. are present.

- In many cyanobacteria (e.g., Anabaena, Gloeotrichia, Microcystis, Oscillatoria, etc.), pseudovacuoles (pockets of gas) are found to be distributed throughout the cytoplasm. These pseudovacules provide greater buoyancy in such species and also act as light screens against intense illumination.

- The proteins present in the cell are synthesized by ribosomes.
- Cyanophycean granules or cyanophycin store reserve food material.
- Polyphosphate bodies are meant for the storage of phosphorus.
- Polyhedral bodies are also called carboxysomes. They produce an important enzyme called ribulose diphosphate carboxylase.
- Other granules are called storehouses of nitrogen.

3.10 REPRODUCTION IN CYANOPHYTA /CYANOPHYCEAE

The Cyanophyta are characterized by the complete absence of sexual reproduction; no sexual organs and no motile reproductive bodies have been observed. Propagation takes place by simple division, by spores (akinetes, endospores, and exospores) or else by fragmentation (fission). The multiplication of unicelluar and colonial forms is brought about mainly by simple cell division.

In all the filamentous forms multiplication is largely effected by the formation of hormogonia.

The hormogonia are the fragments of the filament delimited by the occasional death of cells at intervals along the length of the filament. In certain forms, the hormogonia are enveloped by thick sheath and thus are modified as organs of perennation, known as hormocysts or hormospores, which on germination grow out into new filaments.

Many of the filamentous forms produce heterocysts, which break up the filament into hormogonia. At times the heterocysts may behave as spores to germinate into new filaments. In some Cyanophyta, the akinetes germinate immediately after formation, while in others they remain dormant for long time behaving as resting spores. On germination the protoplast divides producing germling. In a number of genera, particularly in certain unicellular members, small spores, known as endospores are formed endogenously within a cell. They arise by successive division of the protoplast along three planes. The endospores forming cell behaves as a sporangium.

The endospores are generally naked, but a thin wall is secreted after their liberation from the sporangium. In some epiphytic forms the delicate cell wall ruptures apically exposing the protoplast from which spherical spores are abstricted successively from its tip, these are called exospores. The abstricted spores are surrounded by a delicate membrane.

3.11 CLASSIFICATION OF CYANOBACTERIA

Cyanobacteria were previously known as Cyanophyta in the five-kingdom classification scheme and are one of the phyla of the Kingdom Protista. Euglenophyta, Chrysophyta, Pyrrophyta, Chlorophyta, Phaeophyta, and Rhodophyta are the other phyla.

- Because of their photosynthetic ability, these phyla are groups of plant-like protists.
- Unlike embryophytes, they lack true roots, stems, and leaves.
- Cyanophyta (also known as blue-green algae) is now known as Cyanobacteria, a phylum of bacteria.
- This is due to the fact that this clade is made up of prokaryotic species.
- Blue-green algae are the only prokaryotic algae in phycology; the rest are eukaryotes.

- As a result, they are now classified as bacteria of the Phylum Cyanobacteria.
- The specific classification of cyanobacteria is as following;
    - Kingdom - Monera
    - Division - Eubacteria
    - Class - Cyanobacteria
    - Order -Nostocaceae
    - Genus - Nostoc
    - Common Name - Star Jelly

Sub-groups of Cyanobacteria

Based on morphology, cyanobacterial subgroups are classified as follows:

- Chroococcales
- Pleurocapsales
- Oscillatoriales
- Nostocales
- Stigonematales

3.12 IMPORTANT POINTS

- Cyanobacteria played an important role in the evolution of aerobic forms of life.
- In a hostile environment, they provide suitable conditions for the growth of other organisms.
- They convert atmospheric nitrogen into ammonium compounds, and the excess is excreted into the soil, enriching it.
- Nitrogen fixation is carried out by approximately 50 species of cyanobacteria.
- They are classified into two types based on nitrogen fixation: free-living N_2-fixing cyanobacteria and non-free-living N_2-fixing cyanobacteria
- Examples are Anabaena, Nostoc, Aulosira, Scytonema. TolypothrixStigonema, Gloetrichia etc.
- Symbiotic N_2-fixing cyanobacteria (such as Nostoc and Anabaena) are common in Anthoceros lichens.
- Azolla and Cycas root; Anabaena azollae is found in the flora of Azolla pinnata.
- They serve as bio-fertilizers.
- Mosquito larvae are not allowed to grow in Anabaena and Aulosira.
- Lyngbya, a cyanobacterium extract, is used in the production of antibiotics.
- Some hydrogen-producing cyanobacteria, in addition to algae, are being considered as an alternative energy source.

Phylogeny is an evolutionary reconstruction of the past relationships of DNA or protein sequences and it can further be used as a tool to assess population structuring, genetic diversity and biogeographic patterns. In the microbial world, the concept that everything is everywhere is widely accepted. However, it is much debated whether microbes are easily dispersed globally or whether they, like many macro-organisms, have historical biogeographies. Biogeography can be defined as the science that documents the spatial and temporal distribution of a given taxa in the environment at local, regional and continental scales. Speciation, extinction and dispersal are proposed to explain the generation of biogeographic patterns. Cyanobacteria are a diverse group of microorganisms that inhabit a wide range of ecological niches and are well known for their toxic secondary metabolite production. Knowledge of the evolution and dispersal of these microorganisms is still limited, and further research to understand such topics is imperative

Cyanobacteria have played a significant role in Earth history as primary producers and the ultimate source of atmospheric oxygen. To date, however, how and when the group diversified has remained unclear. Here, we combine molecular phylogenetic and paleontological studies to elucidate the pattern and timing of early cyanobacterial diversification. 16S rRNA, *rbcL*, and *hetR* genes were sequenced from 20 cyanobacterial strains distributed among 16 genera, with particular care taken to represent the known diversity of filamentous taxa. Unlike most other bacteria, some filamentous cyanobacteria evolved a degree of cell differentiation, producing both specialized cells for nitrogen fixation (heterocysts) and resting cells able to endure environmental stress (akinetes).

Phylogenetic analyses support the hypothesis that cyanobacteria capable of cell differentiation are monophyletic, and the geological record provides both upper and lower bounds on the origin of this clade. Fossil akinetes have been identified in 1,650- to 1,400-mega-annum (Ma) cherts from Siberia, China, and Australia, and what may be the earliest known akinetes are preserved in ≈2,100-Ma chert from West Africa. Geochemical evidence suggests that oxygen first reached levels that would compromise nitrogen fixation (and hence select for heterocyst differentiation) 2,450–2,320 Ma. Integrating phylogenetic analyses and geological data, we suggest that the clade of cyanobacteria marked by cell differentiation diverged once between 2,450 and 2,100 Ma, providing an internal bacterial calibration point for studies of molecular evolution in early organisms.

3.13 CYLINDROSPERMUM

Cylindrospermum is a genus of filamentous cyanobacteria that is occasionally found in freshwater phytoplankton assemblages, but is not usually associated with toxic planktonic blooms. Cylindrospermum is more commonly associated with benthic environments, where it can form dense, slimy mats on damp soils or mixed in with shoreline vegetation of lakes and ponds.Cylindrospermum cells are cylindrical or barrel-shaped, tiny (3-7 µm wide; for comparison, a strand of spider silk is about 5 µm wide), and slightly longer than wide. Under magnification the cells are blue-green or gray-green, and may appear granular. The cells are joined together end-to-end to form long, unbranched, untapered, straight or gently curved filaments. The filaments are surrounded by clear, often transparent mucilage, and may slimy form mats on submerged vegetation or other surfaces.

In addition to ordinary (vegetative) cells, one or both ends of the filament may contain pale blue heterocytes (=heterocysts). The filaments may also have one (occasionally two) large, blue-green or brown akinetes adjacent to the heterocytes. Heterocytes are specialized cells that convert dissolved nitrogen gas into ammonium that can be used for cell growth. Akinetes are resting cells that are resistant to cold temperatures and other unfavorable environmental conditions. Akinetes are usually produced near the end of the growing cycle, and can overwinter in lake sediments.

Ecology

Cylindrospermum is not a usually found in planktonic cyanobacteria blooms.

- Cylindrospermum cells lack gas vesicles, which are common in bloom-forming planktonic taxa like Dolichospermum and Microcystis

Cylindrospermum is usually found in shallow water associated with shoreline vegetation in nutrient-poor lakes and ponds, especially water that is slightly acidic, boggy, or peaty. Cylindrospermum is capable of fixing dissolved nitrogen gas, which helps provide nitrogen in boggy sites where inorganic nitrogen (ammonium, nitrate, and nitrite) is limiting to other types of algae.

3.14 TOXICITY

Identifying which cyanobacteria species are producing toxins is more difficult that itsounds.Historically, cyanobacteria taxa were described as "potentially" toxic based on whether they were collected in a toxic bloom. With the advancement of culturing techniques and genetic analysis, toxicity information is becoming more exact. But this is an ongoing process, so the toxicity information on these pages should be considered a work in progress.*Cylindrospermum* cells may produce anatoxins (nerve toxin), lipopolysaccharides (skin irritants), and BMAA (beta-Methylamino-L-alanine; nerve toxin). These toxins are released into the ambient environment when the cell wall is disrupted (cell lysis).

- Anatoxins are rapidly degraded by sunlight and at pH levels that are slightly above neutral (neutral pH = 7.0). At low pH levels, and in the absence of light, anatoxins may persist in the aquatic environment for a few weeks.
- There is some evidence that anatoxins can be degraded by specialized bacteria, similar to microcystins, but this process is not well documented.
- BMAA can bioaccumulate in zooplankton and fish, so this nerve toxin can contribute to health risks long after the toxic bloom has died back.

In some instances, higher water temperatures and light appear to be associated with increased toxin production, but toxic *Cylindrospermum* blooms have not been well documented.

3.15 STIGONEMA

Filamentous cyanobacteria are morphologically diverse. The most complex morphologies occur in the genus *Stigonema* (Stigonemataceae, Nostocales), which is heterocystous and characterized by true-branched, multiseriate or uniseriate trichomes surrounded by a sheath. There is virtually no documentation of fossil equivalents to *Stigonema*. This unit describes a specimen of a new filamentous cyanobacterium, *Rhystigonemaobscurum* nov. gen. et sp., from the Lower Devonian Rhynie chert that appears to have been preserved due to the fortuitous circumstance that it was located in a microbial mat at the time of silicification. The specimen consists of a large (> 50 µm wide), true-branched, multiseriate trichome enveloped in a prominent sheath. It can satisfactorily be placed in Stigonemataceae based on morphology; were it not for the lack of molecular evidence, it could also be assigned to *Stigonema*. *Rhystigonemaobscurum* broadens our knowledge of cyanobacterial biodiversity in early non-marine ecosystems.

There is most complex morphology in all bacteria. At least until 1927 *Stigonema mammilosum* was considered to be a primitive eukaryote with an unbound nucleus in the center of each vegetative cell, dividing amitotically without microtubules (Lee 1927).Filaments made of several cells in width (multiseriate), forming branches by the division of cells perpendicularly to the main filament axis (true branching).A single pit connection (plasmodesma) is reported between cells that apparently disappears in parts of the branched filament.

Difficult to distinguish from *Fischerella*, a uniseriate true-branching cyanobacterium that occupies the same habitats, although *Stigonema* forms branches that are typically multiseriate. Other filamentous cyanobacteria with true branching but having few multiseriate regions, including Capsosira, Hapalosiphon and Mastigocladus.

3.16 SUMMARY

Under this unit we have summarized the concept of characteristics, occurrence and cellular organization of Cyanophyceae. They are primitive group of algae, consists of 150 genera and about 2,500 species. In India, the division is represented by 98 genera and about 833 species. Members of the class Myxophyceae (Cyanophyceae) are commonly known as blue green algae. The name blue green algae is given because of the presence of a dominant pigment c-phycocyanin, the blue green pigment.In addition, other pigments like chlorophyll a (green), c-phycoerythrin (red), β-carotene and different xanthophylls are also present. The members of this class are the simplest living autotrophic prokaryotes.

In all living species, cellular metabolism is critical because adenosine triphosphate (ATP) is required for practically every cellular action, not only as a primary energy currency but also as a signalling molecule. Monitoring cellular bioenergetics will lead to a better knowledge of a wide range of biologically relevant processes in both physiological and pathological settings, given their importance. Although cell-based assays have made significant progress, fluorescence probes provide a significant advantage by allowing high-resolution visualisation of spatiotemporal dynamics of intracellular nucleotides in real time of individual intact live cells, especially when using genetically encoded fluorophores and variants.

3.17 TERMINAL QUESTIONS

Q.1 What do you mean bycharacteristics of cyanophyceae? Explain it.

Answer:---

Q. 2 Describe the cellular organization of cyanophyceae.

Answer:---

Q.3 Write short notes on the following.

(a) Cylindrospermum

(b) Stigonema

(C) Cytoplasmic Inclusions

Answer:---

Q.4 Describe the reproduction in cyanophyta.

Answer:---

Q.5 Write short notes on the following.

(a) Cell wall

(b) Cell sheath

(C) Toxicity

Answer:---

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 4: CHLOROPHYCEAE-I

Structure

4.1 INTRODUCTION

Kingdom Plantae incorporates every one of the plants. They are eukaryotic, multicellular, and autotrophic life forms. The plant cell contains an unbending cell wall. Plants have chloroplast and chlorophyll shade, which is expected for photosynthesis. The Chlorophyceae are one of the classes of green growth, recognized primarily based on ultrastructural morphology. They are typically green because of the strength of the colors chlorophyll an and chlorophyll b. The chloroplast might be discoid, plate-like, reticulate, cup-molded, winding, or lace formed in various species. The greater part of the individuals has at least one stockpiling body called pyrenoids situated in the chloroplast. Pyrenoids contain proteins other than starch. Some green growth might store food as oil drops. They generally have a cell wall comprised of an inward layer of cellulose and an external layer of pectose.

Objectives

This is the fourth unit (Chlorophyceae-I) on Algae-I. Under fourth unit, we have following objectives. These are as under:

- To know about general qualities of chlorophytes
- To know about phylogeny and classification of chlorophyceae
- To know about thallus of Chlorophyceae (green algae)
- To discuss chlorella, enteromorpha and sphaeroplea

The Chlorophyceae encompass the widest range of morphologies in the green algae. The colonial Volvocaceae (Volvocales) and their unicellular relative Chlamydomonas *reinhardtii* (Chlamydomonaceae) have frequently been used as a model in studies addressing the evolutionary pathways leading from unicellularity to multicellularity, including a division of labor within the algal thallus. Molecular evidence suggests a minimum age of 400–500 Ma for a few *Chlamydomonas* species. Nevertheless, the fossil record of Chlamydomonaceae is virtually nonexistent, and that of Volvocaceae is meager, perhaps because colonies (coenobia) disintegrate almost immediately upon death. Fossil unicellular algae suggestive of *Chlamydomonas* are preserved in Cenomanian amber from southern Germany.

Ulva *is* the most common edible green algae species and belongs to the Chlorophyceae family. This species of green algae shows cholesterol-lowering, antioxidative, and antiatherosclerotic activity. A 2009 study demonstrated cardiovascular and oxidative stress–protective effects of green algae supplementation in high-cholesterol-fed golden Syrian hamsters. *U. rigida* lowered plasma cholesterol, non-HDL cholesterol, and notably triglycerides. Furthermore, the plasma antioxidant capacity was improved, and the area of the aortic fatty streak was reduced by 70%. The study also demonstrated that the crude form of the drug was more potent, as processing it resulted in the loss of around 50% of the soluble polysaccharides, which indicated that they were significantly responsible for the exhibited hypolipidemic effects. Experimental rats respond effectively to *U. rigida*, and the incorporation of algae into the diet had no effect on nutritional metrics other than lowering LDL cholesterol levels. Furthermore, the ethanolic precipitate of *U. rigida* had significantly greater 2,2-diphenyl-1-picrylhydrazy (DPPH) scavenging activity than that of the positive control gallic acid and preventive antioxidant activity comparable to that of the powerful antioxidant product N-acetylcysteine.

The algal cells are thick-walled, oval in lateral view, up to 10 μm long and display a single, cup-shaped chloroplast, which is characteristic of extant *Chlamydomonas*; flagella are not recognizable. A rare microfossil that has been interpreted as a volvocacean alga is *Eovolvoxsilesiensis* from the Devonian of Poland. This fossil consists of hollow spherules with a surface layer composed of closely spaced, ovoid, pyriform, or spindle-shaped isomorphic cells. It is similar in basic structure to *Symphysosphaera radialis* from the Lower Cambrian of China. Affinities with the Volvocaceae have also been suggested for a few other Paleozoic and Mesozoic microfossils. Few of these records, however, can be regarded as unequivocal.

The most biologically interesting fossil with possible affinities to the Volvocales is the endophyte *Lageniastrummacrosporae* (Lageniastraceae) from the Lower Carboniferous of France. This alga occurs inside lycopsid megaspores in the form of dome-shaped, three-dimensional colonies composed of up to 500 lens- to pear-shaped cells arranged in a single layer and bounded by a transparent membrane. *Lageniastrummacrosporae* colonies display a striking similarity in organization to certain extant species of Volvox, including the presence of radiating protoplasmic strands that interconnect adjacent cells in the colony.

4.2 QUALITIES OF KINGDOM PLANTAE

- The plant kingdom has the accompanying trademark highlights:
- They are non-motile.
- They make their own food and thus are called autotrophs.
- They replicate abiogenetically by vegetative engendering or physically.
- These are multicellular eukaryotes. The plant cell contains the external cell wall and a huge focal vacuole.
- Plants contain photosynthetic shades called chlorophyll present in the plastids.
- They have various organelles for jetty, propagation, backing, and photosynthesis.

4.3 CHARACTERISTICS

- The majority of Chlorophyceae species are aquatic, though a small number also grow on land and in brackish and saline water.
- They exhibit a wide range of variations in their thallus structures, including heterotrichous (Coleochaete), siphonaceous (Vaucheria), palmelloid (Tetraspora), dendroid (Ecballocystis), unbranched (Spirogyra), unicellular motile (Chlamydomonas), and unicellular non-motile (Chlorella) (Ulva).
- Flagella are inserted either apically or subapically, are one in number, and are of equal size. Viewed under E.M., the flagella have a typical 9+2 configuration.
- Eukaryotic cells make up the organism. In most cells, there is only one nucleus, but the coenocytic bodies of Siphonales and Cladophorales have many nuclei. In contrast to the normal rule of one nucleolus per nucleus, Conjugales members have several nucleoli.
- Cellulose, which is primarily composed of xylans and mannans and hydroxyproline glycosides, makes up the majority of the cell wall. In Chara, calcium and magnesium carbonate are embedded in the cell wall.
- The protoplast is surrounded by a semipermeable cell membrane that is found inside the cell wall. Numerous tiny vacuoles in the cytoplasm push the nucleus and surrounding cytoplasm outward and are known as primordial utricles.
- The anterior portion of the flagellate cells has an eye spot or stigma that is still inserted on one side of the chloroplast.
- The chloroplast is where the pigments are found. Pyrenoid is typically present in chloroplast (s).

4.4 GENERAL QUALITIES OF CHLOROPHYTES

- The body might be unicellular, pilgrim, filamentous or multicellular.
- They are generally green because of the presence of chlorophyll a, chlorophyll b, and beta-carotene.
- The chloroplast might be discoid, cup-formed (for example Chlamydomonas), twisting or strip molded
- Most chlorophytes have at least one stockpiling body called pyrenoids (focal proteinaceous body covered with a starch sheath) that are confined around the chloroplast.

- The inward cell wall layer is made of cellulose and the external layer of pectose.
- Abiogenetic proliferation is by zoospores. They are lashes delivered from the parent cells by mitosis. Likewise by aplanospores, hypnospores, akinetes, Palmella stage, and so forth.
- Sexual multiplication of Chlorophyceae is isogamous, anisogamous, or oogamous.
- The chlorophycean CW clade and chlorophycean DO clade, are characterized by the plan of their flagella. Individuals from the CW clade have flagella that are dislodged in a "clockwise" (CW, 1-7 o'clock) heading for example Chlamydomonadales. Individuals from the DO clade have flagella that are "straightforwardly against" (DO, 12-6 o'clock) for example Sphaeropleales.

4.5 REPRODUCTION

Asexual Propogation

Vegetative proliferation typically happens by fracture. Agamic propagation is by lashed zoospores. Furthermore, haplospore, perrination (akinate and palmellastage). Agamic propagation by mitospore missing in spirogyra. Sexual proliferation shows significant variation in the kind and arrangement of sex cells and it very well might be isogamous for example Chlamydomonas, Ulothrix, anisogamous for example Chlamydomonas, Eudorina, or Oogamous for example Chlamydomonas, Volvox.

Chlamydomonas has every one of the three sorts of sexual proliferation. They share numerous clones with the higher plants, including the presence of uneven lashed cells, the breakdown of the atomic envelope at mitosis, and the presence of phytochromes, flavonoids, and synthetic antecedents to the fingernail skin. The sole technique for multiplication in Chlorella is abiogenetic and azosporic. The substance of the cell partitions into 2, 4, 8 now and again little daughter protoplasts. Every girl's protoplast adjusts to shape a non-motile spore. These autospores (spores having a similar particular shape as the parent cell) are freed by the break of the parent cell wall. On discharge, each autospore develops to turn into another person. The presence of sulfur in the way of life medium is viewed as fundamental for cell division.

It happens even in obscurity with sulfur alone as the source material yet under light circumstances nitrogen is likewise expected also. Pearsal and Loose detailed the event of motile cells in Chlorella. Bendix additionally saw that Chlorella produces motile cells which may be gametes. These perceptions have a significant bearing on the idea of the existing pattern of Chlorella, which at present is viewed as stringently abiogenetic in character. Abiogenetic multiplication in Chlorella ellipsoides has been concentrated exhaustively and the accompanying four stages have been seen during the agamic propagation.

Growth Phase:

During this stage, the phones fill in size by using photosynthetic items.

Ripening stage:

In this stage, the cells mature and set themselves up for division.

Post-aging stage:

During this stage, each adult cell separates two times either in dull or in light. The cells framed in dim are known as dull to the light stage, cells again fill in size.

Division Phase:

During this stage, the parent cell wall bursts, and unicells are delivered.

4.6 SEXUAL PROPAGATION

Isogamy:

The gametes are comparable in size and shape. These gametes are not named male or female.

Anisogamy:

It is the combination of two gametes that are either different in size or in both size and morphology. It is seen in Chlamydomonas.

Oogamy:

Oogamy is a sort of anisogamy. The male gamete is more modest than the female gamete.

4.7 PHYLOGENY OF CHLOROPHYCEAE

The green lineage (Viridiplantae) comprises the green algae and their descendants the land plants, and is one of the major groups of oxygenic photosynthetic eukaryotes. Current hypotheses posit the early divergence of two discrete clades from an ancestral green flagellate. One clade, the Chlorophyta, comprises the early diverging prasinophytes, which gave rise to the core chlorophytes. The other clade, the Streptophyta, includes the charophyte green algae from which the land plants evolved. Multi-marker and genome scale phylogenetic studies have greatly improved our understanding of broad-scale relationships of the green lineage, yet many questions persist, including the branching orders of the prasinophyte lineages, the relationships among core chlorophyte clades (Chlorodendrophyceae, Ulvophyceae, Trebouxiophyceae and Chlorophyceae), and the relationships among the streptophytes. Current phylogenetic hypotheses provide an evolutionary framework for molecular evolutionary studies and comparative genomics.

This unit summarizes the understanding of organelle genome evolution in the green algae, genomic insights into the ecology of oceanic picoplanktonic prasinophytes, molecular mechanisms underlying the evolution of complexity in volvocine green algae, and the evolution of genetic codes and the translational apparatus in green seaweeds. Finally, we discuss molecular evolution in the streptophyte lineage, emphasizing the genetic facilitation of land plant origins.

4.8 CLASSIFICATION OF CHLOROPHYCEAE

Order 1: Volvocales

There are about 500 species and 60 genera in the order Volvocales. Important features include:

- They are typically found in bodies of fresh water. Some are cultivated on the surface of the soil as well as in marine and brackish waters.
- The plant's body, or thallus, can be single or multicellular (many-celled), and multicellular plants typically live in colonies.

Order 2: Ulotrichales (Chlorophyceae)

There are 80 genera and roughly 430 species in the Order Ulotrichales. While some of them are marine, most of them are found in freshwater (e.g., Ulva). Important features include:

- They are mostly found on soil or in freshwater bodies of water (like Ulothrix), however, a few are marine (e.g., Ulva, Enteromorpha).
- The body of a plant is typically unbranched and filamentous, however, in the ulvaceae family, it is parenchymatous or foliaceous.

- Cells have a single uninucleate nucleus and different forms of chloroplast, including axial, parietal, and C-shaped chloroplast.

Order 3: Chaetophorales: Chlorophyceae

The plants in the family Chaetophorales have hair or setae. Important features include:

- Chaetophorales members are typically found in freshwater.
- Although the plant body is filamentous and exhibits a prominent heterotrichous (prostrate + erect system) habit, Coleochaete has a well-developed prostrate system (creeping), while
- Microthamnion has a well-developed erect system.

Order 4: Oedogoniales Chlorophyceae

Important features include:

- The majority of the members thrive in freshwater. Only three genera—Oedogomium, Oedocladium, and Bulbochaete—represent the order.
- They are filamentous, and the filaments can either be unbranched or branched (Oedocladium and Bulbochaete) (Oedogomium).
- The apical and basal regions of the plant body are distinct from one another.

Order 5: Siphonales

- Siphonales consist primarily of marine species. A few are freshwater species. A few of the members develop as endophytes or epiphytes.
- The thalloid plant body is coenocytic, multinucleate, and variably branching.
- Plant bodies can range from being very branching filamentous types to simple vesicular types (Protosiphon).
- Small, discoid chromatophores are widely dispersed throughout the thallus.

Order 6: Charales

There are people in this rank all across the world.

- A muddy or sandy bottom in fresh water, as well as water flowing through limestone, are common habitats for them.
- Plants are typically up to 30 cm long, very upright, and very branching.

Order 7: Chlorococcales

- Almost exclusively freshwater-based, unicellular or colonial, and non-motile when in the vegetative state.

Order 8: Cladophorales

- Simple or branched, filamentous, usually isogamous, with cells containing two too many nuclei and large, elaborate chloroplasts.

Order 9: kingdoms Conjugales

- They are primarily unicellular or colonial (typically filamentous), have complex chloroplasts, and motile gametes, and reproduce only in freshwater through vegetative cell division or the conjugation of amoeboid gametes.

4.9 THALLUS OF CHLOROPHYCEAE (GREEN ALGAE)

The structure of plants in the Chlorophyceae class exhibits a wide variety of variations (thallus). It includes both single- and multicellular structures, such as Chlamydomonas, Chlorella, Sphaerella, etc. Different types of multicellular formations could exist. They might contain many cells grouped in colonies with a specific shape, called coenobiums. As in Volvox, Pandorina, Pleodorina, etc., the number of cells in a coenobium can be fixed and motile, or it can be indeterminate, arranged in net-like masses, and non-motile as in Hydrodictyon. As in Tetraspora and Palmodictyon, the multi cells may aggregate and create a non-motile palmelloid structure, where the cells stay entrenched in an amorphous or gelatinous matrix.

The heterotrichous habit is evident, and the erect system is fully formed. In certain species, such as Vaucheria, the plant body resembles a cylindrical tube. The plant body of some algae, including Ulva, resembles leaves. In the Chlorophyceae family, Chara has the most highly organized plant body due to its extremely complex structure and well-protected sex organs**.**

4.10 QUESTIONS ON CHLOROPHYCEAE

Q 1: What are the fundamental kinds of green growth?

Ans: Euglenophyta (Euglenoids), Chrysophyta (Golden-earthy colored green growth and Diatoms), Pyrrophyta (Fire algae), Chlorophyta (Green algae), Rhodophyta (Red green growth)

Q. 2 : What are the 5 kinds of the plant kingdom?

Ans: The plant kingdom has been characterized into five subgroups as per the previously mentioned measures:

- Thallophytes.
- Bryophyta.
- Pteridophyte.
- Gymnosperms.
- Angiosperms.

Q 3: What family name does Chlorophyceae go by?

Ans: Chlorophyceae class Chlamydomonas, Chlorella, Dunaliella, Oedogonium, and Volvox are mostly freshwater organisms.

Q 4: What category do algae fall under?

Ans: Three classes of algae are recognized. There are three of them: Rhodophyceae, Phaeophycean, and Chlorophyceae.

Q. 5 : What is called a plant kingdom?

Ans: The kingdom Plantae remembers organic entities that reach for size from minuscule greeneries to goliath trees. Regardless of this gigantic variety, all plants are multicellular and eukaryotic (i.e., every cell has a film bound core that contains the chromosomes).

Q. 6: What are the 3 divisions of plants?

Ans: This kingdom is partitioned into three divisions in particular Bryophytes, Pteridophytes and Spermaphyte.

4.11 CHLORELLA

Chlorella is a genus of about thirteen species of single-celled green algae of the division Chlorophyta. The cells are spherical in shape, about 2 to 10 μm in diameter, and are without flagella. Their chloroplasts contain the green photosynthetic pigments chlorophyll-a and -b. In ideal conditions cells of *Chlorella* multiply rapidly, requiring only carbon dioxide, water, sunlight, and a small amount of minerals to reproduce

The name *Chlorella* is taken from the Greek, *chlōros/khlōros*, meaning green, and the Latin diminutive suffix *ella*, meaning small. German biochemist and cell physiologist Otto Heinrich Warburg, awarded with the Nobel Prize in Physiology or Medicine in 1931 for his research on cell respiration, also studied photosynthesis in *Chlorella*. In 1961, Melvin Calvin of the University of California received the Nobel Prize in Chemistry for his research on the pathways of carbon dioxide assimilation in plants using Chlorella. Chlorella has been considered as a source of food and energy because its photosynthetic efficiency can reach 8%, which exceeds that of other highly efficient crops such as sugar cane.

4.12 TAXONOMY

Chlorella was first described by Martinus Beijerinck in 1890. Since then, over a hundred taxa have been described within the genus. However, biochemical and genomic data has revealed that many of these species were not closely related to each other, even being placed in a separate class Chlorophyceae. In other words, the "green ball" form of Chlorella appears to be a product of convergent evolution and not a natural taxon. Identifying Chlorella-like algae based on morphological features alone is generally not possible.Some strains of "Chlorella" used for food are incorrectly identified, or correspond to genera that were classified out of true Chlorella. For example, Heterochlorellaluteoviridis is typically known as Chlorella luteoviridis which is no longer considered a valid name.

As a food source

Chlorella is a food source because it is high in protein and other essential nutrients; when dried, it is about 45% protein, 20% fat, 20% carbohydrate, 5% fiber, and 10% minerals and vitamins. Mass-production methods are now being used to cultivate it in large man-made circular ponds. It is commonly used as a superfood and can be found as an ingredient in certain liquid-based cocktails.

When first harvested, *Chlorella* was suggested as an inexpensive protein supplement to the human diet. Advocates sometimes focus on other supposed health benefits of the algae, such as claims of weight control, cancer prevention, and immune system support. According to the American Cancer Society, "available scientific studies do not support its effectiveness for preventing or treating cancer or any other disease in humans".Under certain growing conditions, *Chlorella* yields oils that are high in polyunsaturated fats—*Chlorella minutissima* has yielded eicosapentaenoic acid at 39.9% of total lipids. Some companies producing *Chlorella* commercially as a human food includeTerraVia and Allma.

Health concerns

A 2002 study showed that Chlorella cell walls contain lipopolysaccharides, endotoxins found in Gram-negative bacteria that affect the immune system and may cause inflammation. However, more recent studies have found that the lipopolysaccharides in organisms other than Gram-negative bacteria, for example in cyanobacteria, are considerably different from the lipopolysaccharides in Gram-negative bacteria.

Hydrodictyon

The water net (genus Hydrodictyon) is a taxon of freshwater green algae in the family Hydrodictyaceae. Hydrodictyon does well in clean, eutrophicwater, and has become a nuisance in New Zealand, where it has been recently introduced. The name water net comes from the (usually pentagonal or hexagonal) mesh structure of their colonies, which can extend several decimeters.

Hydrodictyon, known as the "water net", has large colonies composed of elongate cells linked in a reticulated, net-like pattern. Each cell is connected at its end walls to two other cells, forming meshes of five or six cells. The colonies can be as large 4-6 cm wide and 1 m long. The cells are coenocytic and multinucleate. Young cells have a single parietal chloroplast with one pyrenoid, while in older cells the chloroplasts become net-like with multiple pyrenoids. Large vacuoles take up most of the cellular space and push the cytoplasm around the periphery of the cell. Research has shown that resistant algaenans do not build up in the cell walls of Hydrodictyon as they do in Scenedesmus and Pediastrum, despite molecular sequence data indicating that the three taxa are closely related. Instead of forming protective compounds that would allow them to survive unfavorable conditions, Hydrodictyon cells have instead evolved the ability to reproduce rapidly.

4.13 REPRODUCTION IN HYDRODICTYON

Algae in the genus can reproduce asexually or sexually. Asexual reproduction takes place by biflagellated (having two flagella) zoospores formed by the thousands inside a cell. However, the zoospores hardly move, as they are packed very densely. The zoospores form a cell wall, become cylindrical in shape, and arrange themselves in a hexagonal pattern, much like the mature tissue. The mother cell disintegrates, releasing the microscopic daughter net.

During sexual reproduction, which takes place by iso-gametes (gametes of the same size) even smaller than the zoospores, the iso-gametes escape through a hole in the cell wall of the mother cell. Two gametes fuse, forming a zygote, which then develops a thick cell wall and becomes angular in shape. After a rest period, 2-5 zoospores, which are bigger than the ones formed by asexual reproduction, are produced. The zoospores then enlarge into polygonal cells. The cytoplasm of the cells then divide into new zoospores which lose their flagella and form a new net by lying against each other.

4.14 ENTEROMORPHA

Enteromorpha (division Chlorophyta**)** A genus of macroscopic green algae in which the thallus consists of elongated, hollow, tubular fronds with walls only one cell thick. The fronds may be simple or branched. The species are often difficult to distinguish from one another. *E. intestinalis* is a common species in Britain, occurring in rock pools on the upper shore and in estuaries; the thallus is typically irregularly inflated, giving the resemblance to an intestine, and may reach up to 1.5 m in length and 1.5–2.0 cm in diameter. *Enteromorpha flexuosa* is a very common high intertidal green alga found wherever there is freshwater intrusion, such as freshwater stream or underwater spring input to the ocean. It is often associated with coastal areas of high nutrients, including areas with residential and industrial development.

E. flexuosa is considered an invasive and fouling species in much of the world. This is an opportunistic species that has a very successful reproductive stage. Under the right conditions it will release propagules daily. The motile reproductive cells actually have the ability to photosynthesis, thus increasing their potential viability and dispersion. Because of this high reproductive ability, *E. flexuosa* is markedly fecund and, therefore, an excellent pioneer species, settling available substrates quickly. But it does not compete well with other successional species. In studies of disturbance and settlement, *E. flexuosa* was found to maintain a low percent cover in undisturbed areas but, following a disturbance, density increased dramatically.

E. flexuosa is often found in communities with or near Ulva fasciata, another pioneer green alga species. Both are fouling organisms associated with industrial pollution. Anti-fouling studies investigating control and/or eradication of fouling species identify these two species as serious pests in shipping and industrial areas.

4.15 SPHAEROPLEA

Sphaeropleales is an order of green algae that used to be called Chlorococcales.[2] The order includes some of the most common freshwater planktonic algae such as Scenedesmus and Pediastrum. The Spaeropleales includes vegetatively non-motile unicellular or colonial taxa that have biflagellate zoospores with flagella that are directly opposed in direction (the DO arrangement): Sphaeroplea, Atractomorpha, Neochloris, Hydrodictyon, and Pediastrum. All of these taxa have basal body core connections.

With an increase in the number of taxa for which sequence data are available, there is evidence of an expanded DO clade that includes additional zoosporic (Bracteacoccus, Schroederia) and some strictly autosporic genera such as Ankistrodesmus, Scenedesmus, Selenastrum, and Monoraphidium. The filamentous Microspora has been allied with the coccoid genus *Bracteacoccus* based on molecular data. Monophyly of the DO clade is supported by phylogenetic analysis of multi-gene data.

The order Sphaeropleales comprises vegetatively nonmotile unicellular or colonial taxa with biflagellate zoospores having DO basal body orientation. After molecular phylogenetic studies, the scope of this order has been remarkably extended after inclusion of numerous autospore-forming taxa of the classical order Chlorococcales *sensu lato*. For example, the species-rich coccoid families of Hydrodictyaceae, Scenedesmaceae, and Selenastraceae now belong to the Sphaeropleales. All taxa of the order Oedogoniales grow in filaments on submerged surfaces in freshwaters. The oedogonialean zoids (either asexual zoospores or male gametes) exhibit a unique stephanokont flagellation developing an anterior ring of flagella. The order Chaetophorales contains filamentous taxa producing quadriflagellate zoids with upper and lower pairs of CW orientated basal bodies.

Chloroplasts in the chlorophyte orders considered here vary greatly in size and shape. Commonly there is a single chloroplast lying against the inner cell wall and these vary from disk- or platelike, ringlike, or netlike. There are many exceptions that include the Prasiolales, where the centrally positioned chloroplast is marginally lobed. Often the chlorophyll in terrestrial algae is masked by red carotenoid pigments (e.g., astaxanthin), which are sometimes dissolved in lipid droplets within the cell. Each chloroplast normally contains one to several pyrenoids (proteinaceous bodies) surrounded by a sheath of starch; pyrenoid number is a character of taxonomic importance. Its absence has to be viewed with caution, since they are known to arise *de novo* and are not always visible using the light microscope (LM).

Taxonomically important characters are associated with ultrastructural features of the chloroplast and pyrenoid. Of the orders considered, only the Cladophorales, Siphonales, and Sphaeropleales are multinucleate. In the Siphonales, cross walls develop only during reproduction and thus the vegetative thallus is nonseptate (acellular) and multinucleate. The cellulose cell wall of green algae has a structural fibrillar component and an amorphous matrix component; the latter is predominantly on the outer wall and often forms a slimy or mucilaginous outer layer. In a few orders the outermost layer is very hard and provides a suitable attachment surface for many algal epiphytes.

The algae considered here, only the Trentepohliales and the Charales possess sporopollenin, a very hard and phenol-containing substance present in higher plant spore walls. Other green algae have decay-resistant wall compounds which differs chemically from sporopollenin in consisting of polymers of unbranched hydrocarbons and lacking phenolic groups. Some green algae are characterized by having a diffluent or firm mucilaginous sheath or envelope.

4.16 SUMMARY

Under this unit we have summarized concept of qualities of kingdom planti, qualities of chlorophytes, phylogeny & classification of chlorophyceae etc. in spite of these, we have also discussed Chlorella, Hydrodictyon, Eneromorpha and Sphaeroplea. Kingdom Plantae includes all the plants. They are eukaryotic, multicellular and autotrophic organisms. The plant cell contains a rigid cell wall. Plants have chloroplast and chlorophyll pigment, which is required for photosynthesis. Chlorophyta or green algae constitute a division that has the following set of attributes: chloroplasts with no external endoplasmic reticulum, thylakoids typically in stacks of two to six, chlorophyll-a and -b as photosynthetic pigments, true starch, and cellulosic walls or scales

The Chlorophyta, comprises the early diverging prasinophytes, which gave rise to the core chlorophytes. The other clade, the Streptophyta, includes the charophyte green algae from which the land plants evolved. Multi-marker and genome scale phylogenetic studies have greatly improved our understanding of broad-scale relationships of the green lineage, yet many questions persist, including the branching orders of the prasinophyte lineages, the relationships among core chlorophyte clades. Algae are broadly classified into three algal divisions as red (Rhodophyceae), green (Chlorophyceae), and brown algae (Phaeophyceae) based on the presence of natural pigments.

Chlorella (Chlorella pyrenoidosa) is a type of algae that grows in fresh water. It's sometimes called seaweed. It's used for nutrition and as medicine. Chlorella is a good source of protein, fats, carbohydrates, fiber, chlorophyll, vitamins, and minerals.Water net, (genus Hydrodictyon), genus of filamentous green algae (family Hydrodictyaceae) sometimes found on the surface of quiet freshwater bodies. Because of its reproductive efficiency, Hydrodictyon proliferates rapidly and can be a problem in ponds, recreational waters, and irrigation canals.Enteromorpha (Ulva) prolifera (E. prolifera) is a seaweed green alga (Chlorophyta) that contains many bioactive compounds, of which polysaccharide is the main component.

4.17 TERMINAL QUESTIONS

Q.1 What do you mean bythallus of Chlorophyceae (green algae)? Explain it.

Answer:---

Q.2 Describe the qualities of kingdom plantae.

Answer:---

Q.3 Describe the general qualities of chlorophytes.

Answer:---

Q. 4 Write short notes on the following.

(a) Chlorella

(b) **Enteromorpha**

Answer:--

Q.5 Describe the phylogeny and classification of Chlorophyceae.

Answer:--

Q.6 Write short notes on reproduction in hydrodictyon.

Answer:--

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 5: CHLOROPHYCEAE-II

Structure

5.1 INTRODUCTION

Chlorophyceae (chloros, green; phyceae, algal organisation) is commonly known as green algae'. Fritsch (1935) considered to include the green algae under the class Chlorophyceae, which have been raised to the rank of division Chlorophyta by Smith (1938), Tippo (1942) and Bold (1950). Later Prescott (1969) and Round (1973) considered it to the rank of phylum Chlorophyta. Papenfuss (1946) included the suffix 'phyco' to the divisions of algae and named chlorophyta as Chlorophycophyta. Later Bold and Wynne (1978) also followed the same suggestion. Considering more appropriate, the classification of Fritsch (1935) is followed in this unit.

This class consists of 425 genera and about 6,500 species but, later Prescott (1969) reported that the number of species may be as many as 20,000; with more being discovered continuously. The name green alga is given because of the presence of dominant pigments like Chlorophylls a and b over the carotenoids and xanthophylls. They are all eukaryotes.

Objectives

This is the fifth unit (Chlorophyceae II) of block 1st (Algae-I). Under this unit, we have following objectives. These are as under:

- To know the general features of Chlorophyceae.
- To conceptualize their reproduction, classification and phlogeny
- To know the concept of vegetative structures, reproduction and thallus organization
- To discuss different genera such as Cladophora,Draparnaldiopsis etc.

5.2 OCCURRENCE OF CHLOROPHYCEAE (GREEN ALGAE)

The members of Chlorophyceae generally grow in fresh water (about 90%) and the rest in saline water, terrestrial habitat etc. The fresh water members such as Volvox, Oedogonium, Spirogyra etc. grow in ponds, pools and lakes. Members of conjugales (e.g., Spirogyra, Zygnema etc.) and Oedogoniales (e.g., Oedogonium etc.) are strictly fresh water, but the members of Ulvaceae and Siphonales are predominantly marine. Some members of Volvocales, Chaetophorales and Cladophorales grow both in fresh and saline water.

Some species of Ulothrix and Vaucheria are subaerial and grow on damp soil. Some members may be terrestrial and grow as epiphytes on tree trunk, leaves etc. (e.g., Trentepohlia); as epizoic i.e., (growing on animal bodies (species of Characium and Cladophora); as endophytes (e.g., Chlorella), as parasites (e.g., Cephaleuros, Rhodochytrium and Phyllosiphon) and also cause diseases.

They can also grow in further different habitats like hot springs (Chlorella), snow (Chlamydomonas yellowstonensis), saline water (C. ehrenbergi) and some remain as partners in lichen associations.

5.3 IMPORTANT CHARACTERISTICS OF CHLOROPHYCEAE (GREEN ALGAE):

- Members of Chlorophyceae grow mostly in fresh water, a few in brackish and saline water and a few are terrestrial.
- They show wide range of variations in their thallus structures like unicellular motile (Chlamydomonas) and non-motile (Chlorella), coenobium (Volvox), palmelloid (Tetraspora), dendroid (Ecballocystis), filamentous branched (Cladophora) and unbranched (Spirogyra), heterotrichous (Coleochaete), siphonaceous (Vaucheria) and parenchymatous (Ulva).
- Flagella are 1-many, equal in size and inserted either apically or sub-apically. The flagella show typical 9+2 arrangement when viewed under E.M.
- The cells are eukaryotic in nature. Usually there is only one nucleus in each cell, but in Siphonales and Cladophorales many nuclei are present in their coenocytic body. Normally the number of nucleolus is one per nucleus, but several nucleoli are present in the members of Conjugales.
- The cell wall is mainly made up of cellulose, which comprised of hydroxyproline glycosides or xylans and mannans. In Chara the cell wall is encrusted with calcium and magnesium carbonate.
- Inner to the cell wall, semipermeable cell membrane is present which encircles the

protoplast. The cytoplasm contains many small vacuoles which pushes the nucleus with cytoplasm towards the periphery and called primordial utricle.

- The flagellate cells have eye-spot or stigma in the anterior portion, which remain inserted at one side of the chloroplast.
- The pigments are located in the chloroplast. Chkiroplast generally contains pyrenoid(s).
- The main pigment is chlorophylls a and b; those dominate over α-and β-carotenes and xanthophylls.
- Phycobilins are absent.
- The reserve food is starch, composed of amylose and amylopectin.
- They reproduce by all the three means i.e., vegetative (cell division and fragmentation), asexual (zoospore, aplanospore, akinete etc.) and sexual (isogamy to oogamy). The sexual reproduction is absent in some members of Chlorococcales.

5.4 THALLUS ORGANISATION OF CHLOROPHYCEAE (GREEN ALGAE):

The class Chlorophyceae shows a range of variation in the structure of plant body (thallus). It ranges from unicellular e.g., Chlamydomonas, Chlorella, Sphaerella etc. to multicellular structure. The multicellular forms may be of different types. They may have a number of cells arranged in colonies of definite shape, the coenobium. The number of cells in a coenobium may be definite and motile as in Volvox, Pandorina, Pleodorina etc. or the number may be indefinite, arranged in net-like masses and are non-motile as in Hydrodictyon. The multicells may aggregate and form a non-motile palmelloid structure, where the cells remain embedded in an amorphous or gelatinous matrix as found in Tetraspora and Palmodictyon.

In multicellular forms the cells may be arranged in a single row to form the filament. The filament may be branched (e.g., Pithophora, Cladophora etc.) or unbranched (e.g., Oedogonium, Spirogyra, Ulothrixetc.). The multicells may aggregate and form an expanded sheet-like structure as found in Coleochaete. It shows heterotrichous habit where the erect system is well-developed. In some members the plant body is like cylindrical tube i.e., coenocy- tic as in Vaucheria. In some algae like Ulva, the plant body is leaf-like. The highly organised plant body in Chlorophyceae is found in Chara, where the plant is very much complicated in structure with well protected sex organs.

5.5 CLASSIFICATION OF CHLOROPHYCEAE (GREEN ALGAE):

1. **Order. Volvocales:**

The order Volvocales includes 60 genera and about 500 species.

Important characteristics:

- They are commonly found in fresh water. Some are grown in brackish water, marine water and also on soil.
- The plant body is unicellular or multicellular and the multicellular ones are colonial in habit.

- Both unicellular and colonial members are motile, either throughout or some part of their life cycles.
- They reproduce both asexually and sexually. Asexual reproduction takes place by zoospores, aplanospores, hypnospores etc. and sexual reproduction by iso-, aniso-, and oogamy.

5.6 CLASSIFICATION:VOLVOCALES

Fritsch (1935) divided the order Volvocales into 3 suborders and 7 families. **The outline of classification is given below:**

I. Sub order. Chlamydomonadineae

Family.

i. Chlamydomonadaceae

ii. Sphaerellaceae

iii. Polyblepharidaceae

iv. Phacotaceae

II. Sub order. Tetrasporineae

Family.

i. Tetrasporaceae

ii. Palmellaceae

III. Sub order. Chlorodendrineae

Family. i.

Chlorodendraceae

Family. Chlamydomonadaceae

Important characteristics:

- Plant body is unicellular, uninucleate with definite cell wall.
- Cells have 2-4 flagella which a.re equal in length.
- Chloroplast is generally cup-shaped, but it may be H-shaped, reticulate, stellate etc.
- Asexual reproduction takes place mainly by zoospores.
- Sexual reproduction takes place by all the three means iso-, aniso-, and oogamy.

2. Order. Ulotrichales

Important characteristics:

The order Ulotricales includes 80 genera and about 430 species. Most of them are fresh water, while a few are marine (e.g., Ulva).

The important characteristics of the order are:

- They are commonly found in fresh water (e.g., Ulothrix) or on soil, but a few are marine (e.g., Ulva, Enteromorpha).
- Plant body is commonly an unbranched filament; but in Ulvaceae it is parenchymatous

or foliaceous.

- Cells are uninucleate and contain chloroplast of different types like C-shaped, parietal, axial etc.
- Each chloroplast contains one or more pyrenoids.
- Asexual reproduction takes place by means of bi- or quadriflagellate zoospores, aplanospore and akinetes.
- Sexual reproduction takes place by gametic union and may be iso-, aniso-, or oogamous type.

5.7 CLASSIFICATION:ULOTRICHALES

Fritsch (1935) divided the order Ulotrichales into 3 suborders and 6 families.

The outline of classification is given below:

Order. Ulotrichales

I. Sub order. Ulotrichineae

Family.

i. Ulotrichaceae

ii. Microsporaceae

iii. Cylindrocapsaceae

iv. Ulvaceae

II. Sub order. Prasiolineae

Family.i. Prasiolaceae

III. Sub order. Sphaeropleineae

Family. i. Sphaeropleaceae

Family. Ulotrichaceae

Important characteristics:

- The plant body is an unbranched filament.
- Cells of the filament are uninucleate.
- Cells have single girdle-shaped, parietal chloroplasts.
- Sexual reproduction is isogamous and takes place by the union of biflagellated gametes.

3. Order. Chaetophorales:

Chaetophorales are the plants with hair or setae.

The important characteristics of the order are given below:

- Members are generally found in fresh water.
- Plant body is filamentous and shows prominent heterotrichous habit; however, in Coleochaete, the prostrate system is well- developed and in Microthamnion the erect system is well-developed.

- Some members have setae (Coleochaete) or hairs (Stigeoclonium) of different types. The hairs may be in the form of single elongated cell or rows of fine and elongated cells.
- The cells contain a parietal chloroplast with many pyrenoids.
- Erect system bears reproductive structures.
- Vegetative reproduction takes place by fragmentation.
- Asexual reproduction takes place by bi- or quadriflagellate zoospores, aplanospores or akinetes.

viii. Sexual reproduction is commonly isogamous (Fritschiella, Stigeoclonium), anisogamy (Aphanochaete) and oogamy (Coleochaete) are found occasionally.

Fritsch (1935) classified the order into 5 families.

These are:

Chaetophoraceae, Trentepohliaceae, Coleochaetaceae, Chaetosphaeridiaceae and Pleurococcaceae.

Family. Coleochaetaceae:

Important characteristics:

- Plant bodies possess a typical heterotrichous habit. Generally the projecting system is dominant and looks like disc.
- Cells are uninucleate with single lamellate parietal chloroplast with one or two pyrenoids.
- All or some cells bear a single long sheathed bristle or seta.
- The sheath is present in the form of a basal cylinder of mucilage.
- The growth is always through the apical region.
- Asexual reproduction takes place by means of biflagellate zoospores.
- Sexual reproduction is oogamous.

4. Order. Oedogoniales

Important characteristics:

- Most of the members grow in fresh water. The order is represented by only three genera, Oedogomium, Oedocladium and Bulbochaete.
- They are filamentous and the filaments may be branched (Oedocladium and Bulbochaete) or unbranched (Oedogomium).
- The plant body is differentiated into apical and basal region.
- It consists of cylindrical cells and the cells are longer than breadth.
- Cells are uninucleate and have reticulate chloroplast with pyrenoids.
- Cell division is elaborate and a cap is formed at the upper end of the daughter cell.
- Asexual reproduction takes place by pyri- form, multinucleate and multiflagellate zoospores. Flagella are arranged in a ring around the beak-like anterior end.
- Sexual reproduction is advanced oogamous type.
- Both androspores and antherozoides are multiflagellate.

- Male gametes are similar to zoospore but smaller in size.
- Heterothallic or dioecious species are of two types: macrandrous (where male and female filaments are of normal size) and nannandrous type (where male is very small i.e., dwarf male or nannandrium and the female one is of normal size).

5.8 CLASSIFICATION:

According to Fritsch (1935) the order Oedogoniales contains only one family Oedogoniaceae. The family has only three genera: Oedogomium, Oedocladium and Bulbochaete.

5. **Order. Siphonales:**

Important characteristics:

- Most of the members of Siphonales are marine. A few members are freshwater. Some members grow as epiphytes or endophytes.
- Thalloid plant body is variously branched, aseptate and multinucleate i.e., coenocytic.
- Plant body may be simple vesicular type (Protosiphon) to much branched filamentous type.
- Numerous small and discoid chromato- phores are arranged peripherally inside the thallus.
- Nuclei are present towards the inner layer.
- The characteristic pigments of this order are siphonin and siphonoxanthin.
- Presence of siphon-like central vacuole throughout the plant body, which remains filled with sap. Cytoplasm is present between the outer wall and vacuole. The order is named “Siphonales” because of the presence of siphon-like vacuole.
- The plant reproduces by all the three means vegetative, asexual and sexual. Vegetative reproduction takes place by fragmentation, asexual reproduction by multiflagellate zoospore, aplanospore or hypnospore and sexual reproduction by oogamy. Rarely they perform iso- and anisogamy.

Classification:

Fritsch (1935) divided the order Siphonales into 9 families.

These are:

- Protosiphonaceae,
- Caulerpaceae,
- Dasycladaceae,
- Derbesiaceae,
- Codiaceae,
- Valoniaceae,
- Chaetosiphonaceae,
- Phyllosiphonaceae, and
- Vaucheriaceae.

This classification is also followed by M. O. P. lyenger (1951)

6. **Order. Charales**

Important characteristics:

- Members of this order are distributed throughout the world.
- Commonly they are found in fresh water with muddy or sandy bottom and also in water flowing over limestone.
- Plants are macroscopic, much branched, and erect and commonly up to 30 cm in length.
- The plants are differentiated into nodes and internodes. Some of the nodes bear branches of unlimited growth, those are again divided into nodes and internodes. Each node of the main axis and branch of unlimited growth bear a number of branches of limited growth.
- Cells are very long, uninucleate and contain many discoid chloroplasts.
- Most of the species show cortication in the internodes. The cortex consists of vertically elongated row of cells.
- Sexual reproduction is highly advanced, oogamous type.
- The male and female reproductive bodies are globule and nucule, respectively. Globule develops many antherozoids and nucule contains only one egg.
- Zygote is produced after sexual reproduction. It shows very much elaborate post-fertilization changes. During germination, zygote undergoes meiosis and gradually it forms the plant body.

Classification:

Fritsch (1935) placed the order Charales under the class Chlorophyceae includes only one family the Characeae having 2 sub families:

1. Nitelleae and
2. Chareae.

Bold and Wynne (1978) placed the order Charales alone under the only class Charophyceae, under the division Charophyta. The order Charales includes only one family Characeae. Divn. Charophyta: Class. Charophyceae.H. C. Bold and M. J. Wynne (1978) in their classification took out Chara along with some other genera like Tolypella, Nitella, Nitellopsis, Protochara, Lamprothamnium and Lychnotham- nus from Chlorophyceae and placed them in a separate Division Charophyta. The Charophyta consists of single class Charophyceae; order Charales and family Characeae.

Important characteristics of Characeae:

- The division Charophyta includes the members of green algae, commonly known as stoneworts.
- Plant body shows much elaboration of vegetative structures encrusted with calcium carbonate.
- Plant body is erect and consists of elongated, jointed, commonly green main axis bearing branches, differentiated into nodes and internodes.
- Each node bears a whorl of lateral branchlets.

- Asexual reproduction is absent.
- Sexual reproduction is of oogamous type.
- Antheridia (globule) and oogonia (nucule) show more complexity and elaboration than other Chlorophycean members.
- Motile cells are asymmetrical and two flagella are attached in lateral position of an antherozoid.
- Sex organs are so large that they can be visible with naked eye.
- Zygote on germination forms proto- nema (Chara, Nitella) from which vegetative plants are developed.

5.9 ECONOMIC IMPORTANCE OF CHLOROPHYCEAE (GREEN ALGAE):

The green algae are not so economically important except a few members. Among them Chlorella is very important because of its high protein content, presence of vitamins and its use in baking industry in the preparation of cake, pastries etc. It is also used in the preparation of an antibiotic, chlorellin; which is used to control bacteria. It is also used in different physiological experiments.

Another important member, Chara, is very useful to control malaria for its larvicidal properties. It is used as fertiliser and in the preparation of polishes. Monostroma is used to prepare the common food 'aonori' in Japan. In South India, Green Laver, a kind of food, is prepared from Spirogyra and Oedogonium. Ulva and Enteromorpha are also eaten' by some people. Many members are used as a source of food and O_2 for many aquatic animals.

5.10 CLADOPHORA

The chlorophyte *Cladophora* (Chlorophyta, Ulvophyceae; more than 400 species) is widely regarded as the most important harmful filamentous alga of inland waters, and the most abundant alga in alkaline streams throughout the world. It also thrives in many freshwater and brackish lakes, and among the most famous of its habitats are the Laurentian Great Lakes. As a 'poster child' of the 1960s ecology movement in the United States, Cladophora glomerata focused international attention on the west basin of Great Lake Erie where it proliferated in response to phosphorus pollution, then drifted into shore in rotting masses from major seasonal die-offs that were sometimes measured in tonnes of fresh weight. *Cladophora* thrives in P-enriched waters with dependable substrata (e.g., large boulders) for attachment. In some habitats, increased nitrogen enrichment (N_i, urea) can also stimulate increased production. *Cladophora* has a relatively high light optimum for photosynthesis, can rapidly acclimate to low or high light.

Like other benthic algae, *Cladophora* is highly patchy in spatial and temporal distribution. Its adverse effects include overgrowing irrigation systems and drainage canals, clogging of water intakes leading to power outages, overgrowth, and displacement of beneficial aquatic plants, reductions in invertebrate densities and fish spawning, reduction in species biodiversity, anoxia from decaying mats resulting in kills of other aquatic life, retention of pathogenic microbes such as *Escherichia coli* Migula and enteroocci fecal bacteria as a potential human health hazard, negative effects on recreational use of affected shoreline and nearshore areas, and depressed property values of adjacent homes.

Cladophora is a genus of reticulated filamentous Ulvophyceae (green algae). The genus *Cladophora* contains many species that are very hard to tell apart and classify, mainly because of the great variation in their appearances, which is affected by habitat, age and environmental conditions. Unlike Spirogyra the filaments of *Cladophora* branch and do not undergo conjugation. There are two multicellular stages in its life cycle – a haploid gametophyte and a diploid sporophyte – which look highly similar. The only way to tell the two stages apart is to either count their chromosomes, or examine their offspring. The haploid gametophyte produces haploid gametes by mitosis and the diploid sporophyte produces haploid spores by meiosis. The only visible difference between the gametes and spores of *Cladophora* is that the gametes have two flagella and the spores have four. The *Cladophora* species can be a major nuisance causing major alteration to benthic conditions linked particularly with increased phosphorus loading.

5.11 DRAPARNALDIOPSIS (CHLOROPHYCEAE)

Classification:

Draparnaldiopsis G.M.Smith & Klyver, 1929; 8 of 9 species descripsions are currently accepted taxonomically (Guiry and Guiry 2014).

Order Chaetophorales; Family Chaetophoraceae

Morphology:

Consisting of branched, filaments. Main axes of cylindrical cells of different length, short cells alternating with longer cells. Contains secondary branches that are short and alternate from one another. Cells of secondary branches cylindrical, inflated or fusiform, with terminal cells narrowly obtuse or bearing long multicellular hairs.(Smith 1902). Cells uninucleated. Reproduction by zoospores often produced in cells of main axes and gametes in those of secondary branches

Similar genera:

Draparnaldia has uniform length of cylindrical cells in main axis.

Habitat:

Wide variety of aquatic habitats.

Draparnaldia is a genus of freshwater green algae in the family Chaetophoraceae. *Draparnaldia* are uniseriate; each filament is composed of a chain of cells arranged in one row. Chloroplasts appear as a band within the center of each cell. The length of the main axis cells are generally the same, regardless of whether or not they bear branches. These side branches are divided extensively into terminal hairs. The entire plant is enveloped in loose, slippery mucilage. *Draparnaldia* is a cosmopolitan genus with wide distribution and it is usually found in cold aerated waters. They are either attached to sand or grow epiphytically on other aquatic plants. *Draparnaldia* can be seen growing in clear streams trailing on stones and boulders. Herman S. Forest of The Southern Appalachian Botanical Club has stated that while not common, it is present frequently enough to be recorded in almost all local flora lists of green algae that have been compiled. A multitude of species are present in Lake Baikal, Siberia and have been described by Meyer and Jasnitzky. A species of the genus had been placed and described in the Linnean

Herbarium as *ConfervaMutabilis* Roth in 1797. Nowadays *Conferva* is no longer used and the species is described as *Draparnaldiamutabilis* (Roth) Bory. Bory is added in honour of the researcher of the same name, based on whose description the genus was separated from similar appearing forms. Bory is accredited with the establishment of the genus.

Morphology

Draparnaldia attaches to the substrate with rhizoids and is composed of erect, branching filaments surrounded by soft mucilage. Branches born in alternating, opposite, or whorls of tufts from the main axis. Chloroplasts tend to be parietal bands (i.e. "barrel shaped"). Tips of branches usually bear long, tapering hairs. The morphology is highly variable [2] being dependent upon several environmental conditions. The hairs develop through the elongation of the apical cell on the branch tips; as they elongate, the chloroplast is lost. Hair development is affected by the levels of phosphorus, nitrogen, carbon dioxide, and light. Although hair production can be suppressed under lab conditions, they are always present in the field.

Ecology

Draparnaldia is usually found attached to sand, sticks or rocky substrate. It can be located in streams, ditches, springs, and shallow, peaty lakes, but usually only in cold, soft flowing waters. The hairs seem to function in nutrient uptake. Under low nutrient levels, the intensity of hair formation increases. It has been demonstrated that phosphatase activity is localized to the hairs and can be induced with decreasing phosphorus level

5.12 DRAPARNALDIOPSIS: VEGETATIVE BODY AND REPRODUCTION

In this unit we will discuss about the vegetative body and reproduction of draparnaldiopsis.

Vegetative Body of Draparnaldiopsis

The thallus has a main axis, which is differentiated into cylindrical, elongated and somewhat barrel-shaped internodal cells, which alternate with one another in a very regular fashion. The internodal cells are about two to three times longer than the nodal cells. The axis is attenuated towards the apex and the base. The lowest of the basal cells forms a rhizoid, while a few other cells situated above develop rhizoidal branches forming a dense cortex around the base of the main axis.

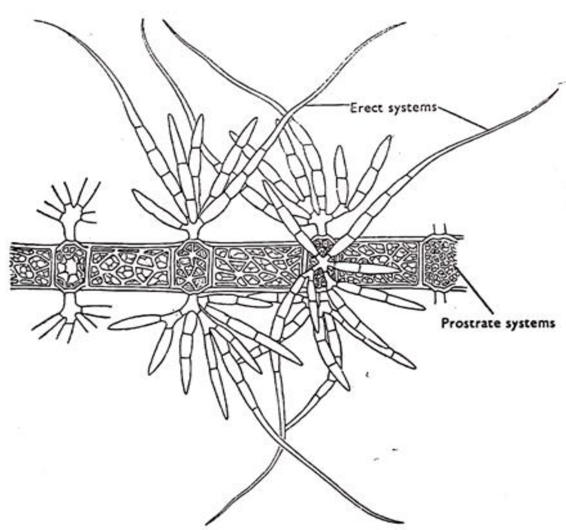


Fig.5.1 The portion of thallus body in draparnaldiopsis

The main axis usually bears a number of lateral branches of unlimited growth. They arise from some of the nodal cells. Short branches of limited growth also arise from the nodal cells as opposite pairs in whorls of four. They may develop also on the branches of unlimited growth. Some of the nodal cells may bear both branches of limited and unlimited growth. The branches of limited growth form more or less orbicular clusters due to their spreading character. Each branch is subulate and is terminated in a long, hyaline hair at the distal end. In this species, there is a great tendency for the transformation of branches of limited growth into rhizoid-like structures, particularly at the points where branches of unlimited growth arise. The entire thallus is enveloped by mucilage.

Chloroplasts are present in each cell excepting in the cells of hairs and rhizoids. They are parietal, reticulate and occupy the whole length of the cell. One or two pyrenoids may be present in the chloroplasts of branches of limited growth. Rhizoids are much branched and usually are not differentiated into nodal and internodal cells. Their cells are elongated and their chloroplasts gradually disorganize and disappear.

Reproduction in Draparnaldiopsis:

Zoospore and gamete-formation have not yet been observed in this species. This Indian alga agrees with the American species, D. alpinia Smith and Klyver, in many respects. The main points of difference lie in the structure of the thallus with its long, projecting mucilaginous threads and in the occasional barrel-shaped cells of the main axis.

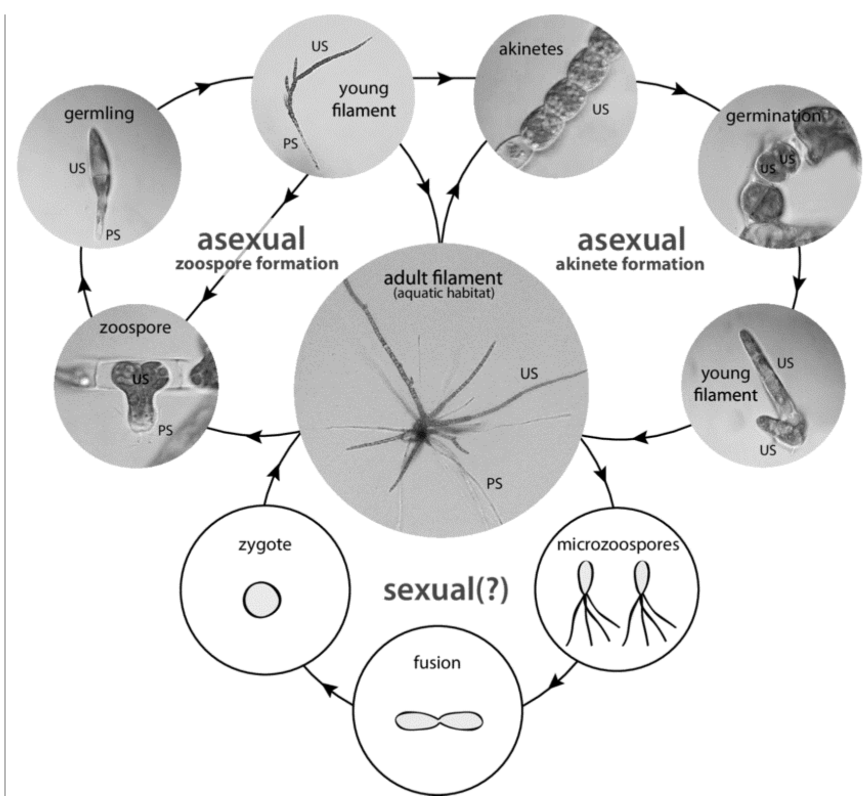


Fig.5.2 Reproduction in Draparnaldiopsis:

5.13 LIFE CYCLE OF DRAPARNALDIA

There aretwo types of asexual reproduction are presented in Draparnaldia. Zoospores are strictly aquatic reproductive stages and have a distinct Upright Sytem (US) and Prostrate System (PS). Akinetes (= resting stages) are zoospores arrested in a parental filament. They are formed during drought periods and enable a long-term survival in the terrestrial habitat. However, water availability is required for their germination. The germinating akinetes have only the US, the PS is formed later. It is noted, that Draparnaldia is also capable of fragmentation. Fragmentation is initiated with algal transition from the aquatic to the terrestrial habitat. It leads to the filament splitting into two new filaments with a fully developed UP and PS. In addition, a sexual reproduction of Draparnaldia has been reported, but it has not been confirmed for this specific strain

5.14 CEPHALEUROS

Cephaleuros is a genus of the family Trentepohliaceae and the division Chlorophyta. It is a genus of parasitic thalloid green alga that overall comprises 14 species approximately. Members of the family Trentepohliaceae are epiphytic, which means they grow upon another plant or object merely for physical support. Such members are also found on tree trunks, damp woodwork, and shady leaves. Parasitic, which means organisms that cause diseases. Although Cephaleuros are categorised under the division of Chlorophyta, still they lack green colour.

The common name of Cephaleuros is red rust, as they are responsible for the causation of red rust disease in tea plants, coffee plants, mango plants, etc. Some members of this genera may also grow in association with a fungus that leads to the formation of a lichen that does not cause any damage to plant tissues. Because lichens refer to the symbiotic relationship between algae and a fungus. According to the Oxford Dictionary, Cephaleuros is a genus that comprises of epiphytic and parasitic green algae that specifically includes the causative organism of red rust. Epiphytic means they grow on other plants to provide physical support. The specimens of this genus can vary from 8-10 mm in size.

Cephaleuros is a genus of parasitic thalloid **green algae** comprising approximately 14 species. Its common name is red rust. Specimens can reach around 10 mm in size. **Dichotomous branches** are formed. The alga is parasitic on some important economic plants of the **tropics** and **subtropics** such as **tea**, **coffee**, **mango** and **guava** causing damage limited to the area of algal growth on leaves (algal leaf spot), or killing new shoots, or disfiguring fruit. Members of the genera may also grow with a **fungus** to form a **lichen** that does not damage the plants.

Characteristics of the genus Cephaleuros

Members of Cephaleuros species have epidermis with cuticles, palisade cells, showing thallus. They reproduce sexually by forming gametangia, and asexually by sporangiophores, or zoosporangia. Sporangiophores project outside from the upper leaf surface. Some of the members of the Cephaleuros like Cephaleuros virescens have filamentous cells across their body structure. They are found in tropical and sub-tropical regions worldwide. They also contain the photosynthetic organisms known as Green algae. The thallus structure of the Cephaleuros family is generally composed of a prostate system and an erect system that provide mutual support during growth and development.

Cephaleuros virescens Causes

Being a member of the genus Cephaleuros, it is a parasitic alga that causes some serious diseases in plants and affects its productivity. These are aerophilic and filamentous green algae.

Cephaleuros virescens is a parasite of guava (Psidium guajava) leaves and fruits in Hawaii, causing leaf and fruit spot diseases. It causes leaf spot disease of guava plants. These spots are reddish-black in a colour that is visible with naked eyes. Apart from guava, C. virescens also infects the crop of tea, coffee, and coconut plants by causing algal leaf spots or algal rust (red rust). The pathogen of this alga is usually dispersed through water or air. They cause infection by depositing their sporangia or thallus filaments over the surface of the leaves. Cephaleuros infections on tea or coffee plants have been called red rust. When the environment is favourable for their growth, zoospores are released from those sporangia, and symptoms become visible. The most favourable environment for their growth is moist and humid with little rainfall.

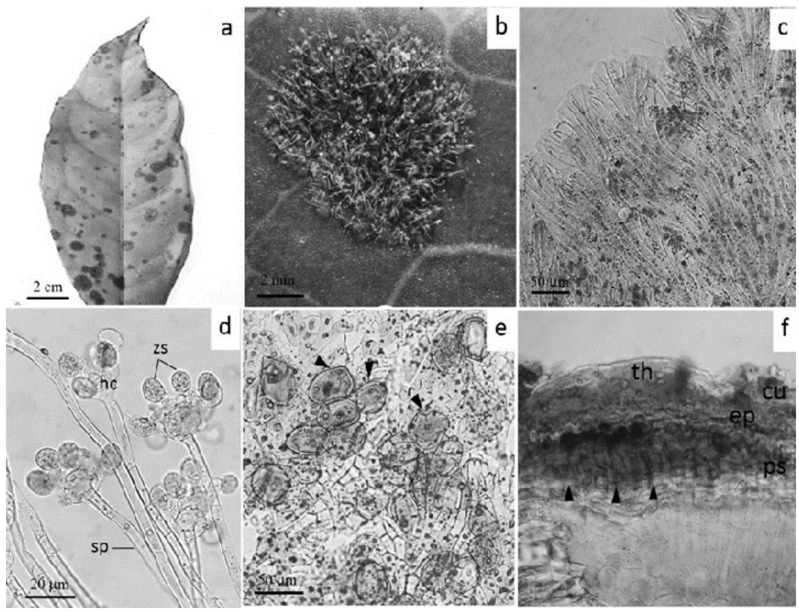


Fig.5.3 General characters of Cephaleuros species: a) orange to dark brown velvety spot lesions on leaf, b) sporangiophores project from upper leaf surface, c) filamentous cells of Cephaleuros virescens, d) asexual reproductive structures composed of sporangiophores (sp), head cells (hc), and zoosporangia (zs), e) gametangia, sexual reproductive structures (arrows), and f) subcuticular growth habit of Cephaleuros species, showing thallus (th), cuticle (cu), epidermis (ep), and palisade cells (ps), and necrotic plant tissue beneath the algal thallus (arrows).

Examples of Cephaleuros

Some of the species of Cephaleuros include C. minimus, C. pilosa, C. expansa, C. solutus, C. virescens, etc. All of these species have almost all unique features, division, life-cycle, mode of infections, and symptoms. But C. virescens is most commonly seen and causes diseases in all the continents of the tropical and subtropical areas.

5.15 SPECIES

The species currently recognised are:

- Cephaleuros virescens
- Cephaleurosbiolophus
- Cephaleurosdiffusus
- Cephaleurosdrouetii

- Cephaleurosendophyticus
- Cephaleurosexpansa
- Cephaleuroshenningsii
- Cephaleuroskarstenii
- Cephaleuroslagerheimii
- Cephaleurosminimus
- Cephaleurosparasiticus
- Cephaleurospilosa
- Cephaleurossolutus
- Cephaleurostumidae-setae

Questions for practice

Q.1 What do you mean by Cephaleuros?

Q.2 Name the common disease caused by Cephaleuros.

Q.3 Gives the characteristics of the division Chlorophyta.

Q.4 How does Cephaleuros form lichen?

Q.5 Why is Cephaleuros parasitic?

Q.6 Give some characteristics of the genus Cephaleuros

Cephaleuros virescens

CephaleuroSvirescens IsAn Algal PlantPathogen ThatInfects Tea, CoffeeAnd Coconut Plants, Causing Algal Leaf Spot Or Algal Rust.

Host and symptoms

Cephaleuros virescens is known to have a broad host range, the widest host range of the species. It has been recorded on 287 plant species and cultivars on the U.S. Gulf coast alone. Common hosts of the plant include tropical trees and shrubs, with the following being the more common or economically important; tea, kava, pepper, para rubber, magnolia, coffee, holly, Indian hawthorn, oil palm, avocado, vanilla, mango, breadfruit, guava, coconut, cashews, cacao, citrus, etc.

Fig.5.4 Cephaleurosparasiticus as a parasite of guava leaves and fruit in Hawaii,causing a leaf and fruit spot disease.

Most commonly *Cephaleuros virescens* is identified by the leaf spots it causes. Theses leaf spots are an orange-brown rust in color and usually occur entirely on the upper leaf surface, although leaf spots on the undersides of infected leaves have been reported. The spots are fuzzy in texture and approximately 2 cm (0.8 in) in diameter. In some cases, commonly in more susceptible hosts, stem and fruit spots can occur as a result of infection as well. These leaf spots cause a reduction in plant photosynthetic surface area. While usually harmless, severe causes of these leaf spots can lead to defoliation, twig dieback, tissue necrosis, and loss of marketable fruit.

Life cycle

Although both a sexual and an asexual form of reproduction occur, the asexual stage is considered to be important due to it being the more common mode 9k of inoculum in the pathogen's disease cycle. Infection occurs when either the sporangia or thallus filaments are deposited on the tissues of a susceptible plant host. The pathogen is usually dispersed through water or wind. Under the right environmental conditions, zoospores are released from the sporangia, and symptoms will begin to develop. The zoospores are able to penetrate the host cuticle in a haustorial manner. A flat, circular thallus develops subcuticularly. Algal filaments extend from these thalli further increasing the surface area this pathogen infects. The pathogen survives on existing leaf and stems as spores, and in fallen plant debris. As the pathogen lives in tropical climates it is able to survive year-round rather than relying on survival structures.

Environment

As this plant pathogen is an algal species, it thrives under similar conditions as other algal organisms. *Cephaleuros virescens* prefers moist, humid weather. Areas with frequent rain, and warm to high temperatures are where this pathogen flourishes. It has been recorded in all continents with tropical and sub-tropical environments. It is commonly seen in Hawaii and Florida, but there has also been recorded incidents of the disease in India and Thailand.

Management

Often, leaf spot caused by *Cephaleuros virescens* is not damaging enough to the host plant's vigor or crop yield and therefore generally does not warrant management. If however the crop is highly susceptible, a form of integrated pest management can be used to prevent the spread and infection of the disease. This includes sanitation and pruning of infected plant parts. Since lower branches are usually infected, make sure to remove them as well as any debris that has littered the ground below the infected plant. Reducing humidity or increasing air flow can also help, as the pathogen is most successful in moist, humid environments. Keep the plant or crop in a sunny, aerated, well-drained area. Selecting for a tolerant variety of plant, and if needed, intercropping, can reduce the rate of infection. If needed copper fungicides may assist but would need to be applied every two weeks if the environment remains wet.

Importance

Although the plant pathogen is commonly mild enough to not cause serious effects to crop vigor and yield, in susceptible plants it can cause significant damage. Most commonly, economically detrimental infections occur in guava. Guava is considered to be a susceptible host, and the leaf spot symptoms can grow to be severe enough to reduce plant vigor and cause defoliation. In guava, *Cephaleuros virescens* can cause fruit spots as well, leading to a reduction in crop yield.

5.16 Fritschiella

Fritschiella is a genus of green algae in the family Fritschiellaceae. There are two species F. tuberosa and a new freshwater species from China, F. aquatilis. The genus name of *Fritschiella* is in honour of Felix Eugen Fritsch (1879–1954), who was a British biologist. The genus was circumscribed by MandeyamOsuri and Parthasarathy Iyengar in New Phytol. Vol.31 on page 335 in 1932.

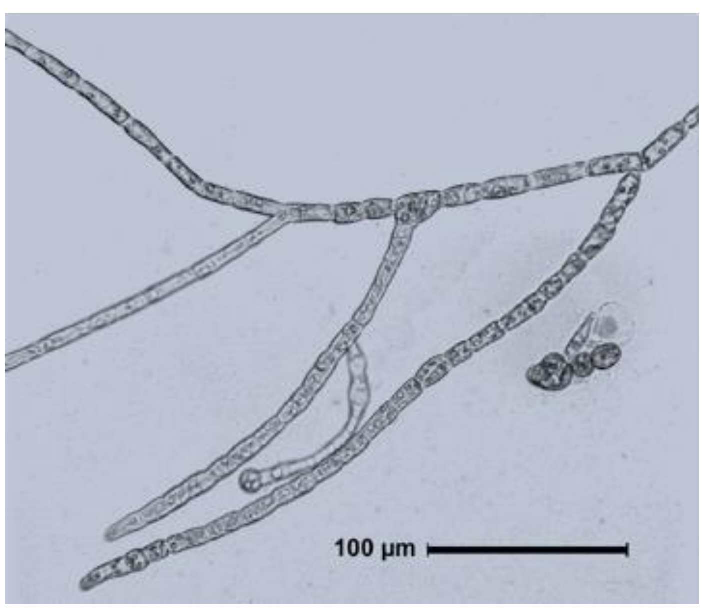


Fig.5.5*Fritschiella sp.* (Chlorophyceae)

Plants filamentous and heterotrichous, consisting of colourless, rhizoidal filaments penetrating soil surface. Prostrate system of crowded, irregularly rounded, clusters of small cells with dense contents, and erect system of irregularly branched filaments of short cells below, more elongated cells above, and terminating in conical cells. Both cell types uninucleate, with parietal chloroplast and several pyrenoids. Reproduction confined to cells of prostate system. Zoospores of 3 types quadriflagellate macro- and microzoospores, and biflagellate microzoospores. Sexual reproduction isogamous and gametes biflagellate. *Fritschiella* terrestrial, more or less gregarious on moist soil or silt including drying rain-water puddles; also reported from hair of sloths. Widely distributed in tropical and subtropical parts of North Africa and Asia. Ultrastructural investigations reveal plasmodesmata, a phycoplast, and membranes closely appressed to pyrenoids. Detailed information exists on the fine structure (e.g. cytoskeleton) of naked zoospores.

The green thallus of *Fritschiella* has upright branches of uniseriate filaments, prostrate regions of tissue-like filaments, and colorless rhizoids that extend below the soil surface. The upright filaments are tufted and irregularly branched with cells that become increasingly elongated and conical towards the apex of the branch. The end cells lack caps. Each cell growing above ground has a single parietal chloroplast with several pyrenoids. These morphological features are an example of a parallel evolutionary adaptation to terrestrial life with the land plants. The flagellated reproductive cells show that *Fritschiella* is in fact closely related to the chlorophyte green algae, rather than to the charophyte green algae that gave rise to land plants.

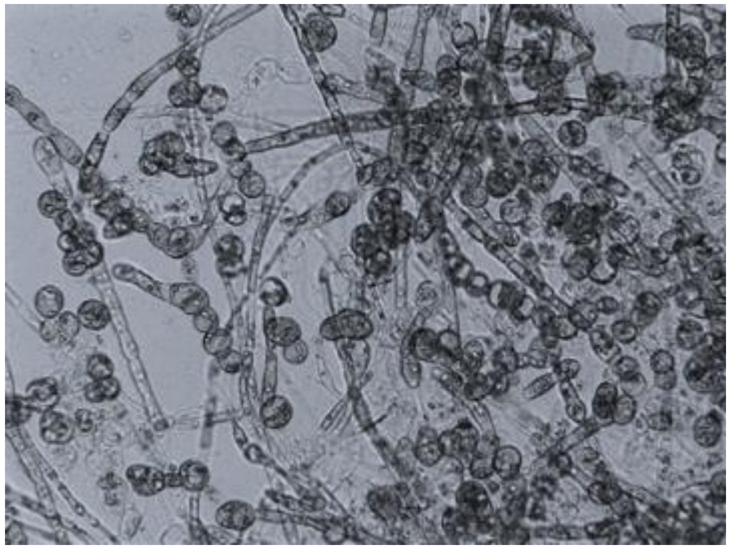


Fig.5.6 Both the cells and thallus are distinctly irregular in shape

This alga was growing more or less gregariously, together with Protosiphon botryoides or Botrydium tuberoswn, on the moist silt of drying rain-water pools at Madras and occurred in a similar situation, together with Botrydium tttberosmn, at Talguppa in the Mysore Province. The alga has been repeatedly observed in Madras in different years, when the pools were drying up after the north-east monsoon. At first sight the alga recalls a dense growth of Siigeoclonium, but careful examination shows that it possesses a complicated structure which is much more specialised than that of the latter genus.

The mature plant consists of (i) a rhizoidal system, penetrating the substratum and comprising one or more downwardly directed rhizoid like filaments made up of much elongated eolourless cells with very scanty contents and sometimes with a few branches (2) a prostrate system composed of a number of rounded or irregular swollen clusters of cells with dense contents and thin walls, the whole forming an irregular system with short congested branches (3) a primary projecting system, arising from the prostrate system and consisting of a number of upright short-celled branched threads; and (4) a secondary projecting system composed of somewhat elongate branches having longer cells with bright green contents. In the natural habitat only the secondary projecting system arises as a tuft above the surface of the substratum, the remaining portions of the alga being situated on a level with or slightly beneath the surface of the soil.

5.17 Summary

Under this unit we have summarized the concept of important characteristics, thallus organization and classification of chlorophyceae.Fritsch (1935) divided the order Volvocales and Ulotrichales in different suborders and families. Cladophora is a filamentous green alga that grows attached to hard substrates within the littoral zone. A common component of freshwater ecosystems, Cladophora sp. provide food and shelter for invertebrates and small fish. Draparnaldia is a genus of freshwater greenalgae in the family Chaetophoraceae. *Draparnaldia* are uniseriate; each filament is composed of a chain of cells arranged in one row. Chloroplasts appear as a band within the center of each cell. The length of the main axis cells are generally the same, regardless of whether or not they bear branches. These side branches are divided extensively into terminal hairs. The entire plant is enveloped in loose, slippery mucilage. *Draparnaldia* is a cosmopolitan genus with wide distribution and it is usually found in cold aerated waters.

Cephaleuros is a member of the family TrentepohliaCeae and the division Chlorophyta. It is a group of epiphytic and parasitic algae. The genus of Cephaleuros includes almost 14 different species. Among 14 species, Cephaleuros virescens is more common. Being algae, they also show a symbiotic relationship with fungus and lead to the synthesis of lichens. They cause infection in the leaves of tea, coffee, mango, and guava, leading to a decline in their productivity. Their common name is red rust. They cause symptoms including red to orange-brown spots over the surface, and beneath the leaves, that are visible with naked eyes. They are found in tropical and sub-tropical regions worldwide. They also contain the photosynthetic organisms known as Green algae. The thallus structure of the Cephaleuros family is generally composed of a prostate system and an erect system that provide mutual support during growth and development.

5.18 Terminal questions

Q.1 What do you mean bygreen algae? Explain it.

Answer:---

Q. 2 Describe the economic importance of chlorophyceae.

Answer:---

Q.3 Describe the life cycle of Fritschiella.

Answer:---

Q. 4 Describe the life cycle of Draparnaldia.

Answer:---

Q. 5 Write short notes on the following.

(a) Cephaleuros

(b) Fritschiella

Answer:---

Q. 6. Describe the vegetative body and reproduction of Draparnaldiopsis

Answer:---

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson

- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 6: CHLOROPHYCEAE -III

Structure

6.1 INTRODUCTION

Green algae are the most diverse of the algal groups, with at least 7000 species. Most are aquatic, but many are found in a variety of habitats that include soils, tree bark, snow, and in symbiotic relationships with a variety of organisms ranging from fungi to animals. Like cyanobacteria, green algae are found on all continents and in almost all terrestrial habitats and may be either unicellular, colonial, or filamentous. The earliest evidence of green algae comes from fossils estimated to be a billion years old (Tang et al., 2020). Similar to vascular plant cells, green algae have Golgi bodies, vacuoles, mitochondria, membrane-bound nuclei containing genomic DNA, and plastids. The latter contain the photosynthetic machinery, including chlorophylls, electron-transport chains, and the enzymes in the Calvin cycle necessary for carbon assimilation. Green algae have firm cell walls made of cellulose and other polysaccharides. Solitary green algal cells are generally larger than those of cyanobacteria and can have cell diameters ranging from approximately 1 μm to the single-celled and multi-nucleated seaweed *Caulerpa* sp. which can be up to 3 m long; most cells, however, range from 2 to 7 μm in size. Reproduction can be asexual (through mitotic division or fragmentation) or sexual (involving meiosis and fusion of gametes), the latter producing a **zygospore.**

The green algae include unicellular and colonial flagellates, most with two flagella per cell, as well as various colonial, coccoid and filamentous forms, and macroscopic, multicellular seaweeds. There are about 22,000 species of green algae. Many species live most of their lives as single cells, while other species form coenobia (colonies), long filaments, or highly differentiated macroscopic seaweeds. A few other organisms rely on green algae to conduct photosynthesis for them. The chloroplasts in dinoflagellates of the genus Lepidodinium, euglenids and chlorarachniophytes were acquired from ingested green algae, and in the latter retain a nucleomorph (vestigial nucleus). Green algae are also found symbiotically in the ciliate Paramecium, and in Hydra viridissima and in flatworms.

Objectives

This is the sixth unit (chlorophyceae-III) of block-I (Algae -I). Under sixth unit, we have following objectives. These are as under:

- To discuss general characteristics of green algae
- To know about range of thallus structure
- To have brief study of *Acetabularia* and *Caulerpa*
- To have brief study of *Closterium, Zygnema and Nitella*

Some species of green algae, particularly of genera Trebouxia of the class Trebouxiophyceae and Trentepohlia (class Ulvophyceae), can be found in symbiotic associations with fungi to form lichens. In general the fungal species that partner in lichens cannot live on their own, while the algal species is often found living in nature without the fungus. *Trentepohlia* is a filamentous green alga that can live independently on humid soil, rocks or tree bark or form the photosymbiont in lichens of the family Graphidaceae. Also the macroalga Prasiola calophylla (Trebouxiophyceae) is terrestrial, and Prasiolacrispa, which live in the supralittoral zone, is terrestrial and can in the Antarctic form large carpets on humid soil, especially near bird colonies.

6.2 GENERAL CHARACTERISTICS OF GREEN ALGAE

Chlorophyceae is characterized by the presence of chlorophyll a and b, starch as reserve food, pyrenoids which are surrounded by starch sheath, cellulosic cell wall, sexual reproduction is isogamous to oogamous. The thallus ranges from single unicellular motile form to complex heterotrichous form. Most of the green algae are aquatic, about 90% of which are fresh water. Chlorophyceae have been divided into nine orders: Volvocales, Chlorococcales, Ulotrichales, Cladophorales, Chaetophorales, Oedogoniales, Conjugales, Siphonalesales and Charales. All the members of Oedogoniales and Conjugales are fresh water. Members of the two groups Siphonales and Ulvaceae, are marine. Members of Volvocales, Cladophorales and Chaetophorales are found both in the fresh water and marine waters. Vaucheria and Ulothrix are usually found in damp soil, in the form of sheets. Sexual reproduction occurs by isogamy, anisogamy and oogamy. The sex organs are usually unicellular. Zygote represents the diploid phase. The life cycle in different genera may be haplontic (e.g Chlamydomonas), diplontic (e.g Codium), isomorphic (e.g. Cladophra), or heteromorphic (e.g. Urospora).

6.3 RANGE OF THALLUS STRUCTURE IN GREEN ALGAE

Green algae show great variety in the vegetative organization, life cycle and habitat, than any other group of algae. There is great variation in thallus structure in green algae, which ranges from simple, but primitive motile unicells, to complex, but highly evolved large multicellular forms. Thalli vary from a few microns to several feet in length. Volvocales form the most primitive order of the Chlorophyceae; the most primitive and simple thallus is represented by their motile unicells. All other forms of thalli can be derived from motile unicells:

(a) Motile colonies:

When motile unicells combine together loosely, a motile colony is formed. This is the first line of evolution in algae being called the volvocine line, and culminates in Volvox.

(b) Nonmotile colonies:

When the motile cells lose their flagella and combine together, a nonmotile colony is formed. This line of evolution is called the chlorococcine line.

(c) Filamentous forms:

If the cells are held tightly after transverse divisions by the middle lamella, a filament is formed.

(d) Membranous body:

It is formed when orientation of the cell divisions is controlled precisely, such that all the new walls occur in only two planes. A thin sheet of cells is thus formed.

(e) Parenchymateous body.

If the cell divisions occur in all the three planes, a bulky three dimensional parenchymatous body is formed.

(f) Siphonous body:

If the nuclear division is not followed by cytokinesis, multinucleate cells get formed. This is the siphonalean line of evolution.

The different kinds of thalli of green algae can be described as follows:

(i) Unicellular thallus:

It comprises of a single cell and is the simplest thallus, which can be motile or non motile.

(a) Motile unicellular thallus:

Such algal forms are unicellular, spherical or oval, and flagellated, e.g., Chlamydomonas and Haematococcus. Chlamydomonas is a unicellular motile alga, which has spherical or ellipsoidal body, with two flagella placed at its anterior end.

(b) Non-motile unicellular thallus:

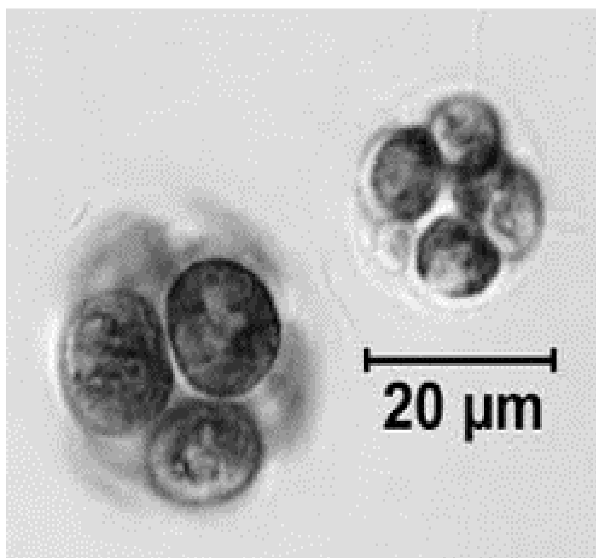
Such algae are unicellular, but lack the flagella, eye spot and contractile vacuole. They are also called coccoid forms, e.g. Chlorella and Chlorococcum.

(ii) Colonial thallus:

If the unicells adhere together loosely, the resulting structure is a colony. All the cells are simple and unspecialized. The colonial thallus may be motile or non motile.

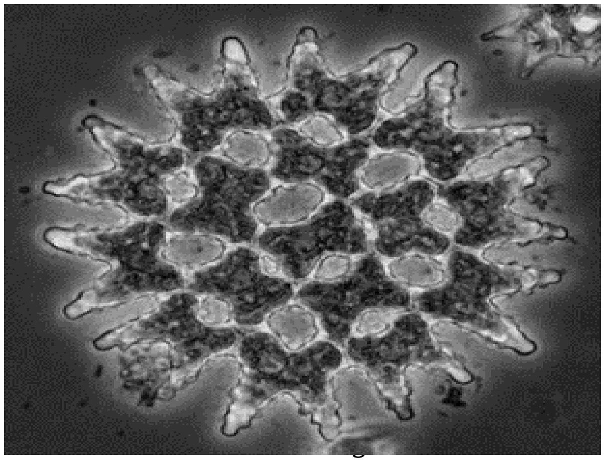
(a) Motile colonial forms :

When a definite number of flagellated unicells unite together, they form a motile colony. It may consist of 4,8,16 or more flagellated unicells, united by mucilage. All the cells of a colony are physiologically independent, and each resembles Chlamydomonas and behaves as one unit. If the cells in a colony are definite in number, arrangement and having an anterior, posterior polarity, the colony is called coenobium, e.g Gonium, Volvox and Pandorena. Gonium colony contains only a few cells, and the only sign of being organized is that all the flagella beat in a coordinated fashion. Pandorina is of about the same size as Gonium, but is more advanced, because some differentiation of cells between the anterior and posterior end has taken place. In Volvox, the coenobium is spherical and consists of about 50,000 Chalamydomonas type, biflagellate cells. It is visible to the naked eye. Volvox is a multicellular colony, but not a multicellular individual, because individual cells in the colony coordinate only for the movement of the colony; otherwise they show complete individuality or non interdependence in the matters of nutrition, respiration and other life supporting activities. Volvox on maturity shows polarity, because it shows two different types of cells, viz. Chalamydomanas type cells (95%) present in the anterior part, and gonidial cells (10%), confined to posterior part of the colony.



Pandorena

Gonium



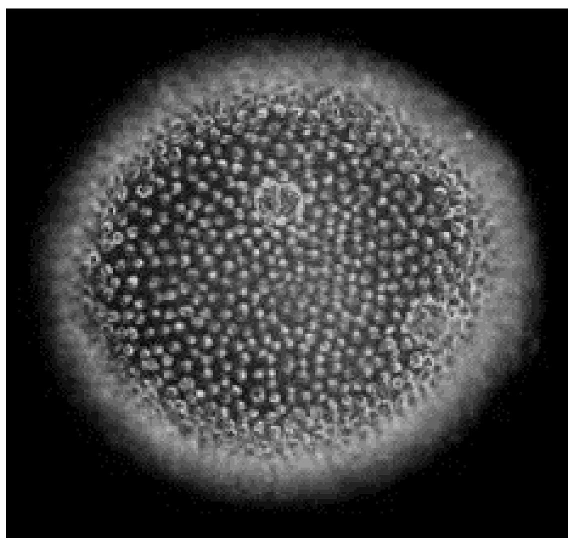


Fig.6.2 Volvox colony

(b) Non motile colonial forms:

If the unicells loose their flagella, or do not develop flagella, and then aggregate together, a non motile colony results, e.g. Hydrodictyon. A mature colony of Hydrodictyon (waternet) consists of elongated cells joined at their ends to make polygonal shapes. These cells are coenocytic and contain many nuclei. The whole colony is a hollow cylinder that can grow up to 75 cm in length.

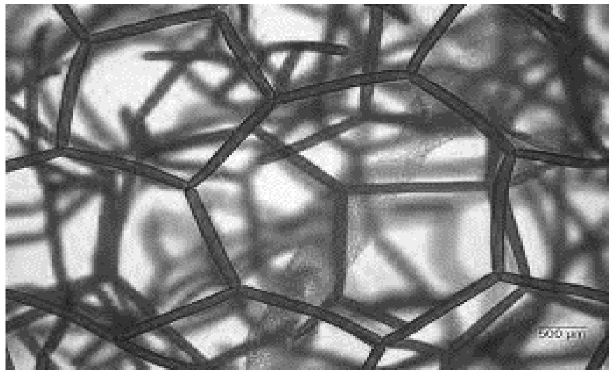


Fig.6.3 : Hydrodictyon (water net)

(iii) Siphonaceous or coenocytic thallus: Some single celled algae elongate to form a nonseptate multinucleate, tubular or sac like structure. This condition is called coenocytic condition, which is the result of karyokinesis without cytokinesis, e.g. Codium and Vaucheria. The latter has a long and branched, coenocytic and siphonaceous thallus. The thallus is aseptate; and the septa are formed only at the time of reproduction or at the site of injury. Internally, there is a siphon like central vacuole, which gives the order the name Siphonales. Acetabularia is a siphonaceous alga, which consists of a stalk ending in an umbrella shaped cap. The stalk bears the only nucleus present in thallus. In Caulerpa, a large coenocytic thallus consists of a branched creeping rhizome and erect assimilatory shoots of various shapes.

Fig.6.4 Acetabularia

(iv) Filamentous thallus:

It results if the cells are held tightly by the middle lamella after multiple transverse divisions, i.e., when a unicell divides several times in a single plane. When the filamentous cells undergo longitudinal divisions, the filament branches. The filamentous forms are of the following two main types:

(a) Simple filament:

Such type of thallus consists of a straight row of cells. In Spirogyra, the cells are arranged from end to end in a single row or file. Such filaments are unbranched and such a thallus is regarded as advanced filamentous thallus. In Ulotrix, the cells are arranged in a single row as in Spirogyra, but it has a rhizoidal cell at one end, by which it gets attached, to substratum and at other end it has an apical cell. In Oedogonium, there is division of labour between various cells. It shows apical-basal polarity. The thallus is a long unbranched filament. This alga has a rhizoidal cell for attachment. The filament consists of green vegetative cells which are photosynthetic, cap cells for cell division, specialized anthredia and oogonia for reproduction.

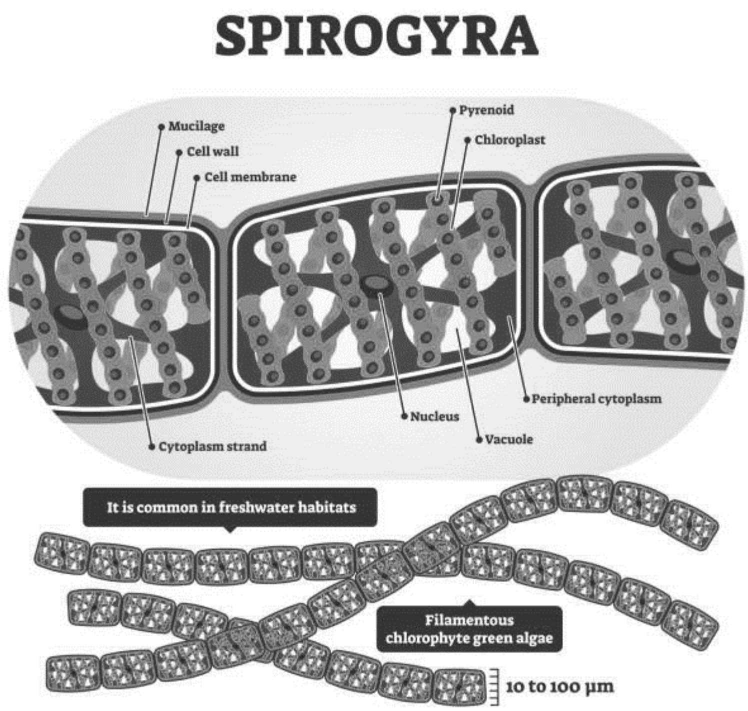


Fig.6.5 Spirogyra

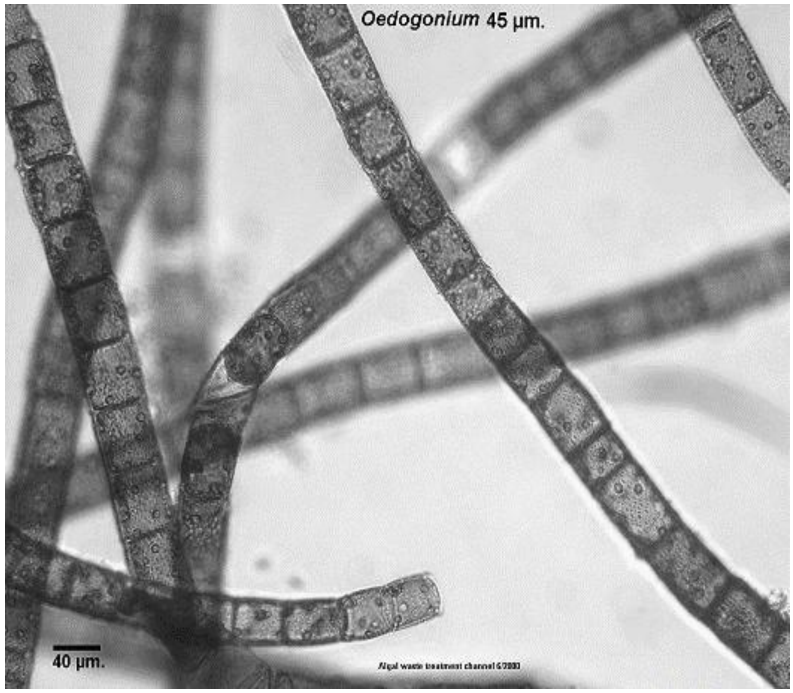


Fig.6.6 Oedogonium

(b) Branched filament:

If some cells in a filament divide in a second plane (longitudinally), a branched filament results. The branches arise from the main axis as lateral outgrowths, e.g. Cladophora. It shows bush like thallus, and is attached to rocks. The individual cells are large, multinucleate, and cylindrical and placed end to end. The thallus is attached to the substratum by rhizoidal outgrowths arising from the base of the plant. In Aegagropila group growing in water, rolling wave action leads to the aggregation of young branches to form balls floating on water.

(v) Chara like forms:

It has a plant like body. It resembles Equisetum in having nodes and internodes on the axis. From the node arise three types of appendages:

i. Branches of limited growth:

These branches arise in whorls of 6-16 at the nodes of the main axis and branches of unlimited growth. They stop their growth after some time. They are also called primary laterals, leaves or branchlets. Reproductive structures are borne on these branches.

ii. Branches of unlimited growth:

These branches arise from the axils of the branches of limited growth. They also bear nodes and internodes besides, a whorl of primary laterals at the node. They grow indefinitely.

iii. Stipulodes:

The basal nodes of the branches of limited growth develop some unicellular outgrowths, called stipulodes. Main axis shows apical growth. The plant is attached to the substratum by awell developed rhizoidal system.

(vi) Foliaceous Thallus :

A membranous or foliaceous body results if the cells of a filament divide in two planes (transversely and longitudinally). Such forms appear as a green paper sheet, e.g. Ulva. It has a lettuce leaf like shape, hence called sea lettuce. Basal part of the thallus forms a stalk.

(vii) Massive parenchymatous thallus:

If the cell divisions occur regularly in all 3 planes, a bulky three dimensional parenchymatous body results, e.g., Enteromorpha.

(viii) Heterotrichous filament:

Heterotrichy means presence of two types of branching, prostrate branching forming the prostrate system and erect branches forming the erect system. It is the most highly evolved and advanced type of thallus found in the Chaetophorales. The prostrate system creeps along the substratum and sends rhizoids to fix the thallus. From the prostrate system arise the upright filaments, forming the erect system. In some algae, both the prostrate and the upright systems may be well developed (e.g. Stigeoclonium and Fritschiella).

In Coloeochaet the erect system is reduced to a few hairs. In Chaetophora, the erect system is better developed. In Fritschiella, the prostrate system consists of a rounded cluster of cells buried in the mud, while the erect system consists of two regions, a lower primary projecting system, and upper secondary projecting system. By modification of the heterotrichous habit the other thalli were formed. In Draparnaldia, the prostrate system is reduced to the hold fast, and the erect system is differentiated in to the main axis, from which lateral branches arise. In Drapernaldiopsis, the main branches bear short and long cells, alternately, nodes and internodes are also present. The main axis is meant for support, while the laterals perform photosynthesis and reproduction.

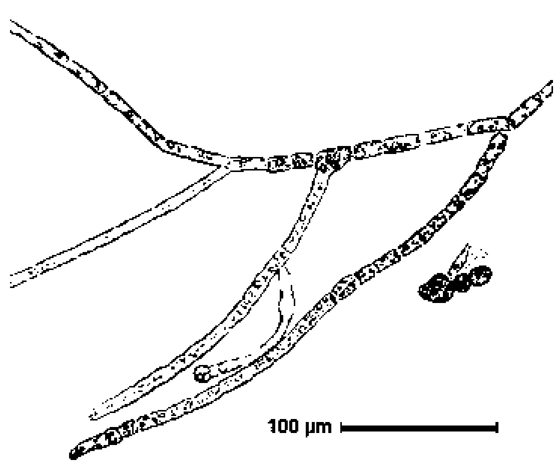


Fig.6.7 Fritschiella

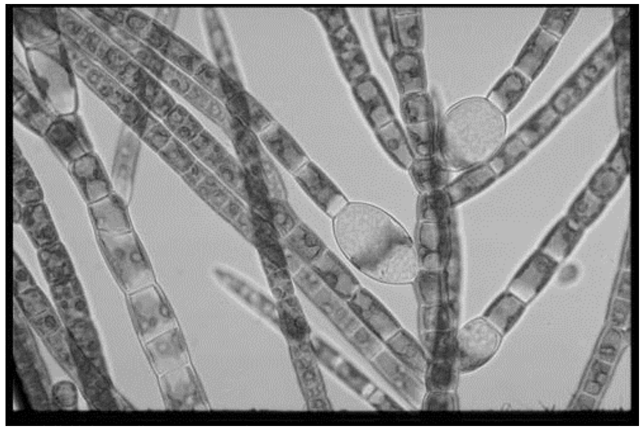


Fig.6.8 Stigeoclonium

6.4 ACETABULARIA

The name, *Acetabularia*, derives from the Latin word acetabulum, a broad, shallow cup used for dipping bread; the upturned cap of *Acetabularia* resembles such a cup. For this reason, it is also sometimes called mermaid's wineglass. In the 19th century, the same designation *Acetabularia* was proposed by George Edward Massee for a genus of fungi (now Cyphellopus), but this usage is obsolete and considered invalid as the algal name takes precedence. ***Acetabularia*** is a genus of green algae in the family Polyphysaceae. Typically found in subtropical waters, *Acetabularia* is a single-celled organism, but gigantic in size and complex in form, making it an excellent model organism for studying cell biology. In form, the mature *Acetabularia* resembles the round leaves of a nasturtium, is 4 to 10 centimetres (1.6 to 3.9 in) tall and has three anatomical parts: a bottom rhizoid that resembles a set of short roots; a long stalk in the middle; and a top umbrella of branches that may fuse into a cap. Unlike other giant unicellular organisms, which are multinucleate, members of this genus a single nucleus located in the rhizoid and allows the cell to regenerate completely if its cap is removed. The caps of two *Acetabularia* may also be exchanged, even from two different species. In addition, if a piece of the stem is removed, with no access to the nucleus in the rhizoid, this isolated stem piece will also grow a new cap.

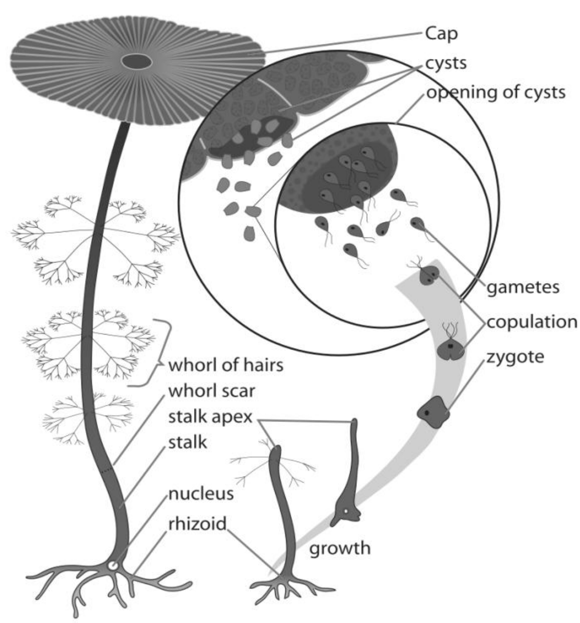


Fig.6.9 Life cycle of *Acetabularia acetabulum*

This alga adheres to the substrate with rhizoids (root-like processes), and these are the only part of the alga present in the winter. The thallus consists of a single cell, and in the spring a slender stem develops from the holdfast, growing vertically to a length of about 5 cm (2 in). Growth is interrupted at intervals while a whorl of hairs develop which encircle the stem, branching dichotomously. As the stem lengthens and more whorls grow, the lower hairs drop off leaving behind a circular scar. When the stem is fully developed, a disc-shaped cap up to 1.2 cm (0.5 in) wide grows at the tip, the whole frond resembling a pale green parasol; further whorls of hairs grow from the upper surface of the cap.

Before cap expansion, the organism consists of a single cell with a single nucleus, located at the base of the stem. As the cap expands, the nucleus divides once by meiosis after which it divides multiple times by mitosis, producing thousands of haploid "secondary" nuclei. These migrate up the stem into the cap, each becoming enclosed in a gametangium containing the nucleus and a small amount of cytoplasm. Inside the gametangium, the nucleus undergoes further repeated mitotic division, so that by the end of summer, when the cap disintegrates, thousands of "tertiary" nuclei are released into the sea as gametes from each gametangial ray. Fertilisation occurs in the open water, and the zygotes settle on the seabed.

This alga is unicellular, each frond being formed from a single large cell containing several million chloroplasts. These are in constant motion: in the daytime, they move to expose to themselves to the maximum degree possible to the light and the stems appear uniformly dark green, while at night they aggregate into clusters and the stem becomes pale green. This effect can be demonstrated by shining a ray of blue light on a stem in the dark and extinguishing it sometime later, forming a transient green band. This alga has been used as a model organism in developmental biology, being useful for this purpose because of the enormous size of its single cell with its single nucleus, and its complex cell structure and development. The main storage polysaccharide of *Acetabularia acetabulum* is starch as granules within the chloroplast's stroma.

6.5 CAULERPA

Caulerpa is a genus of seaweeds in the family Caulerpaceae (among the green algae). They are unusual because they consist of only one cell with many nuclei, making them among the biggest single cells in the world. Referring to the crawling habit of its thallus, the name means 'stem (that) creeps', from the Ancient Greek *kaulos* (to creep).

6.6 TAXONOMY AND NOMENCLATURE

First described by Jean Vincent Lamouroux in 1809, *Caulerpa* is the only genus under the family Caulerpaceae, from the order Bryopsidales, class Ulvophyceae, and phylum Chlorophyta. Through the use of *tuf*A gene sequencing, it was revealed that *Pseudochlorodesmis* F. Børgesen was a sister clade of *Caulerpa*. Cremen et al. proposed a new classification scheme in Bryopsidales, wherein Caulerpaceae and Halimedaceae were described as sister families. Species discrimination via morphology-based identification is often hampered by the high degree of variation among traits. Thus, several species are often misidentified without the use if molecular analyses. As of 2019, there are 101 accepted species, with 40 varieties and 67 forms.

6.7 BIOLOGY

Caulerpa species support their large cell size by having the cytoplasm circulate constantly, supported by a network of microtubules. This behavior was known in 1967.The cytoplasm does not leak out when the cell is cut. Regeneration is directional, with rhizoids at the bottom and fronds at the top.The genus produces a number of secondary metabolites thought to be related to its toxicity and peppery taste. These include the red pigment alkaloid caulerpin and its derivative caulerchlorin and the amine mixture caulerpicin.

6.8 MORPHOLOGY

External characteristics

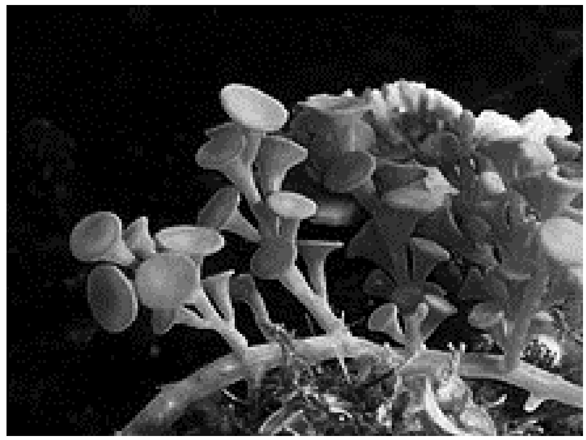


Fig.6.10 Caulerpa racemosa showing irregular vesiculate ramuli

The genus *Caulerpa* exhibits several different growth forms. They possess a stolon with rhizoids which grow downward, anchoring the plant to the substrate. The stolons support upright fronds or leaves known as assimilators. The structure of the assimilator may be ligulate (leaf-like, e.g. *Caulerpa prolifera*), or they may have a central axis known as a rachis. The rachis may have lateral branchlets known as ramuli which themselves come in different forms (terete, turbinate, clavate, peltate, falcate, vesiculate) and arrangements: distichous - ramuli are arranged evenly opposite each other (e.g. *Caulerpa taxifolia*), irregular - vesiculate ramuli with no distinct arrangement (e.g. *Caulerpa racemosa*), verticillate - whorled ramuli (e.g. *Caulerpa cuppresoides*).

Internal anatomy

Caulerpa is coenocytic, meaning it has a multinucleate thallus organization. It is also siphonous, meaning unlike other algae, the thallus and the nuclei are not separated by cell walls. They are instead one long mass of protoplasm surrounded by a single cell wall.[12] The genus also possesses trabeculae, which are inward growing cell wall extensions that pass through the central lumen of siphons. It is hypothesized that these provide the thallus with structural support, facilitate diffusion to the inner cytoplasm, and can possibly help in determining cell shape - which may contribute to the diversity of growth forms found in the genus.

Distribution

Caulerpa is mostly found in tropical regions; however its distribution may also extend up to temperate locations. Diversity is highest in the Caribbean and the Indo-Malay region, as well as in southern Australia, where a majority of *Caulerpa* species are endemic.

Ecology

The genus is typically found in shallow intertidal zones and can reach up to depths of 100 meters. They are known to be able to adapt and thrive in different environmental conditions, which contribute to their potential for becoming invasive species. Some of their traits include having a high tolerance for a wide range of temperatures, their capacity for asexual reproduction through rhizoid extension and fragmentation, their fast growth rate, as well as their capacity for nutrient intake from sediments through their rhizoids. This last trait gives them a competitive edge over other macroalgal species who mainly absorb nutrients from the water column.

Life history

Many studies on the life cycle of *Caulerpa* have been found to contradict each other, leading researchers to conclude that it varies with species and geographical region.Earlier research revealed that *Caulerpa* has a diplontic life cycle with a diploid vegetative phase and haploid biflagellate gametes. However, it was later found that ploidy status and genome size can vary within and between species.

Exploitation and cultivation

Some species of *Caulerpa* are edible. The two most commonly eaten are Caulerpa lentillifera and Caulerpa racemosa, both called sea grapes in English. Both are traditionally harvested in the wild and sold in local markets in Southeast Asia, Oceania, and East Asia. They are eaten raw in salads and have a characteristic "sea" flavor and a crunchy texture.Both species are cultivated in aquaculture. Their cultivation began in the 1950s in Cebu, Philippines, after accidental introduction of *C. lentillifera* to fish ponds. Cultivation of *C. lentillifera* continued in Japan in 1986, where it was cultivated in tanks in the tropical waters of Okinawa. Commercial cultivation has since spread to other countries, including Vietnam, Taiwan, and China (in Fujian and Hainan). Most are for domestic consumption, but they are also exported to Japan.

6.9 CHEMICAL COMPOSITION

Caulerpa contains a high amount of iron (up to 81.3 mg per 100 g of dry matter in C. racemosa), magnesium, and calcium. Water content is species-specific and generally ranges from 75 - 94%. The genus is known to have a high bioaccumulation rate, which can make it less than ideal to consume on a regular basis. Carbohydrate content can range from 3.6 - 83.2% of dry matter depending on the species. The main pigments of Caulerpa are chlorophyll a and b. It has a high diversity of chemical compounds which have pharmaceutical potential. Although the genus is known to exhibit high toxicity, it was found to be of low risk to humans.

Utilization

Aside from being a source of food, *Caulerpa* has several uses from bioremediation, to fertilizer, and health and wellness. The anti-oxidant compounds of *Caulerpa* have been well-studied, and these are used in treating various diseases and health conditions such as cancer and cardiovascular disorders. *Caulerpa* has been shown to be effective in filtering water used in culturing fish, mollusks, and shrimp (in particular *C. lentillifera*). The use of *Caulerpa* as a biofertilizer has also been studied particularly in India, where fertilizers composed of 25% *Caulerpa* extracts enhanced the growth and reduced the total sugar content, among other things, of *Vigna mungo.*

Invasive behaviour

Another species, Caulerpa taxifolia, has become an invasive species in the Mediterranean Sea, Australia and southern California (where it has since been eradicated). In U.S. waters, the Mediterranean strain of *Caulerpa taxifolia* is listed as a federal noxious weed, under the Plant Protection Act. The Aquatic Nuisance Species Taskforce has also created a National Management Plan for the Genus *Caulerpa*. The state of California also prohibits possession of nine different species of *Caulerpa*.

It is thought that *Caulerpa* species have such invasive properties in these regions due to their capability to thrive in temperate waters, along with their freedom from natural predators. Most *Caulerpa* species evolved in tropical waters, where herbivores have immunity to toxic compounds (mainly caulerpicin) within the alga. Temperate water herbivores have no natural immunity to these toxins, allowing *Caulerpa* to grow unchecked if introduced to temperate waters.

Use in aquariums

Caulerpa is common in the aquarium hobby as a nitrate absorber because of its rapid growth under relatively adverse conditions. It may also be used in refugiums for a long-term nitrite absorber. Many introductions of invasive *Caulerpa* to the wild are thought to have occurred via aquarium dumping although there is no proof that this is so. For this reason, some aquarium hobbyists have begun using Chaetomorpha or an algae scrubber instead.

6.10 CLOSTERIUM

Closterium is a genus of desmid, a group of charophyte green algae. It is placed in the family Closteriaceae. Species of *Closterium* are a common component of freshwater microalgae flora worldwide.

Classification:

Closterium Nitzsch ex Ralfs 1848; 141 of 1,234 species descriptions are currently accepted taxonomically (Guiry and Guiry 2013).

Order Desmidiales; Family Closteriaceae

6.11 MOLECULAR SEQUENCES:

Nuclear small subunit (SSU) rDNA of 19 species clarifies monophyly in Closterium (Takashi et al. 2001)

Morphology:

Unicellular lunate desmids up to 660 µm long (Neindl and Url 1985) with two large chloroplasts, one per semicell. Lack an isthmus (found in many desmid genera) yet the overlap of the two hemicell walls is often evident, often by a change in color (older wall stained by iron oxide, etc.). Near each cell terminus is a transparent spherical or elongate vacuole containing from one to many barium sulfate granules (Brook et al. 1980) visible with light microscopy, which may act as gravity sensors. Some species walk by tumbling end over end across substrates.

Similar genera:

Habitat:

Freshwater lake plankton and benthos

Description

Closterium is a diverse genus consisting of solitary cells, each made of two identical halves called semicells. Usually they are microscopic, but the largest can become easily visible to the naked eye. Cells are many times longer than broad, and are variously elongate to lunate (crescent-shaped). The poles are rounded, truncated, or pointed. The surface of the cell may be smooth or decorated with various features, such as striations or punctae. The cell wall is transparent, but with age it may become dark brown due to accumulated iron and manganese compounds. The cell nucleus is located in the middle of the cell. Each semicell contains a single axial chloroplast dotted with several pyrenoids. At either end of the cell, there is a generally a polar vacuole. The vacuoles often contain conspicuous barium sulfate crystals.

Taxonomy

Closterium regulare was first described from Lower Normandy by Brebisson.

Species

Closterium sp. during a miotic phase (upper-left is a diatom) Closterium sp. Closterium sp. Closterium includes the following species:

- C. acerosum
- C. calosporum
- C. calosporum var. himalayense
- C. cornu
- C. ehrenbergii
- C. gracile
- C. incurvum

6.12REPRODUCTION

Asexual: binary fission from a partitioned parent cell.

Sexual: Conjugation to form a hypnozygote.

The *Closterium peracerosum-strigosum-littorale (C. psl)* complex is a unicellular, isogamous charophycean alga cells that is the closest unicellular relative to land plants. These algae are capable of forming two types of dormant diploid zygospores. Some populations form zygospores within single clones of cells (homothallic), whereas others form zygospores between different clones of cells (heterothallic). The heterothallic strains have two mating types, mt (-) and mt (+). When cells of opposite mating types are mixed in a nitrogen-deficient mating medium, mt (-) and mt (+) cells pair with each other and release protoplasts. This release is then followed by protoplast fusion (conjugation) leading to formation of a diploid zygospore. Sex pheromones termed protoplast-release inducing proteins produced by mt (-) and mt (+) cells facilitate this process.

Habitats

Like other desmids, *Closterium* is found in freshwater habitats. *Closterium* is usually attached to sediments or aquatic plants, but may sometimes be planktonic, i.e. free-floating in the water column, or found in wet soils. Most species prefer oligotrophic and slightly acidic waters, but a few species (for example Closterium aciculare) prefer eutrophic, slightly alkaline lakes.

6.13ZYGNEMATALES

The Zygnematales comprise 18 genera, with more than more than 600 species. *Spirogyra* and *Zygnema* are the best-known members of the order, and because of the beauty of these organisms when seen under a microscope, they are commonly used in biology classes as examples of the "green algae". However, the Zygnematales are not representative of the green algae in general, and have many unusual features which suggest a closer relationship to the plants than to the other green algae.

Almost all species of Zygnematales live in freshwater environments, where they are important as primary producers. They are commonly called pondscum, and make up the filamentous **periphyton** in ponds, growing on and around the larger aquatic plants. Mature zygnemataleans are **filamentous** and unbranched, growing as long chains of cells connected end-to-end. The filament grows when cells in the chain divide, developing into two new full-sized cells. Some species will produce **rhizoids** at one end of the filament to help anchor them to objects in the water. Each cell is encased in a cell wall composed of three layers, two cellulosic inner layers and and outer layer of mucus, which probably helps to keep the alga moist.

Like all organisms called "algae", zygnemataleans have **plastids** which allow them to manufacture their own food. There is a great deal of variation in chloroplast morphology in the group. They are stellate in *Zygnema,* while in *Spirogyra* the chloroplasts are ribbonlike and are wound around the inside of the cell like a spiral, giving the genus its name. The photo at left shows this in *Spirogyra submaxima*. The "bumps" visisble along the chloroplast are **pyrenoids** used to store starch reserves.

Members of the order may reproduce in one of two ways, asexually by fragmentation, or sexually by **conjugation**. Conjugation is a very distinctive mode of reproduction which only occurs among algae in the Zygnematales and Desmidiales. The process begins with a parallel pairing of two filaments, aligning neighboring cells. Then, a bridge-like conjugation tube is formed to connect neighboring cells, and the amoeboid cells from one filament move over into the neighboring filament. Alternatively in some species, cells from both filaments will move into the cojugation tube. In either case, the cells meet and fuse, producing a diploid **zygote** which forms a spore. The zygote will undergo meiosis directly to produce the next generation. Mature algae are therefore haploid, though polyploidy is known in some taxa, resulting in size variation. Like plants, zygnemataleans have uniparental inheritance of plastids; the plastids of only one gamete are passed on to the next generation.

6.14ZYGNEMA

Zygnema is a genus of freshwater filamentous thalloid alga comprising about 100 species. A terrestrial species, *Z. terrestre,* is known from India. *Zygnema* grows as a free-floating mass of filaments, although young plants may be found anchored to streambeds with a holdfast. The filaments form a yellow-green to bright green colored tangled mat, and are composed of elongate barrel-shaped cells, each with two star-shaped (stellate) chloroplasts arrayed along the axis of the cell.

Species

Some species include:

- Z. atrocoeruleum
- Z. binuclearioides
- Z. carinthiacum
- Z. carteri

- Z. circumcarinatum
- Z. coeruleum
- Z. conspicuum

A common sight floating atop stagnant water, algae of the genus ***Zygnema*** can be identified microscopically by its two star-shaped chloroplasts per cell. Found often alongside ***Spirogyra***, another still water green algal genus, ***Zygnema*** filaments combine to form green or yellow-brown mats and can reproduce sexually or asexually, including vegetatively.

Positive

When their environment becomes unsuitable, akinetes, which are spore-like bodies, are produced asexually. Their very thick cell walls allow these algae to withstand droughts and harsh winters. Sexual reproduction may also commence in poor environments as two side-by-side filaments grow conjugation tubes toward each other. DNA from each plant moves toward the center of the tube, combines, and forms a zygospore. The zygospore sinks into the sediments of the still waters, awaiting more favorable habitat conditions before emerging as new algal strands. However, when nitrates and phosphates are available in sufficient quantities, most frequently vegetative reproduction, or fragmentation of *Zygnema*, occurs. As with *Spirogyra*, thick mats and green clouds of *Zygnema* can indicate over-fertilization or "enrichment" of water bodies, often by contaminated storm water runoff.

Negative

During the day, the hair-like strands of green algae produce relatively large volumes of dissolved oxygen. At night, the metabolic processes reverse and the masses of green algae consume oxygen and produce carbon dioxide gas as a cellular respiratory waste product. The rapid creation of carbon dioxide in the water can change the pH level too quickly for aquatic organisms, such as fish, resulting in stress, and abnormal behaviors that make them much more susceptible to predators. During winter months in temperate regions the algal mats die and decompose, creating a significant biological oxygen demand due to bacteria feeding on the decaying organic plant matter. Severe competition for limited oxygen resources often results in a phenomenon referred to as winterkill, a large die-off of fish populations that remains generally undiscovered until the following spring.

Nitella

- Kingdom - Plants - Plantae
- Division - Green Algae - Chlorophyta
- Class - Chlorophycean Green Algae - Chlorophyceae
- Order - Green Algae - Charales
- Family - Green Algae - Characeae
- Species - Nitella - *Nitella sp.*

General Description

Nitella, one of the genera of green algae, grows submerged in water. *Nitella*'s root-like rhizoids, which attach the plants to the muddy substrate, are colorless and well-developed (DiTomaso and Kyser et al. 2013). The shoot-like central axis or stipe is ridged (Swistock and Smiles 2008) with regularly-spaced nodes or joints. Between the nodes, the axis is solid. Whorls of slender, leaf-like branches develop from each node, some of these branches grow as long as 12 inches or more (DiTomaso and Kyser et al. 2013). *Nitella* species are typically deep, translucent green, and very smooth and delicate (DiTomaso and Kyser et al. 2013).

Diagnostic Characteristics

Nitella can initially appear as an aquatic vascular plant because of its size; however, it lacks leaves, flowers, and seeds. The genus *Chara* is similar to *Nitella*. However, *Chara* often becomes encrusted with carbonates, making it rough or gritty to the touch, and giving it an unpleasant smell like garlic or skunk when crushed. *Nitella* is very smooth and lacks an unpleasant odor when crushed. *Chara* is also grayish-green and coarse, while *Nitella* tends to be a deeper green and is more delicate (DiTomaso and Kyser et al. 2013; Swistock and Smiles 2008). *Chara* usually inhabits hard waters and *Nitella* prefers acidic waters with soft, muddy bottoms (Swistock and Smiles 2008). Possessing rhizoids, a central axis, and branches, *Nitella* gametophytes are easily confused with some aquatic vascular plants, particularly species of *Myriophyllum*. However, the rhizoids are clear and do not have root caps or other structures found in roots of vascular plants. Unlike a true vascular plant stem, the *Nitella* axis lacks vascular tissue (xylem or phloem), and the filamentous branches of the whorls do not broaden into leaves (DiTomaso and Kyser et al. 2013).

Habitat

Ponds, lakes, reservoirs, streams,d rivers, bogs, and dikes; frequently acids waters with muddy substrates (Swistock and Smiles 2008).

Ecology

Nitella is an important constituent of natural aquatic ecosystems, commonly beneficial to lakes and ponds by providing food and cover to wildlife (DiTomaso and Kyser et al. 2013). Its branches provide food for waterfowl, and foraging areas for grazing insects, who eventually provide food for fish and wildlife. Like roots, the rhizoids help prevent muddy water by stabilizing the sediment (Swistock and Smiles 2008). Excessive *Nitella* growth, however, may deplete water oxygen levels, jam filters, afford breeding sites for mosquitoes, impede water flow, or hamper recreational activities. Excessive growth occurs with an overabundance of nitrogen and phosphorus nutrients in the water (Swistock and Smiles 2008).

Reproductive Characteristics

Sexual reproduction results in a zygote that develops into an oospore. The oospore stays dormant, awaiting favorable conditions for germination, undergoing meiosis and growing into the easily-visible gametophyte (DiTomaso and Kyser et al. 2013). Vegetative reproduction occurs by fragmentation and other methods (DiTomaso and Kyser et al. 2013).

Management

Prevention and Cultural Control

Reduce or divert nutrient-runoff away from the pond. Such runoff originates from barnyards, septic systems, crop fields, and fertilized lawns and golf courses. This can be accomplished by reducing fertilizer treatments near ponds and lakes, properly maintaining septic systems, and retaining vegetative buffers around the ponds, lakes, and streams (Swistock and Smiles 2008). Establishing native submersed plants can reduce the light and space needed by *Nitella* (DiTomaso and Kyser et al. 2013). To help prevent *Nitella*'s spread, clean and destroy stem fragments from boats, fishing gear, and other recreational equipment.

Physical Control

Raking, pulling, and cutting provide short-term control since spores and fragments left behind allow recolonization. Install bottom barriers in spring before plants have established much biomass and are still under 10 inches in height. Barrier materials include sheets of polyvinyl chloride, jute, burlap and other natural fibers, and small-mesh screens (DiTomaso and Kyser et al. 2013).

6.15SUMMARY

Under this unit we have summarized the characteristics and thallus structure of green algae, brief study about Acetabularia, Caulerpa, Closterium andZygnema. Thallus organization of algae show a range of organization starting from unicellular form to highly organized multicellular habit where the plant body is differentiated into root-like, stem-like, and leaf like structures giving a higher plant-like appearance.

The unicellular thallus is mainly found in the lower fungi. It is spherical and unicellular. Thallus takes an important role in fungal reproduction. In the case of the holocarpic fungi, no reproductive and vegetative stages occur together. Acetabularia acetabulum is a single-celled green alga that in its vegetative state is morphologically differentiated into a basal rhizoid and an axially elongated stalk, which bears whorls of branching hairs. The single diploid nucleus resides in the rhizoid.

The Caulerpa genus has classically been divided into two major albeit tenuous groups, the frond-like bilateral leaf species, which grow below the littoral zone in relatively still water, and the radially branched species, which characteristically prefer habitats associated with the brighter shallower but turbulent. The genus Closterium is a unicellular alga of the order Desmidiales in the class Zygnematophyceae, which inhabits fresh water worldwide. The life cycle of Closterium involves vegetative and sexual reproduction. Zygnema is a genus of freshwater filamentous thalloid alga comprising about 100 species. A terrestrial species, Z. terrestre, is known from India. Zygnema grows as a free-floating mass of filaments, although young plants may be found anchored to streambeds with a holdfast.

6.16TERMINAL QUESTIONS

Q. 1 What do you mean bythallus structure in green algae? Describe it.

Answer:--

Q. 2 What are the characteristics of Acetabularia? Describe the life cycle of Acetabularia.

Answer:--

Q. 3 What are the special features of Caulerpa? Describe the life cycle ofCaulerpa.

Answer:--

Q.4 Describe the taxonomy and reproduction of Closterium.

Answer:--

Q.5 What is the role of Closterium? Describe the life cycle of Closterium.

Answer:--

Q.6 How many chloroplasts are in Zygnema? Describe the life cycle of Zygnema.

Answer:--

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

Block -2 Introduction

This is the second block (Phaeophyceae, Rhodohyceae, Xanthophyceae and Bacillariophyceae) of Phycology. It consists of remaining six units The objective of this block deals basic introduction to Phaeophyceae, Rhodophyceae, Xanthophyceae and Bacillariophyceae in concern to their occurrence, habitat, characteristics properties, classification, reproduction and economic importance respectively. The Phaeophyceae (brown algae) include 16 orders with approximately 285 genera and about 1800 species. Morphologies range from simple microscopic filaments to giant kelps that may reach 60 m in length. The large multicellular Phaeophyceae, or giant kelps, play important roles in coastal marine environments They are brown algae are distinguished by chloroplasts that have four surrounding membranes, thylakoids in stacks of three, fucoxanthin that masks chlorophyll-a and -c, laminarin as the photosynthetic reserve, and alginates commonly as the wall matrix component.

Red algae are red because of the presence of the pigment **phycoerythrin**; this pigment reflects red light and absorbs blue light. Because blue light penetrates water to a greater depth than light of longer wavelengths, these pigments allow red algae to photosynthesize and live at somewhat greater depths than most other "algae". Some rhodophytes have very little phycoerythrin, and may appear green or bluish from the chlorophyll and other pigments present in them. Some rhodophytes are also important in the formation of tropical reefs, an activity with which they have been involved for millions of years; in some Pacific atolls, red algae have contributed far more to reef structure than other organisms, even more than corals.

Xanthophyceae are in general less frequent in marine than in freshwater environment, although several benthic species are common in brackish waters. They occur often under dystrophic or mesotrophic conditions, showing their highest diversity in acidic waters enriched with dissolved organic matter. They include a variety of cell organizations. Single flagellated cells are relatively rare, except in brackish waters, where they are usually metaphytic or epiphytic among submersed vascular plants. Solitary and coenobial coccal types are much more common in freshwater euplankton and epiphyton. However, their presence is often overlooked since they are easily mistaken for coccal green algae because of the similar morphology and their yellow-greenish color, which is due to the lack of fucoxanthin,

Bacillariophyceae class of unicellular algae, usually occurring singly, but may be colonial or filamentous. Cell size ranges from 5 to 2000 µm. The cell wall (frustule) is impregnated with silica and consists of two valves, one of which overlaps the other like the lid on a box. The frustule is commonly delicately ornamented and pierced by tiny holes (punctae) which may be covered by porous sieve membranes. There are two orders. The Centrales (centric diatoms) are circular, with radial symmetry, and are predominantly marine. The Pennales (pennate diatoms) are elliptical, with bilateral symmetry, and dominate freshwater environments. The frustules have formed an important constituent of deep-sea deposits since the Cretaceous. The oldest known diatom is usually taken to be *Pyxidicula bollensis* from the Jurassic.

UNIT 7 : PHAEOPHYCEAE I

Structure

7.1 INTRODUCTION

The class Phaeophyceae includes a group of algae known as brown algae. Their colour, which ranges from would be in the colour of dark or light brown to green which is olive, inspired their names. The majority of their habitats are maritime. The size and shape of the approximately a thousand five hundred species of Phaeophyceae vary widely. They have many cells, and the proportion of fucoxanthin to chlorophyll determines their color. They contain seaweeds, with Ectocarpus, Fucus, huge kelps, Sargassum, etc. as some famous examples.

Brown algae, comprising the class **Phaeophyceae**, are a large group of multicellular algae, including many seaweeds located in colder waters within the Northern Hemisphere. Brown algae are the major seaweeds of the temperate and polar regions. They are dominant on rocky shores throughout cooler areas of the world. Most brown algae live in marine environments, where they play an important role both as food and as a potential habitat. For instance, Macrocystis, a kelp of the order Laminariales, may reach 60 m (200 ft) in length and forms prominent underwater kelp forests. Kelp forests like these contain a high level of biodiversity. Another example is Sargassum, which creates unique floating mats of seaweed in the tropical waters of the Sargasso Sea that serve as the habitats for many species. Many brown algae, such as members of the order Fucales, commonly grow along rocky seashores. Some members of the class, such as kelps, are used by humans as food.

Objectives

This is the seventh unit on Phaeophyceae-I of block-II (Algae-II). Under seventh unit, we have following objectives. These are as under:

- To know the characteristics of Phaeophyceae
- **To discuss various reproduction** in Phaeophyceae
- To know the classification of Phaeophyceae and its economic importance
- To discuss Dictyota and Laminaria in brief

Between 1,500 and 2,000 species of brown algae are known worldwide. Some species, such as Ascophyllum nodosum, have become subjects of extensive research in their own right due to their commercial importance. They also have environmental significance through carbon fixation. Brown algae belong to the group Heterokontophyta, a large group of eukaryotic organisms distinguished most prominently by having chloroplasts surrounded by four membranes, suggesting an origin from a symbiotic relationship between a basal eukaryote and another eukaryotic organism. Most brown algae contain the pigment fucoxanthin, which is responsible for the distinctive greenish-brown color that gives them their name. Brown algae are unique among heterokonts in developing into multicellular forms with differentiated tissues, but they reproduce by means of flagellatedspores and gametes that closely resemble cells of other heterokonts. Genetic studies show their closest relatives to be the yellow-green algae.

Brown algae are a group of algae belonging to class Phaeophyceae. They are named due to their colour, which varies from brown to olive green. They are mostly found in marine environments. There are around 1500 species of brown algae, which vary greatly in their size and shape. They are multicellular and the colour depends on the ratio of chlorophyll and the pigment, fucoxanthin. They contain seaweeds, some of the notable examples are *Ectocarpus*, *Fucus*, giant kelps, *Sargassum*, etc.

7.2 MORPHOLOGY

Brown algae exist in a wide range of sizes and forms. The smallest members of the group grow as tiny, feathery tufts of threadlike cells no more than a few centimeters (a few inches) long. Some species have a stage in their life cycle that consists of only a few cells, making the entire alga microscopic. Other groups of brown algae grow to much larger sizes. The rockweeds and leathery kelps are often the most conspicuous algae in their habitats. Kelps can range in size from the 60-centimeter-tall (2 ft) sea palm Postelsia to the giant kelp Macrocystis pyrifera, which grows to over 50 m (150 ft) long and is the largest of all the algae. In form, the brown algae range from small crusts or cushions to leafy free-floating mats formed by species of Sargassum. They may consist of delicate felt-like strands of cells, as in Ectocarpus, or of 30-centimeter-long (1 ft) flattened branches resembling a fan, as in Padina.

Regardless of size or form, two visible features set the Phaeophyceae apart from all other algae. First, members of the group possess a characteristic color that ranges from an olive green to various shades of brown. The particular shade depends upon the amount of fucoxanthin present in the alga. Second, all brown algae are multicellular. There are no known species that exist as single cells or as colonies of cells, and the brown algae are the only major group of seaweeds that does not include such forms. However, this may be the result of classificationn rather than a consequence of evolution, as all the groups hypothesized to be the closest relatives of the browns include single-celled or colonial forms. They can change color depending on salinity, ranging from reddish to brown.

7.3 GENERAL CHARACTERISTICS OF PHAEOPHYCEAE (BROWN ALGAE)

7.3. Habitat

Brown algae are mostly marine. They are found in cold waters along the coast. They are either free-floating or found attached to the substratum. *Ectocarpus* is an epiphyte, *Fucus* is found attached to rocks and *Sargassum* is an example of free-floating brownalgae.

7.3.2 Size and Shape

The size and shape of brown algae vary greatly. Their size ranges from a few cms or an inch to 100 metres. *Ectocarpus* is a simple filamentous alga, whereas giant kelp can reach up to 100 m. Kelp forests represent great biodiversity.

7.3.3 Structure

They are multicellular algae. They are filamentous and branched. The plant body is thallus, i.e. they lack true roots, stem and leaves.

- They have a root-like structure called a **holdfast,** which anchors them to their substrate. The structure of holdfast varies in different species. They do not take part in nutrient or water uptake like roots in plants. They prevent algae from being flown away by the water current.
- There is a small stalk present, which is more like a stem. It is called a **stipe.** *Fucus* shows three distinct layers in the stipe region, namely pith (central region), cortex and outer epidermis. Stipe may be rigid or elastic. The centre of the stipe is hollow and helps in keeping the algae buoyant.
- They have a flattened structure called the lamina, blade or frond, which resembles leaves. The surface of the lamina may be smooth or wrinkled. Sometimes it is coated with slime to prevent attachment of epiphytes.
- Some of the brown algae contain special gas-filled bladders called **pneumatocysts.** They are mostly present near the lamina. It provides buoyancy to algae and helps to keep the part of the algae near the surface for photosynthesis.
- The cell wall is made up of two layers, outer gummy, made up of algin and inner cellulose, which provides strength.
- They are autotrophic and contain chlorophyll 'a' and 'c'. They also contain carotenoids and xanthophyll.
- Chloroplast usually does not contain pyrenoids but some species have pyrenoids in them.
- Fucoxanthin ($C_{42}H_{58}O_6$) is the main xanthophyll pigment and is responsible for their characteristic colour.
- Food is stored in the form of complex carbohydrates, viz. Laminarin or mannitol.
- Laminarin is a polysaccharide of glucose. It is a linear polymer with $\beta(1\rightarrow3)$ and $\beta(1\rightarrow6)$ (branching) linkages.
- Mannitol is a sugar alcohol and other than being carbon storage it also acts as an osmoprotectant, antioxidant. It protects them in their harsh habitat.

7.4 TISSUE ORGANIZATION

The simplest browns are filamentous- that is, their cells are elongate and have septa cutting across their width. They branch by getting wider at their tip, and then dividing the widening. These filaments may be haplostichous or polystichous, multiaxial or monoaxial forming or not a pseudoparenchyma. Besides fronds, there are the large in size parenchymatic kelps with three-dimensional development and growth and different tissues (meristoderm, cortex and medulla) which could be consider the trees of the sea. There are also the Fucales and Dictyotales smaller than kelps but still parenchymatic with the same kind of distinct tissues.

The cell wall consists of two layers; the inner layer bears the strength, and consists of cellulose; the outer wall layer is mainly algin, and is gummy when wet but becomes hard and brittle when it dries out. Specifically, the brown algal cell wall consists of several components with alginates and sulphated fucan being its main ingredients, up to 40% each of them. Cellulose, a major component from most plant cell walls, is present in a very small percentage, up to 8%.

Cellulose and alginate biosynthesis pathways seem to have been acquired from other organisms through endosymbiotic and horizontal gene transfer respectively, while the sulphated polysaccharides are of ancestral origin. Specifically, the cellulose synthases seem to come from the red alga endosymbiont of the photosynthetic stramenopiles ancestor, and the ancestor of brown algae acquired the key enzymes for alginates biosynthesis from an actinobacterium. The presence and fine control of alginate structure in combination with the cellulose which existed before it, gave potentially the brown algae the ability to develop complex structurally multicellular organisms like the kelps.

7.5 REPRODUCTIONINPHAEOPHYCEAE

They reproduce by both asexual and sexual means.

- Vegetative reproduction is by fragmentation.
- Asexual reproduction is by the formation of motile zoospores. They are pear-shaped and have two unequal flagella.
- Sexual reproduction is by the formation of motile gametes, which are also biflagellate with two laterally attached flagella.
- Sexual reproduction may be oogamous, isogamous or anisogamous.
- Gametes unite in water or within oogonium.

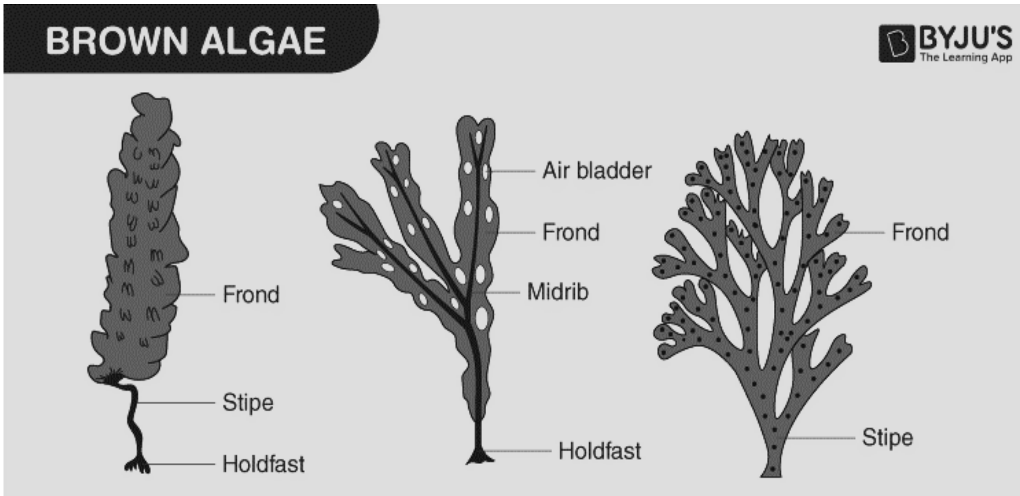


Fig.7.1 Structure of brown algae

The methods of reproduction in Phaeophyceae are very diverse and a brief summary of the principal methods has been given below:

Many brown algae reproduce by vegetative method by the process of fragmentation of the young or adult thallus. Fragments of the thallus, thus produced, may become detached from the parent plant and float away to form new individuals, or they remain united with one another forming an aggregation of individuals, being attached to the substratum by the common holdfast. In some cases, special reproductive branches (propagula) are formed and these are separated from the parent plant, ultimately developing into new individuals.

All brown algae, excepting the Fucus and a few allied genera, reproduce asexually by the production of zoospores or aplanospores. The zoospores are produced within both unilocular (or unicellular) and plurilocular (or multicellular) sporangia and are always borne on the diploid thallus (sporophyte). The unilocular sporangium is a true sporangium, because reduction division of the uninucleate protoplast takes place prior to the formation of the haploid zoospores.

The nucleus of the protoplast first divides reductionally into two nuclei, which subsequently divide and re-divide mitotically into 32, 64 or 128 nuclei. This is followed by the cleavage of the protoplast forming uninucleate masses, each of which is finally metamorphozed into a biflagellate zoospore. Each of these zoospores, after liberation, produces a haploid thallus (gametophyte). On the other hand, the zoospores produced by the plurilocular sporangium are diploid, each of which on germination gives rise to a diploid thallus, similar to the thallus from which it is derived. These zoospores are, therefore, termed neutral zoospores and the sporangium, neutral sporangium.

During the formation of neutral zoospores, the uninucleate protoplast of each cell of the plurilocular sporangium (neutral sporangium), without undergoing reduction division, is directly metamorphozed into a neutral zoospores with two flagella. Thus, by the neutral zoospores the same generation is reduplicated. Sometimes the unilocular sporangium, instead of producing the zoo-spores, may produce 4-8 large, non-flagellate aplanospores.

Sexual reproduction in the brown algae may be a case of:

(i) Isogamy, i.e. by the union of two motile morphologically identical gametes,

(ii) Anisogamy, i.e. by the union of two motile gametes of unequal size, and

(iii) Oogamy, i.e. by the union of a motile, flagellate antherozoid with a non-motile, non-flagellate, passive egg.

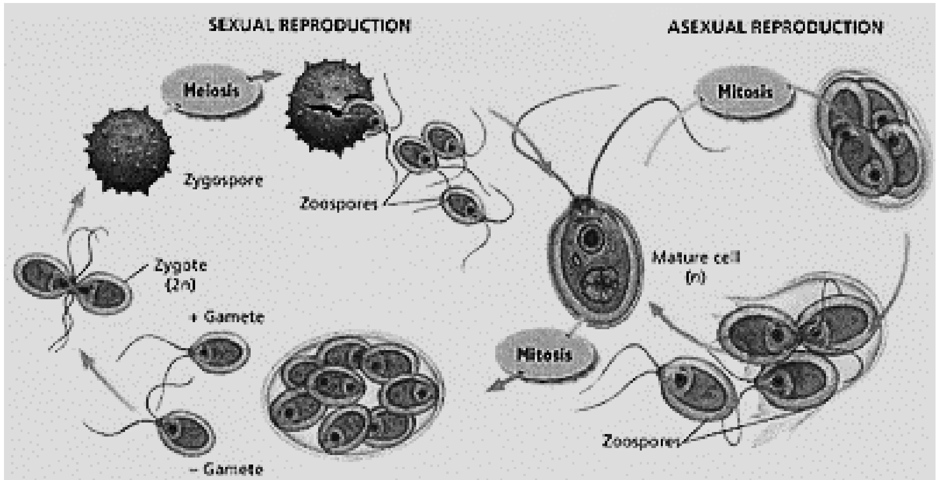


Fig.7.2 Reproduction in Phaeophyceae

The iso- and aniso-gametes are produced within multicellular gametangia, which are similar in appearance with the neutral sporangia but these are always produced on the gametophyte, which is either homothallic or heterothallic. The zygotes, thus produced, develop into new sporophytes. Several members of the Phaeophyceae are oogamous and heterothallic. The male sex organ, the antheridium, may be unicellular or multicellular, and the entire protoplast of each cell is directly metamorphozed into a single antherozoid with two flagella. The female sex organ, the oogonium, is always unicellular containing within it 1-8 oospheres or eggs. In some cases, the egg is extruded from the oogonium or even discharged from it, so that fertilization takes place outside the body of the oogonium. When sexual union fails, the gametes either degenerate or the unsuccessful gametes may develop into parthenospores.

7.6 ALTERNATION OF GENERATIONS OF PHAEOPHYCEAE

Previously it was thought that the Phaeophyceae do not possess any alternation of generations. But, it is well known at present that all the members of this Class, excepting the Order Fucales, have a typical alternation of generations, which may be isomorphic (e.g. Ectocarpales, Dictyotales, etc.) or heteromorphic (e.g. Laminariales, Desmarestiales, etc.). These alternations have been studied chiefly under laboratory conditions, and for this purpose cultures should be examined starting both from the zoospores as well as the zygotes.

The Laminariales and the Dictyotales have a gametophyte regularly alternating with a sporophyte and vice versa; furthermore, this alternation is obligatory. On the other hand, there is a large number of brown algae where the alternation of the two generations is not only well marked, but also further complicated by a reduplicating of the sporophytic and as well as gametophytic generation.

The first method of reduplication of sporophyte is by fragmentation. Secondly, vegetative multiplication may also be due to the formation and abscission of special reproductive branches- The propagula. Thirdly the sporophyte may be reduplicated by means of neutral zoospores. These neutral zoospores are formed inside the neutral sporangium. It develops from a single cell which divides and re-divides to form an elongated multicellular structure composed of many blocks of cells. This is known as pleurilocular or multilocular sporangium. It produces diploid neutral zoospores with two laterally inserted unequal flagella. Zoospores on germination give rise to new sporophyte.

The life cycle may be complicated by the formation of sporophyticdisplonema, the reproduction by which is always vegetative. The gametophyte may also be reduplicated either by vegetative multiplication, by fragmentation or by the formation of vegetative protonema.

Other Phaeophyceae produce dwarf stages, which are called plethysmothalli. This plethysmothallic form may be reduplicated itself or may develop into adult sporophyte. In some cases this form may bear neutral sporangium to produce neutral zoospores which give rise to new sporophytes. Neutral zoospores in turn may produce plethysmothalli or adult sporophyte. Unilocular sporongia may be developed directly from the sporophyte. Its development begins with an enlargement of an uninucleate cell and division and re-division of the nucleus into 32, 64 or 128 daughter nuclei.

The first division of the diploid nucleus is meiotic. There is then cleavages into uninucleate protoplasts and metamorphosis of each protoplast into biflagellate haploid zoospore. These haploid zoospores give rise to gametophytic plants. The gametophyte may be alike morphologically with the sporophyte as in isogeneratae or may be dissimilar with that of sporophyte as in heterogeneratae. The gametophyte then produces either iso- or aniso gametes or antherozoid and egg. The fusion of the gametes results into zygote which again gives rise to new sporophytic plant.

A plethysmothallus may also produce haploid zoospores from unilocular zoosporangium. This zoospores germinates to from gametophyte. From this gametophyte by sexual reproduction plethysmothallus or typical sporophyte may be formed. Gamete produced by gametophyte may also germinate parthenogenetically to repeat the gametophytic generation. The Fucales, however, present a very naughty problem, because here a many-celled diploid generation alternates with a one- celled haploid stage. Strasburger regards the Fucus plant itself as a sporophyte and antheridia and oogonia as micro- and mega-sporangia respectively, the gametophytic stages being restricted to the sperms and eggs only.

7.7 CLASSIFICATION OF PHAEOPHYCEAE

Phaeophyceae is one of three classes of Algae, namely, Chlorophyceae, Phaeophyceae, and Rhodophyceae. Phaeophyceae can be further divided into nine orders as mentioned below. This classification of Phaeophyceae was done by Fritsch (1935, 45).

1. Ectocarpales
2. Tilopteridales
3. Cutleriales
4. Sporochnales
5. Desmarestiales
6. Laminariales
7. Sphacelariales
8. Dictyotales
9. Fucales

The Phaeophyceae has been divided into the following nine orders:

Order 1:

Ectocarpales:

Plants filamentous, pseudo-parenchymatous or truly parenchymatous in form; asexual reproduction by zoospores produced from unilocular and plurilocular zoosporangia; sexual reproduction is usually oogamous, rarely anisogamous.

Examples: Ectocarpus, Punctaria, Castagnea, etc.

Order 2:

Tilopteridales:

Plants filamentous; asexual reproduction by monospores or by zoospores produced from unilocular sporangia; sexual reproduction perhaps anisogamous.

Examples: Tilopteris, Haplospora, etc.

Order 3:

Cutleriales:

Plant body generally composed of thread-like structures; asexual reproduction by zoospores produced in unilocular sporangia; sexual reproduction anisogamous.

Examples: Cutleria, Zonardinia, etc.

Order 4:

Sporochnales:

Thallus bulky and complex; asexual reproduction by zoospores formed within unilocular sporangia; sexual reproduction possibly oogamous.

Examples: Sporochnus, Carpomitra, etc.

Order 5:

Desmarestiales:

Thallus uniaxial in construction with complex cortication; asexual reproduction by zoospores formed within unilocular sporangia; sexual reproduction oogamous.

Examples: Desmarestio, Arthrocladia, etc.

Order 6:

Laminariales:

Plant bulky, body truly parenchymatous; asexual reproduction by zoospores formed within unilocular sporangia; sexual reproduction distinctly oogamous.

Examples: Laminaria, Macrocystis, Postelsia, etc.

Order 7:

Sphacelariales:

Plant small, parenchymatous, heterotrichous; asexual reproduction by zoospores formed within unilocular sporangia; sexual reproduction isogamous.

Examples: Sphacelaria, Halopteris, etc.

Order 8:

Dictyotales:

Plants with frequent dichotomous branching and slightly differentiated parenchymatous forms; asexual reproduction by non-motile tetraspores formed within unilocular sporangia; sexual reproduction oogamous.

Examples: Dictyota, Padina, etc.

Order 9:

Fucales:

Plants with parenchymatous forms and complex external and internal differentiations; asexual reproduction unknown; sexual reproduction oogamous.

Examples: Fucus, Sargassum, etc.

7.8 BROWN ALGAE CLASSIFICATION AND EXAMPLES

Phaeophyceae is a class of brown algae. The other two major classes are Chlorophyceae (green algae) and Rhodophyceae (red algae).

Phaeophyceae is divided into 9 orders by Fritsch. The main orders are:

1. Ectocarpales – e.g. *Ectocarpus,* etc.
2. Laminariales – e.g. *Laminaria, Macrocystis, Nerocystis (Giant Kelp),* etc.
3. Fucales – e.g. *Fucus, Sargassum, etc.*
4. Dictyotales – e.g. *Dictyota,* etc.

7.9 ECONOMIC IMPORTANCE OF BROWN ALGAE

Algae are important for their carbon fixation ability. They are an important component of the aquatic food chain as primary producers. Kelp forests support large numbers of animals.

- They are widely used as edible seaweeds, e.g. *Laminaria, Sargassum, etc.*
- Alginic acid is commercially extracted and used in the food industries as a thickening agent. It is used as a stabilizer in ice cream and baking industries.
- Alginic acid is also used in batteries.
- Alginic acid is used for making pills and surgical threads.
- Several species are used as fertilizers.
- Kelp is used for producing soda ash. It is used in the production of soap and glass.
- Brown algae like *Laminaria* is rich in iodine and has been used to treat iodine deficiency, e.g. Goitre.
- They have been used for medicinal purposes, e.g. sodium laminarin sulphate is an anticoagulant. They also have antibiotic and vermifuge properties.

7.10 DICTYOTA

Dictyota is a genus of brown seaweed in the family Dictyotaceae. Species are predominantly found in tropical and subtropical seas, and are known to contain numerous chemicals (diterpenes) which have potential medicinal value. As at the end of 2017, some 237 different diterpenes had been identified from across the genus.

Taxonomy and Nomenclature

The genus *Dictyota* was first described by Jean Vincent Lamouroux in 1809. The name *Dictyota* is derived from the Greek word which mean “net” or “network”, referring to the inner cellular structure of specimens when viewed under a microscope, which features netted cortical and medullary cells.

Dictyota belongs to the order Dictyotales and the SSDO-clade, which also includes the orders Sphacelariales, Syringodermatales, and Onslowiales. The family Dictyotaceae is divided into two tribes: Dictyoteae and Zonarieae. The former have a single lens-shaped apical cell from which the thallus grows, while the latter are characterized by a row or cluster of apical cells. The genera *Glossophora*, *Glossophorella*, and *Pachdictyon* are synonyms of *Dictyota* as DNA sequencing revealed that they were closely related.

Morphology

External characteristics

Dictyota has "flat, ribbon-like axes" which exhibit dichotomous branching that may be either isotomous (equal or symmetrical) or anisotomous (unequal). Isotomous branches may be recurved, while anisotomous branches may become falcate (hooked), or cervicorn, if combined with twisting axes. Apical meristems of *Dictyota* species have been reported to be either truncate, rounded, or acute. A considerable degree of morphological plasticity has been observed from branching patterns, thus making molecular analyses indispensable when identifying species.

Colors of living thalli range from dark brown to green (as in *D. friabilis*) or blue (as in *D. cyanoloma*). The thalli grow from apical cells which differentiate into an outer cortical and an inner medullary cell layer. Cortical cells on the margins of the thalli may grow into leaf-like projections or teeth (as in *D. ciliolata* and *D. cyanoloma*) while adventitious branches may grow from the central cortical cells. Thalli may also grow hair (20-50 um in diameter). Thalli attach to the substrate via rhizoids which are multicellular, uniseriate, branching, and hyaline (glassy or transparent). Different species may have one or several attachment points which can lead to a wide range of growth forms (i.e. creeping thalli or fully erect).

Fig.7.3 Thallus of *Dictyotadichotoma* (Garcia, 1988)

Internal anatomy

The thalli are parenchymatous and are characterized by one or more apical cells that divide into an outer cortical and an inner medullary cell layer which can have several different configurations (e.g. uni-layered cortex with unilayered medulla, uni-layered cortex with multi-layered medulla, etc.).

Distribution

Dictyota is distributed along tropical to temperate waters with species having generally restricted geographic ranges. It is the most abundant genus of brown algae in the Mediterranean Sea as well as the Atlantic coasts of Europe.

Ecology

Species of the genus are commonly found in subtidal to intertidal rocky pools. Seasonality in species' abundances as well as fertility are driven mainly by temperature, photoperiod, and solar radiation. For instance, populations of *D. dichotoma* in the southern hemisphere are highly abundant for a majority of the year but are largely absent in the warmer months, which is when its northern counterparts are most abundant and fertile.

Life History

Dictyota exhibits an isomorphic life cycle wherein the alternating gametophyte and sporophyte phases appear morphologically similar. This alternation co-occurs with a change in ploidy. The gametophytes produce gametes which undergo fertilization to produce the diploid sporophyte, which then produces sporangia which will release 4 haploid spores through meiosis. Half of the haploid spores will develop into the female gametophytes while the other half will develop into male gametophytes, starting the process over again.

Dictyota is dioecious and reproduces both sexually and asexually. Release of gametes follows a diurnal and lunar periodicity. Gametes are often released 20–30 minutes after first light, with peaks occurring once or twice a month depending on the species. Asexual reproduction may occur via adventitious branching following the loss of the apical meristem.

Chemical Composition

Dictyota is known to have high levels of fatty acids and lipids which makes the genus ideal for use as feedstock. The pigments found in *Dictyota* are Chlorophyll *a*, *c*, fucoxanthin and violaxanthin which are present in a ratio of 13:3:10:1. This ratio may be altered by depth.

Exploitation/Utilization and Management

The genus is not currently cultivated nor harvested on an industrial scale.[3] It is mainly exploited for its secondary metabolites which are known to have anticoagulant, antibacterial, anti-inflammatory properties, among others, making them useful for a wide range of pharmaceutical applications. For instance, there is evidence that methanolic extracts of *Dictyota* inhibits the butyrylcholinesterase (BuChE) enzyme in humans, which could potentially treat Alzheimer's disease.

Other applications include its use as biofuel - due to the high lipid content of some species - and as supplemental feeds for poultry, cattle, and fish. A study in 2014 found that feeds with *D. bartayresiana* supplements could potentially reduce in vitro methane production of ruminants by 92.2%, which may have implications for reducing emissions from the agricultural sector.

Species

The genus *Dictyota* contains the following species:

- Dictyotaacutiloba J.Agardh, 1848
- Dictyotaadhaerens Noda, 1965
- Dictyotaadnata Zanardini, 1878
- Dictyotaadnata f. nana Post
- Dictyotaaegerrima (Allender & Kraft) De Clerck, 2006
- Dictyotaalternifida J.Agardh, 1894

7.11 LAMINARIA

Laminaria is a genus of brown seaweed in the order Laminariales (kelp), comprising 31 species native to the north Atlantic and northern Pacific Oceans. This economically importantgenus is characterized by long, leathery laminae and relatively large size. Some species are called Devil's apron, due to their shape, or sea colander, due to the perforations present on the lamina. Others are referred to as *tangle*. *Laminaria* form a habitat for many fish and invertebrates.

The life cycle of *Laminaria* has heteromorphic alternation of generations which differs from Fucus. At meiosis the male and female zoospores are produced separately, then germinate into male and female gametophytes. The female egg matures in the oogonium until the male sperm fertilizes it. Life-Cycle: The most apparent form of *Laminaria* is its sporophyte phase, a structure composed of the holdfast, the stipe, and the blades. While it spends its time predominately in the sporophyte phase, it alternates between the sporophyte and its microscopic gametophyte phase.

Laminaria japonica (J. E. Areschoug – Japón) is now regarded as a synonym of Saccharina japonica and *Laminaria saccharina* is now classified as Saccharina latissima.

History

Laminaria arrived in China from Hokkaido, Japan in the late 1920s. Once in China, *Laminaria* was cultivated on a much larger industrial scale. The rocky shores at Dalian, the northern coast of the Yellow Sea, along with its cold waters provided excellent growing conditions for these species. *Laminaria* was harvested for food and 1949 yielded 40.3 metric tons of dry weight. *Laminaria* need cold water to survive and can only live above 36° N latitude.

In 1949, the Chinese started to commercially grow *laminaria* as a crop. This increased the production of dry weight to 6,200 metric tons. Farming *laminaria* is still a large production for China. However, since the 1980s production has dropped due to new mariculture technology .

Farming practices

Laminaria is generally farmed using the floating raft method, in which young *laminaria* sporophytes are attached to submerged ropes. These ropes are then attached to floating rafts.

Ecology

Laminaria is found in colder ocean waters, such as arctic regions. Preferring to stay in regions where there are rocky shores, this allows the *laminaria* to attach. Due to the height of the *Laminaria*, they provide protection for creatures that the open ocean does not often give. Invertebrates are just one of the organisms that live among the algae. Sea snails and other invertebrates feed on the blades (leaves) of the *laminaria*. Other organisms, such as sea urchins, feed on the holdfasts, which can kill the algae.[11] Red sea urchins, found on the North America Pacific

Coast, can decimate kelp, including *Laminaria*, if the urchins are not managed by sea otters. Species such as Coelopapilipes feed and lay eggs on *Laminaria* when it is washed up on beaches.

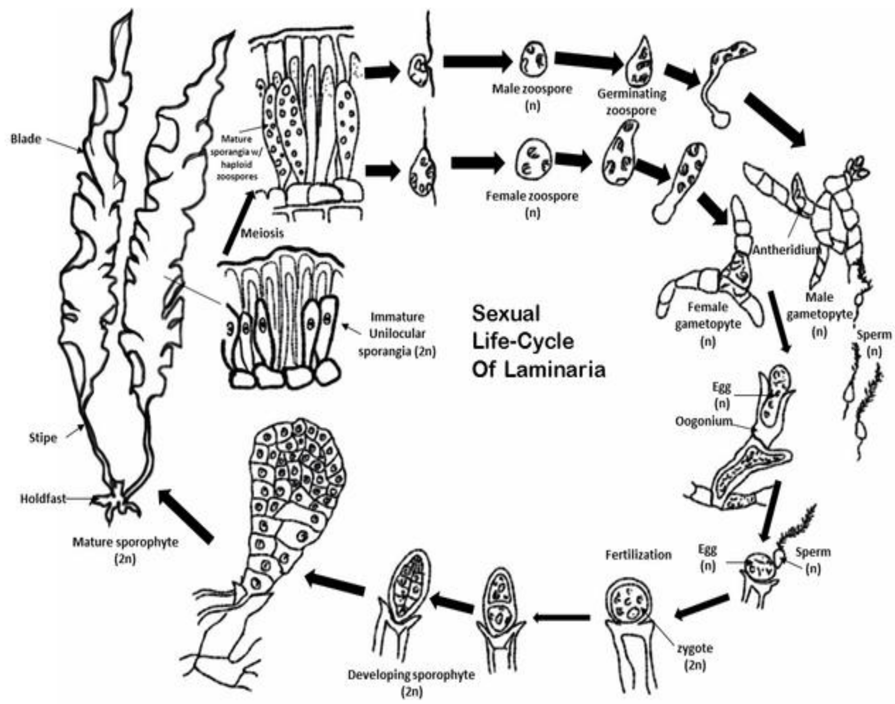


Fig.7.4 The sexual life cycle of Laminaria

Life cycle

Laminaria expresses a haplo-diplophasic life history, in which it alternates from a macroscopic thallic sporophyte structure, consisting of the holdfast, a stipe, and the blades, to a filamentous, microscopic gametophyte. The sporophyte structure of *laminaria* can grow to 7 metres (23 ft), which is large in comparison to other algae, but still smaller than the giant kelps such as Macrocystis and Nereocystis, which can grow up to 40–50 metres (130–160 ft). On the other hand, the gametophyte structure is no more than a few millimeters in length. In opposition to the gametophyte phase, which only consists of one type of tissue, the more complex sporophyte phase is made up of different types of tissue. One of these tissues includes a sieve-like element which translocates photoassimilates. These structures are very similar to mesophyll cells found in higher plant leaves.

Uses**Medical**

A laminaria stick may be used to slowly dilate the cervix to induce labor and delivery, or for surgical procedures including abortions or to facilitate the placement of an intrauterine device. The stick is made up of a bundle of dried and compressed laminaria that expands as water is absorbed. *Laminaria* is a source of the relatively rare element, iodine, which is commonly used to promote thyroid health.

Food

Various species of *Laminaria* have been used for food purposes since ancient times wherever humans have encountered them. Typically, the prepared parts, usually the blade, are consumed either immediately after boiling in broth or water, or consumed after drying. The greater proportion of commercial cultivation is for algin, iodine, and mannitol, which are used in a range of industrial applications. In South Korea it is processed into a sweetmeat known as *laminaria jelly*, in other countries it is also used in fresh salad form, which is also canned for preservation for delivery and selling purposes in other regions. Many countries produce and consume laminaria products, the largest being China.

Energy

Due to their ability to grow underwater and in salt water, algae are being looked into as a source of biofuel. *Laminaria* is one of the five macroalgae farmed for products such as food, chemicals and power. Those five genera contribute to 76% of the total tonnage for farmed macroalgae. *Laminaria* is less desired as a renewable energy source due to its high ash content when burned. *Laminaria* has an ash content of 33%, while wood has about a 2% ash content when burned. Algae have a high water content requiring much energy to dry the algae before being able to properly use it.

More research is being done with anaerobic digestion, which is the most promising practice to extract energy from *Laminaria*. There are still barriers to overcome before moving forward with anaerobic digestion, such as its cost per kwh.

Metal absorption

The ability of laminaria, along with other brown algae, to absorb heavy metals is a current area of interest regarding their use to remove heavy metals from wastewater. Laminaria has been shown by recent research to have a favorable mannuronic/guluronic acid residues ratio (M/G ratio) for heavy metal absorption in its alginate. This M/G ratio is the ratio between the L-gluronate (G) and D-mannuronate (M) in the alginate, a natural anionic polymer that is found in all brown algae. This alginate is able to form a gel that contains carboxyl groups that can bind heavy metal cations such as Cu^{2+}, Cd^{2+}, and Pb^{2+}, thereby allowing these metals to be removed from wastewater.

Predator

Coelopafrigida and related flies from the genus *Coelopa* are known to feed, mate, and create habitats out of different species of *Laminaria*. This is of particular notice when the *Laminaria* is stranded on the beach and not when it is submerged under seawater. With increasing amounts of seaweed washing up on shores, there is an increasing recognition of *Laminaria* and their close pairing with *Coelopa*.

Species

Laminaria digitata, Cyanotype by Anna Atkins, 1843

- Laminaria abyssalis A.B. Joly & E.C. Oliveira – South American Atlantic
- Laminaria agardhii Kjellman– North American Atlantic
- Laminaria appressirhiza J. E. Petrov & V. B. Vozzhinskaya
- Laminaria brasiliensis A. B. Loly & E. C. Oliveira
- Laminaria brongardiana Postels& Ruprecht
- Laminaria bulbosa J. V. Lamouroux
- Laminaria bullata Kjellman

7.12 SUMMARY

Under this unit we have summarized the general characteristics of phaeophyceae (Brown Algae), **reproduction** in Phaeophyceae, Classification of Phaeophyceae and brief study of Dictyota and Laminaria. Further we have discussed the economic importance of brown algae.Brown algae are a group of algae belonging to class Phaeophyceae. They are named due to their colour, which varies from brown to olive green. They are mostly found in marine environments. There are around 1500 species of brown algae, which vary greatly in their size and shape.

They are distinguished by chloroplasts that have four surrounding membranes, thylakoids in stacks of three, fucoxanthin that masks chlorophyll-a and -c, laminarin as the photosynthetic reserve, and alginates commonly as the wall matrix component. They reproduce via vegetative mode by fragmentation. Asexual reproduction takes place by the formation of motile zoospores. Sexual reproduction can be either isogamous, oogamous, or anisogamous. Sexual reproduction takes place by external fertilization or within oogonium (oogamous species).

Phaeophyceae is one of three classes of Algae, namely, Chlorophyceae, Phaeophyceae, and Rhodophyceae. Phaeophyceae can be further divided into nine orders as it was done by Fritsch (1935). Brown algae have found various commercial uses over the years since their discovery. They are rich in various rare nutrients hence used as edibles. They are also used in other industries like soap, fertiliser, the baking industry, etc.

7.13 TERMINAL QUESTIONS

Q. 1 What are the general characteristics of Phaeophyceae (Brown Algae)? Describe it.

Answer:---
--

Q. 2 Describe different type of r**eproduction** in Phaeophyceae.

Answer:---
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Q.3 Describe alternation of generations of Phaeophyceae.

Answer:---
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Q. 4 Explain life cycle of Laminaria in brief.

Answer:---
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Q.5 Describe the classification of Phaeophyceae.

Answer:---
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Q.6 Write short notes on the following.

(a) Tissue organization in Phaeophyceae

(b) Economic Importance of Brown Algae

Answer:---

FURTHER READINGS

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 8: PHAEOPHYCEAE –II

Structure

8.1 INTRODUCTION

R.H. Whittaker categorized living things using the Five Kingdoms system. He divided living things into different categories according to their cellular makeup, mode of nourishment, bodily shape, reproductive ability, phylogenetic relationship, Protista, Planta, monera, and Animalia, and the fungi were the names of these five kingdoms.

Algae are primarily aquatic, having pigment- chlorophyll would be simple, thalloid and these creatures would be autotrophic in nature. They can be found in soils, damp stones, timber, and other environments. Few people establish relationships with lichen and animals. Vegetative, asexual, and sexual means of reproduction. Different kinds of spores, most frequently zoospores, are produced during asexual reproduction. Fragmentation is the method used in vegetative reproduction. Two gametes fuse together during sexual reproduction. These gametes can be similarly sized flagellated gametes, like Ulothrix, or they can be similarly sized non-flagellated (non-motile) gametes (as in Spirogyra). Isogamous reproduction is this type. Three major categories of algae are distinguished: Phyceae, Rhodophyceae, and Chlorophyceae.

Objectives

This is the eighth unit on Phaeophyceae -II of block-II (Algae-II). Under this unit, we have following objectives. These are as under:

- To know about class Phaeophyceae

- To know about taxonomy and phylogeny
- To discuss vegetative organizations inPhaeophyceae
- To discuss about Fucus serratus

8.2 ALGAE

Algae exist in environments ranging from oceans, rivers, and lakes to ponds, brackish waters and even snow. Algae are usually green, but they can be found in a variety of different colours. For instance, algae living in snow contain carotenoid pigments in addition to chlorophyll, hence giving the surrounding snow a distinctive red hue. Multicellular examples of algae include the giant kelp and brown algae. Unicellular examples include diatoms, Euglenophyta and Dinoflagellates.

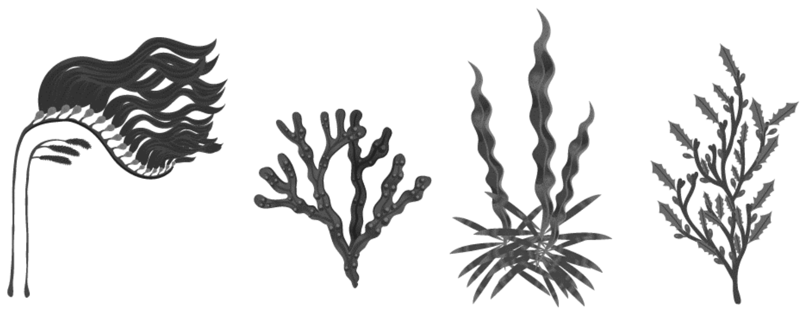


Fig.8.1 Different types of algae

Most algae require a moist or watery environment; hence, they are ubiquitous near or inside water bodies. Anatomically, they are similar to another major group of photosynthetic organisms – the land plants. However, that is where the differences end as algae lack many structural components typically present in plants, such as true stems, shoots, and leaves. Furthermore, they also do not have vascular tissues to circulate essential nutrients and water throughout their body.

8.3 CHARACTERISTICS OF ALGAE

Specific general characteristics of algae are common to plants as well as animals. Algal cells are eukaryotic. For instance, algae can photosynthesize like plants, and they possess specialized structures and cell-organelles, like centrioles and flagella, found only in animals. The algal cell walls consist of mannans, cellulose and Galatians. Listed below are some of the general characteristics of algae.

- Algae are photosynthetic organisms
- Algae can be either unicellular or multicellular organisms
- Algae lack a well-defined body, so, structures like roots, stems or leaves are absent
- Algae are found where there is adequate moisture.
- Reproduction in algae occurs in both asexual and sexual forms. Asexual reproduction occurs by spore formation.
- Algae are free-living, although some can form a symbiotic relationship with other organisms.

8.4 PHAEOPHYCEAE

The class Phaeophyceae includes a group of algae known as brown algae. Their colour, which ranges from would be in the colour of dark or light brown to green which is olive, inspired their names. The majority of their habitats are maritime. The size and shape of the approximately a thousand five hundred species of Phaeophyceae vary widely. They have many cells, and the proportion of fucoxanthin to chlorophyll determines their color. They contain seaweeds, with Ectocarpus, Fucus, huge kelps, Sargassum, etc. as some famous examples. Brown algae multiply by asexual and sexual reproduction; both the motile zoospores and gametes have two unequal flagella. Some seaweed species have gas-filled bladders (pneumatocysts), which keep photosynthetic parts of the algal thallus floating on or near the surface of the water. Once a major source of iodine and potash, brown algae are still an important source of algin, a colloidal gel used as a stabilizer in the baking and ice-cream industries. Certain species are also used as fertilizer, and several are eaten as a vegetable (e.g., *Laminaria*) in East Asia and elsewhere.

8.4.1 Characteristics of Phaeophyceae

- They have a multicellular algae structure. They have branches and filaments. Since there are no genuine roots, stems, or leaves, the plant's body is a thallus.
- The lamina, blade, or frond, which is a flattened structure on them, resembles leaves. The lamina's surface may be wrinkled or smooth.
- Pneumatocysts, which are unique gas-filled bladders, are present in some brown algae. They are primarily found close to the lamina. It gives algae buoyancy and keeps the portion of the algae necessary for photosynthesis close to the surface.
- The Wall of the cell is composed of two layers: an inner layer of cellulose that gives strength and an outside layer that is sticky and formed of algin.
- They include chlorophylls "a" and "c" and they are autotrophic. They also include xanthophyll and carotenoids.
- Pyrenoids are not typically found in chloroplasts, however certain species do.
- The primary xanthophyll pigment, fucoxanthin (C42H58O6), gives these plants their distinctive colour.
- Complex carbohydrates, such as mannitol or laminarin, are used to preserve food.
- A glucose polysaccharide is a laminarin. It would be a polymer containing (branching) links at positions 1 and 3.
- Sugar alcohol known as mannitol functions as an osmoprotectant and antioxidant, in addition to storing carbon. It safeguards them in their hostile environment.

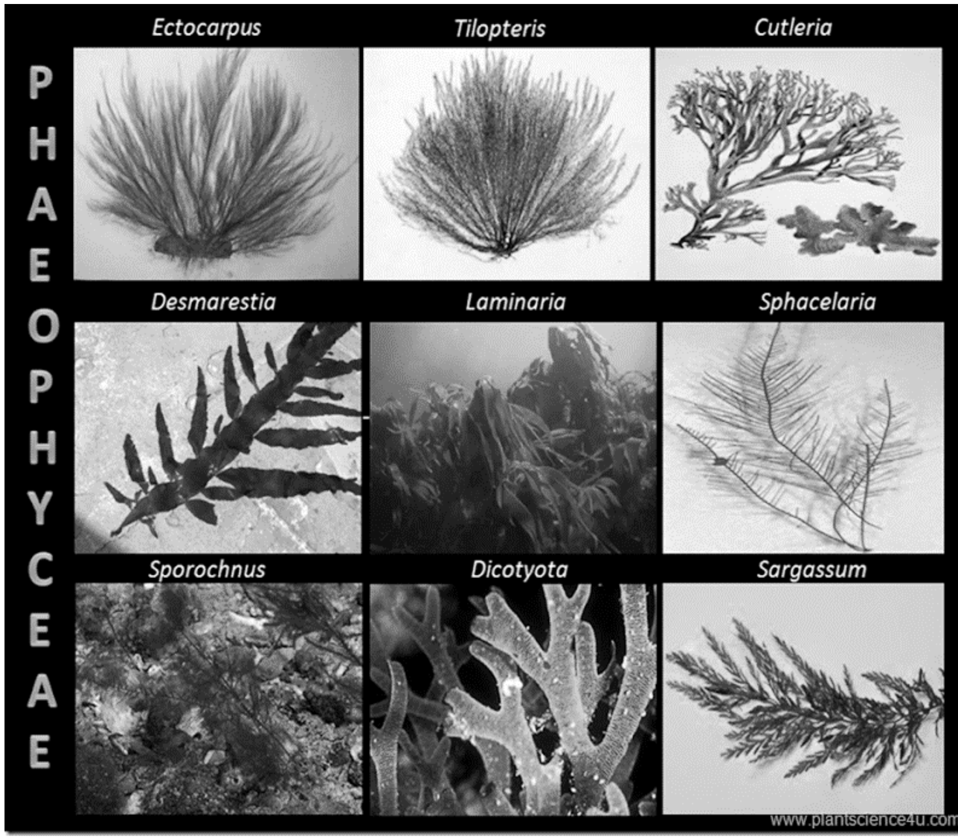


Fig.8.2 Examples of class Phaeophyceae

8.4.2 Vegetative Organizations Of Phaeophyceae

The various vegetative organizations of Phaeophyceae may be classified in the followinggroups. No member is unicellular, colonial or unbranched filament. The simplest member is heterotrichous filament, which shows the highest organization in Chlorophyceae is the lowest organization in Phaeophyceae.

Ectocarpoid

In Ectocarpus the thallus is profusely branched and the cells are joined end to end in a single series. The thallus consists of a prostrate branched portion, from which the erect branched system arises. This is heterotrichous type of organization.

Cable type

This type is represented by mesogloea. Here the thallus consists of several axial strands like a bundle. Some radial branches come out at right angles from these threads, and the whole structure appears like a cable.

Multiseptate cable type

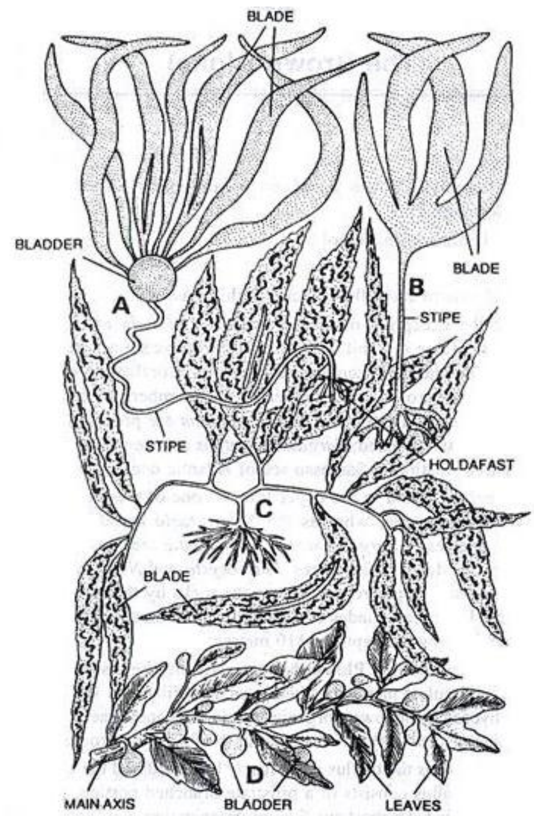
This type is represented by Chorda filum. The thallus is formed by many compact filaments. Actually there is no parenchyma but pseudo parenchyma.

Corticated type

Desmarestia, Arthrocladia, etc., represent this type. Here in the lower region of the plant body the lateral branches become rhizoidal and coil around the main axis to form a compact pseudoparenchymatous cortex around the main axis.

Truly parenchymatous forms

In such forms the thalli are leaf-like or laminate and truly parenchymatous, e.g., Punctaria. The members of Laminariales and Fucales possess improved type of parenchyma in them. The plant body of Macrocystis is 30 to 50 metres long. It has a dichotomously branched holdfast, a stipe and large leaf blades having gas bladders at their bases. This is the longest known giant kelp.



Phaeophyceae. Range of structure. A, *Nereocystis luetkeana*; B. *Laminaria andersonii* (sporophyte); C, *Macrocystis pyrifera*; D, *Sargassum* sp.

fig.8.3

The plant body of Nereocystis is 20 to 25 metres long. It consists of a haptera, a stipe and terminal large gas bladder havingmany blades on it. Laminaria, Fucus, Sargassum, Postelsia, etc., all possess truly parenchymatous structures.

8.5 INTERNAL STRUCTURE

In Laminaria, the stipe consists of epidermis, cortex and medulla. There are ‘trumpet hyphae’. At the junction of the mouths of two trumpets a callus pad develops in winter and dissolves in spring. This refreshes the memory of the callus pads of the sieve tubes of higher angiosperms.

Hairs

The hairs are present in all members of Phaophyceae. They are multicellular and generally ensheathed at their bases.

Cell structure

The cell wall is two layered. The inner layer outer to the protoplast consists of cellulose and the outer layer of mucilaginous substance. The mucilage contains gum like substances such as algin, fucoidin, etc. Callose is found in the cell membranes of Laminaria digitata. The callus pads consists of callose. In Laminariales special mucilage ducts are found, secreting mucilage.

The protoplast

It is less viscous. The cytoplasm contains mitochondria which are in contact of chromatophores. The cell contains numerous vacuoles. In Dictyota and Fucus each cell contains a large vacuole. In cell sap, the colloidal substances are found. The special bodies called fucosan vesicles are abundantly found in meristematic, photosynthetic reproductive cells. They are highly refractive, colourless and rounded bodies. Generally the chromatophores are discoid and parietal in position. In each cell, there may be one or more chloroplasts.

The pyrenoids are usually attached to the inner margins of the chloroplasts. In many cases the pyrenoids are stalked and attached laterally to the chloroplasts. The chromatophores contain chlorophyll a, chlorophyll b, xanthophyll and carotenoids as pigments. Fuco or phycoxanthinovermasks the other pigments, giving a tinge of brown colour to the plant body.

Photosynthetic products

According to Kylin, simple reducing sugar such as dextrose or pentose constitute the first products of photosynthesis. He also reports a disaccharide known as laminarose as first product of photosynthesis.

Food products

The important food products are (1) laminarin (2) certain hydrolases (3) mannitol and anhydride manniton (4) fats and (5) certain oxalates. Besides, in Laminariales and Fucales considerable quantity of vitamin C is found. Iodine is stored in many algae. In Laminaria (kelps) the percentage of iodine ranges from. 08 to 3.5.

Nucleus

Majority of Phaeophyceae have uninucleate cells. Multinucleate condition is rare. The nucleus is quite large in size. The chromatin material is found in less quantity. The nucleus contains one or two nucleoli. In Fucales the nucleoli are vacuolate. The extra or intranuclear centrosome is also present. In Phaeophyceae the number of chromosomes is from 8-32. The basic number is 8.

Swarmers

The swarmers may be zoospores or gametes. They are ovoid or pyriform. The swarmers are biflagellate and flagella are unequal in size. In majority of Phaeophyceae the flagellum directed forward is larger and directed backward is smaller in size. In order Fucales the position of flagella on the swarmer is reverse. Here the flagellum directed forward is smaller and directed backward is larger in size. In order Dictyotales the swarmers are single flagellate. The flagella are attached laterally to the swarmer. Each swarmer contains a large nucleus, 3 or 4 chromatophores, a stigma, a blepharoplast and a plastomere.

8.6 REPRODUCTION

- They can reproduce sexually or asexually.
- Plants reproduce through fragmentation.
- Motile zoospores are produced during asexual reproduction. They feature two uneven flagella and a pear-shaped form.
- Motile gametes, which seem to be likewise biflagellate and have two laterally connected flagella, are formed during sexual reproduction.

- Oogamous, isogamous, or anisogamous sexual reproduction are all possible.
- Gametes can combine in oogonium or water.

Importance

Algae, in their natural habitat, are important as they account for half of the photosynthetic production of organic material on earth. They serve as food for aquatic animals. Some of them also live in symbiosis, such as lichens. Lichen is a symbiotic association between algae and fungi in terrestrial habitats. The presence of lichen could indicate the pollution status of the environment. Algae are used in different industries. For instance, kelps (brown macroscopic algae) are harvested, dried, and processed for the commercial production of soap, glass, etc. They are also used as fertilizers. They are also used in the production of agar, which is used as a growth medium in microbiological studies. Seaweeds are an important food source, especially in Asia. They are an important source of nutrients such as vitamins (A, B1, B2, B6, niacin, and C), iodine, potassium, iron, magnesium, and calcium.

The ability of algae to repair carbon makes them significant. As primary producers, they play a significant role in the aquatic food chain. Numerous animals can be found in kelp forests. Laminaria, sargassum, and other edible seaweeds are only a few examples.

- Commercially extracted alginic acid is utilized as a thickening agent in the food industry. In the baking sector, it serves as a stabilizer.
- Batteries also utilise alginic acid.
- Surgical threads and pills both include alginic acid.
- As fertilisers, several species are employed.
- Soda ash is created using kelp. It is employed in the manufacture of glass and soap.
- Iodine-rich brown Laminaria has been used to treat iodine shortage conditions including goitre.
- They have been utilised in medicine; sodium laminarin sulphate, for example, is an anticoagulant. Additionally, they have vermifuge and antibacterial effects.
- Laminaria act as laxative.

Fucus

Fucus is representative of an interesting group of organisms that are commonly seen attached to rocks and visible at low tide in the intertidal zone. Most of the organisms called ‘seaweeds’ are brown algae, although some are red algae and a few are green algae. Like most (but not all) brown algae, *Fucus* is a large, multicellular organism that well-adapted to life in intertidal and shallow coastal waters, most commonly in relatively cool waters.

8.7 Taxonomy and Phylogeny

The brown algae are a small group of eukaryotes who traditionally were placed in their own phylum, the Phaeophyta, sometimes along with two groups of primarily unicellular algae, the golden algae and the yellow-green algae, based on similarities in pigmentation and other factors. Most modern treatments do not elevate this group to the phylum level but combine it with other ‘heterokonts’, a group defined by having two characteristic flagella, one longer than the other. The heterokonts (sometimes called the Stramenopiles) also includes diatoms and the heterotrophic water molds (Oomycota). The pigmentation of photosynthetic stramenopiles is similar to that of the coccolithophores (haptophytes) and the cryptophytes. This may not represent a common phylogeny but instead that all three groups separately became photosynthetic by acquiring the same photosynthetic endosymbiont. The photosynthetic members of these groups are thought to be produced by secondary endosymbiosis and their chloroplasts have four membranes.

Fig.8.4 Seaweed, Fucus: A brown algae

8.8 STRUCTURE

Typical of most brown algae *Fucus* is truly multicellular, and has three distinct multicellular organs: a holdfast, that attaches the organism to a substrate; flattened, dichotomously branching stems/blades (similar to thalloid liverworts) that carry out photosynthesis; and air bladders, often part of the stems, that carry the blades upward in the water column. Brown algae have transport systems that allow photosynthate from the blade to be distributed throughout the plant.

8.8.1 Reproduction

Most brown algae are sexual and exhibit alternation of generations. The 'dominant' (i.e. larger and more visible) stage is usually the sporophyte (diploid) stage but there are some brown algae that show isomorphic alternation of generations (the sporophyte and gametophyte look identical) and a few where the gametophyte stage is dominant. Rockweed (*Fucus),* shows yet another life cycle, one like humans, with no alternation of generations and where the only haploid cells are gametes. In *Fucus* the gametes are distinct from one another (egg, sperm) and in some brown algae they all look the same (isogametes). Within the brown algae flagellated cells are common and include sperm, isogametes and zoospores, which are mobile cells that can attach to a substrate and grow into a new organism.

Matter and energy

Fucus is a typical photoautotroph, using the energy of sunlight to synthesize carbohydrates from carbon dioxide and then using the carbohydrates as an energy source in cellular respiration and as building materials to synthesize a variety of biomolecules. The brown algae produce a distinct form of a carbohydrate storage polysaccharide called laminaran, made up of glucose units connected by a *beta* 1-3 linkage, rather than the *alpha*, 1-4 linkage found in starch. They also have high concentrations of mannitol which serves as a transport carbohydrate, a role occupied by sucrose in most plants.

Interactions

Fucus is is especially important in the intertidal zone, providing food for a number of organisms and habitats for others**. Fucus,** also called **rockweed,** genus of brown algae, common on rocky seacoasts and in salt marshes of northern temperate regions. *Fucus* species, along with other kelp, are an important source of alginates—colloidal extracts with many industrial uses similar to those of agar. Bladder wrack (*F. vesiculosus*) was one of the original sources of iodine. *Fucus* are perennial algae, some of which have a life span of up to four years. They feature bladderlike floats (pneumatocysts), disk-shaped holdfasts for clinging to rocks, and mucilage-covered blades that resist desiccation and temperature changes. The growth of the thallus is localized at the tips of forked shoots, and most species are between about 2 and 50 cm (0.8 to 20 inches) in length. The male and female reproductive organs may occur on the same organism or on separate ones; some species produce eggs and sperm all year long.

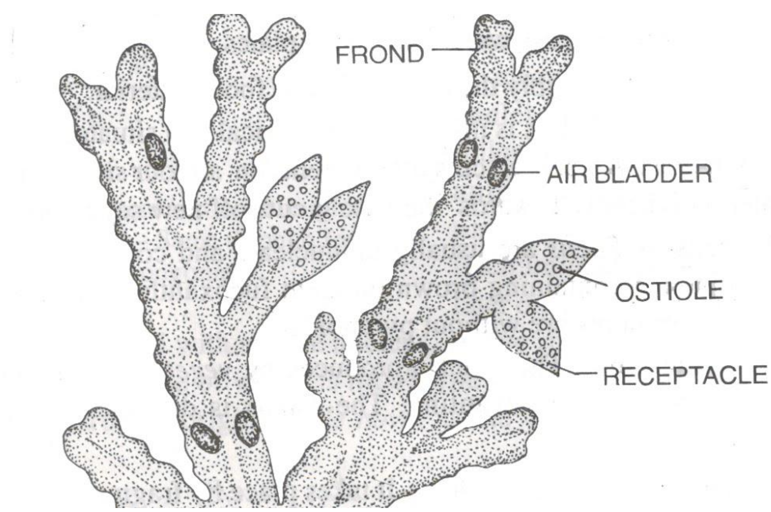


Fig.8.5 Structure of vegetative body and reproduction

Scientific classification

8.9FUCUS SERRATUS

Domain:	Eukaryota
Clade:	Diaphoretickes
Clade:	SAR
Clade:	Stramenopiles

Phylum:	Gyrista
Subphylum:	Ochrophytina
Class:	Phaeophyceae
Order:	Fucales
Family:	Fucaceae
Genus:	*Fucus*

8.10 DESCRIPTION AND LIFE CYCLE

The thallus is perennial with an irregular or disc-shaped holdfast or with haptera. The erect portion of the thallus is dichotomous or subpinnately branched, flattened and with a distinct midrib. Gas-filled pneumatocysts (air-vesicles) are present in pairs in some species, one on either side of the midrib. The erect portion of the thallus bears cryptostomata and caecostomata (sterile surface cavities). The base of the thallus is stipe-like due to abrasion of the tissue lateral to the midrib and it is attached to the rock by a holdfast. The gametangia develop in conceptacles embedded in receptacles in the apices of the final branches. They may be monoecious or dioecious.

These algae have a relatively simple life cycle and produce only one type of thallus which grows to a maximum size of 2 m. Fertile cavities, the conceptacles, containing the reproductive cells are immersed in the receptacles near the ends of the branches. After meiosis oogonia and antheridia, the female and male reproductive organs, produce egg cells and sperm respectively that are released into the sea where fertilisation takes place. The resulting zygote develops directly into the diploid plant. This contrasts with the life cycle of the flowering plant, where the egg cells and sperm are produced by a haploid multicellular generation, albeit very strongly reduced, and the egg cells are fertilised within the ovules of the parent plant and then released as seeds.

Distribution and ecology

Species of *Fucus* are recorded almost worldwide. They are dominant on the shores of the British Isles, the northeastern coast of North America and California. In the British Isles these larger brown algae occur on sheltered shores in fairly well defined zones along the shore from high-water mark to below low water mark. On the more exposed shores not all of these species can be found and on very exposed shores few, if any, occur. Pelvetiacanaliculata forms a zone at the top of the shore. Just below this Fucus spiralis, Fucus vesiculosus, Fucus serratus and Laminaria form clear zones, one below the other, along the shore down to low water mark. On sheltered shores Ascophyllum nodosum usually forms a broad and dominating zone along the shore at the mid-littoral. Other brown algae can be found at the low-littoral such as Himanthalia, Laminaria saxatilis and Alaria esculenta. Small green and red algae and animals occur, protected under these large brown algae. When washed up on beaches, kelp flies such as Coelopapilipes feed and breed on *Fucus* algae.

Uses

In Scotland and Norway, up until the mid-19th century, several seaweed species from *Fucus* and other genera were harvested, dried, burned to ash, and further processed to become "kelp", which was a type of soda ash that was less costly in Britain than the barilla imported from Spain. It has an alkali content of about 2.5%–5% that was mainly sodium carbonate (Na_2CO_3), used in soapmaking, glassmaking, and other industries. The purest barilla had a sodium carbonate concentration of about 30%. The seaweed was also used as fertilizer for crop land in the same areas in which it was harvested. *Fucus* species can also be used for thalassotherapy, along with other species such as Turkish towel (Chondracanthusexasperatus), feather boa (Egregiamenziesii), and finger kelp (Laminaria digitata). In 2005, it was announced that bacteria grown on *Fucus* have the ability to attack and kill the MRSA superbacterium. Because of their easily accessible apolar eggs and free-floating zygotes, several *Fucus* species have been used as model organisms to study cell polarity, the development of growth axes, and the role of the cell wall in establishing and maintaining cell identity.

8.11 SUMMARY

Under this unit we have summarized the characteristics of algae,**taxonomy and phylogeny of** Phaeophyceae, **vegetative organizations** in Phaeophyceae, and brief study of Fucus serratus. Phaeophyceae or Brown Algae is a group of algae that are aquatic in nature. Brown algae are primarily found in marine habitats with few exceptions that grow in freshwater. They possess chlorophyll a, chlorophyll c, carotenoids and xanthophylls in the chromoplasts that give them their characteristic brown to olive green colour. They can reproduce via the vegetative, sexual and asexual modes of reproduction.

The various vegetative organizations of Phaeophyceae may be classified in the different groups. No member is unicellular, colonial or unbranched filament. The simplest member is heterotrichous filament, which shows the highest organization in Chlorophyceae is the lowest organization in Phaeophyceae. *Fucus serratus* is a robust alga, olive-brown in colour and similar to Fucus vesiculosus and Fucus spiralis. It grows from a discoid holdfast up to 180 centimetres long. The fronds are flat, about 2 cm wide, bifurcating, and up to 1 m long including a short stipe. It branches irregularly and dichotomously.

The flattened blade has a distinct midrib and is readily distinguished from related taxa by the serrated edge of the fronds. It does not have air vesicles, such as are found in *F. vesiculosus*, nor is it spirally twisted like *F. spiralis*. Male and female receptacles are on different plants. *Fucus serratus* is used in Ireland and France for the production of cosmetics and for thalassotherapy. In the Western Isles of Scotland, it is harvested for use as a liquid fertilizer.

8.12 TERMINAL QUESTIONS

Q.1 Describe the general characteristics of Phaeophyceae (Brown Algae)?

Answer:---

Q. 2 Describe vegetative organization of Phaeophyceae.

Answer:---

Q.3 Describe **taxonomy and phylogeny** in Phaeophyceae.

Answer:---

Q. 4 Explain life cycle of Fucus serratusin brief.

Answer:--

Q.5 Describe the classification of Phaeophyceae.

Answer:--

Q.6 Write short notes on the following.

(a) Internal structure in Phaeophyceae

(b) Uses of Brown Algae

Answer:--

Further readings

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 9: RHODOPHYCEAE –I

Structure

9.1 INTRODUCTION

The scientific name of Red Algae is Rhodophyta and they belong to Class Rhodophyceae. There are two classes of red algal namely the Florideophyceae and Bangiophyceae. Both Florideophyceae and Bangiophyceae comprise 99% of red algal diversity in marine and freshwater habitats. Red algae or Rhodophyta – It is a distinctive type of species that are mostly found in the freshwater lakes and are the oldest type of eukaryotic algae. They are red in colour due to the presence of a pigment called chlorophyll A, phycocyanin, and phycoerythrin. They are the member of the tribe Amansieae (Rhodomelaceae, Ceramiales, Rhodophyta), in which only Aneurianna and Lenormandia Sonder have foliar blades. They are the distinctive type of species, mostly found in the deep freshwater bodies.

According to the original description of the genus (Phillips, 2006), Aneurianna differs from Lenormandia in having endogenous branching and elliptic surface pattern with various irregularly ordered ellipses on the blade (so-called “elliptical areolation”) and incurved or inflexed apices, in contrast to the absence of endogenous branching, rhombic surface pattern with regularly arranged rhombi (“rhombic areolation”).

Algae, bryophytes, pteridophytes, gymnosperms, and angiosperms are all members of the plant kingdom. Algae are chlorophyll-containing, simple, thalloid, autotrophic, aquatic creatures. Algae are categorised into three groups based on the type of pigment they contain and the type of food they store. These groups are Chlorophyceae, Phaeophyceae, and Rhodophyceae.

Objectives

This is the ninth unit on Rhodophyceae -I of block-II (Algae-II). Under this unit, we have following objectives. These are as under:

- To know about Rhodophyceae and its characteristics.
- To know about plant kingdom classification.
- **To discuss** cell structure and metabolism **in Phaeophyceae.**
- To discuss about *Porphyra* and *Nemalion.*
- To discuss economic importance of Rhodophycae.

9.2 PLANT KINGDOM CLASSIFICATION

Kingdom Plantae (Plant Kingdom) is divided into distinct divisions based on whether plants have a well-differentiated body, the existence or lack of specialised tissues for transport, and the ability to carry seeds. Each division's characteristics and examples are shown below. aquatic creatures that are gently Algae are categorised into three groups based on the type of pigment they contain and the type of food they store. These groups are Chlorophyceae, Phaeophyceae, and Rhodophyceae.

Algae

While algae are plural, an alga is a singular form. The eukaryotic, living organism that is typically cultivated in damp environments is called an alga. As a result, they are referred to as aquatic organisms. These species, like plants, have chlorophyll and other biological pigments, which serve as a key colouring agent and aid in absorbing light energy.

Red Algae

The group of red algae known as Rhodophyta is one of the oldest eukaryotic algae groups. The bulk of species (6,793) is multicellular marine red algae, primarily belonging to the Florideophyceae (class), which also includes numerous well-known seaweeds. Red algal seaweed is prevalent in freshwater, but it is abundant in coastal areas. Red algae in freshwater are present in amounts of about 5%, with warmer regions having higher concentrations. In the asexual class Cyanidiophyceae, there are no terrestrial species other than two coastal cave-dwelling species; this may be the result of an evolutionary bottleneck in which the last common ancestor lost around 25% of its core genes and much of its evolutionary plasticity.

It is a vast category of algae that includes over 831 genera and over 5,250 species. They are usually referred to as red algae because of the presence of r-phycoerythrin, a water-soluble red pigment. The r-phycoerythrin, on the other hand, is present in adequate and full amounts to conceal the chlorophyll a, resulting in the distinctive red colouration. More than 98% of the members are marine, with the remainder growing in fresh water.

The freshwater members thrive in both stagnant and moving water (e.g., Asterocystis, Compsopogon) (e.g., Lamanea, Thorea, Batrachospermum etc.). Marine species can dwell at higher depths (even up to 30-90 metres) than other members of other groups. They have a high level of parasitism and epiphytism. The parasitic members' size and pigmentation are greatly reduced.

On Codium fragile, parasitic species like Ceramiumcondicola and Polysiphonia lanosa can be found. Rhodophyceae members that grow on other Rhodophyceae members include Rhodochorton, Ceratocolax, etc. The unicellular genus Porphyridium is terrestrial and grows best in moist soil. Some marine members, such as Rhodocorton, Corallina, and Bostrychia, grow in the intertidal zone, but this is not the case for most marine members.

9.3.1 Characteristics of Rhodophyceae

A great majority of red algae are strictly marine, but freshwater species are not uncommon. The former are found in all oceans including the Arctic and Antarctic oceans where the number of species is very few. They usually occupy the intertidal or littoral zones, but there are some which grow at levels never exposed by tides. These latter species usually grow in association with Chlorophyceae and Phaeophyceae. The greatest depth at which Rhodophyceae occur has been reported to be 200 metre. The majority of the marine Rhodophyceae are normally sessile, and grow upon rocks or some other inanimate substratum. Some species grow upon other Chlorophyceae, Phaeophyceae and Rhodophyceae, either as epiphytes or as true parasites, being mostly restricted to a single host. The sessile species, when become detached and free-floating, soon die.

In great majority of cases, there is a single, large vacuole in each cell and the protoplasm usually forms a thin lining layer just internal to the cell wall. The cell wall is made up of cellulose and various other pectic compounds. In most cases a pore-like opening is found in the wall between adjacent cells, through which broad cytoplasmic strands connect the two protoplasts. The vegetative cells are mostly uninucleate, but in some multinucleate ones the number of nuclei may go up to three to four thousands in each cell. Each resting nucleus, and an intervening hyaline zone. In each vegetative cell of the primitive red algae there is a single, centrally located, star-shaped chromatophore with a central pyrenoid without any starch sheath.

In more advanced species, they are disciform without pyrenoids, and are usually more than one in each cell. Carbohydrate food reserves are found in the form of small grains known as floridean starch, distributed in the general mass of cytoplasm outside the chromatophores. The floridean starch is an intermediate product between starch and dextrin, and when treated with iodine solution, becomes light brown or wine-red in colour Besides a soluble sugar, floridoside, often accumulates. The chromatophores of red algae contain the same photosynthetic pigments (chlorophyll a, chlorophyll b, carotene and xanthophyll), but the relative proportion is different from that in the higher plants. In addition to these, a water-soluble red pigment, phycoerythrin, is always present. Besides, in some species a blue pigment is also present, and this pigment resembles the phycocyanin of Myxophyceae.

A high light intensity increases the rhodophycean phycocyanin (r-phycocyanin) formation, and retards the development of phycoerythrin. The function of r-phycocyanin is not yet known, while that of phycoerythrin also remains a debatable point. It is generally believed that phycoerythrin functions as a photosynthetic pigment in blue light, and thus enables the deep water Rhodophyceae to carry on with their photosynthesis.

Some workers are of opinion that the deep red colours of some members of this group are due to the absence of r-phycocyanin with a corresponding presence of a high percentage of phycoerythrin, and other shades of colour are due to an increasing proportion of r-phycocyanin. The great diversity of shapes and colours in Rhodophyceae is obviously due to the variation in the component ratio of these pigments. With the exception of two genera, the thallus of Rhodophyceae is multicellular. This multicellular thallus may be a simple, branched filament made up of a row of cells, or it may assume a complex body of definite macroscopic form. The complex types usually attain a height of 10 cm., but may be more than a metre in a few cases.

- More than 98% of the members are marine, and 20 species (according to the research) can thrive in freshwater. The individuals might develop as saprophytes, parasites, or epiphytes.
- The plant body can be multicellular or unicellular (Porphyridium). The multicellular shape might be feathery (Polysiphonia), parenchymatous (Porphyra, Crinellia), pseudoparenchymatous (Helmin- thocladia), filamentous (Gonio- trichum), or ribbon-like (Chondrus).
- In Schizophrenia, they may grow up to 2 metres, which is larger than brown algae (Phaeophyceae), but not as large.
- There is no sign of the flagellated motile phases.
- The cell wall is made up of an inner cellulose layer and an exterior pectic layer. Agar-agar and carrageenans make up the majority of the dry weight of the cell wall and are the main components of the mucilaginous substance of the outer layer.
- Cytoplasmic connections are maintained by holes in the cell walls of multicellular species. The so-called plasmodesmata are these cytoplasmic strands.
- The number of nuclei in a cell varies greatly across Rhodophyceae members. Cells of the subclass Bangioideae are uninucleate, but the majority of members of the subfamily Florideae are multinucleate, with Griffithsia having 3,000–4,000 nuclei.
- The cells may only have one discoid and parietal chromatophore with pyrenoids (Bangioideae) or several of them (Florideae).
- The pigments used in photosynthetic reactions include xanthophylls like teraxanthin, lutein, violaxanthin, zeaxanthin, and flavoxanthin as well as biliproteins like r-phycoerythrin and r-phycocyanin. The algae’s distinctive red colour is caused by a sufficient amount of r-phycoerythrin, which totally obscures the chlorophyll a. Teraxanthin is the dominant Xanthcphyll, while chlorophyll B is not present.
- Mannoglycerate, floridi-side, and floridean starch are the reserve foods.

9.3.1 Reproduction

All three types of reproduction-vegetative asexual and sexual-are possible.

- Only in the unicellular stage does vegetative reproduction occur.
- The monospore, neutral spore, carpospore, bispore, and tetraspore are all forms of asexual reproduction.
- Oogamous sexual reproduction has advanced forms.
- Spermatangium is the name for the male genital organs. Each spermatangium, or spermatium, produces one non-flagellate male gamete.
- Carpogonia or procarp are the names for the female sex organs. Trichogyne, which resembles a flask and has a long neck, are carpogonia.
- With the aid of water circulation, the spermatium makes contact with the trichogyne during fertilisation.
- The post-fertilization modifications in Rhodophyceae are quite complex. Their carposporophyte grows. Each carposporophyte develops into a carposporangium, which

gives rise to a single carpospore.

- The majority of Rhodophycean species exhibit biphasic or triphasic life cycles.

9.3.2 Cell Structure and Metabolism

Most Rhodophyta are multicellular organisms, although a few are unicellular or colonial. Rhodophyta are pigmented with phycoerythrin, phycocyanin and allophycocyanins. These pigments are found in phycobilisomes. Rhydophyta do not have any flagella or centrioles. Nor do they have chloroplast endoplasmic reticulum. Rhodophyta have unstacked thylakoids in plastids. Some species have pit connections between cells. In their research on cell wall composition on certain species of Rhodophyta, Youngs et. al. (1998) found that the cell walls of freshwater organism *Bostrychiamoritziana* were highly adaptive to osmotic and ionic changes in their environment. They believe this adaptation is partially facilitated through changes in cell wall chemistry.

Rhodophyta are autotrophic, obtaining and storing floridian starch from photosynthesis. Rhodophyta tend to reproduce sexually. Life cycles tend to be diplohaplontic, with alternation between haploid and diploid stages. However, this is not the case with all species. *Porphyranereocystis*, for example, has a heteromorphic alternation of generations. Sexual reproduction is oogamous; it involves non-motile spermatia and closed mitosis. Tetraspores are produced in the tetrasporangia during meiosis. If asexual reproduction occurs, it does so through aplanospores.

9.3.3 Occurrence of Rhodophyceae

Rhodophyta are aquatic organisms that exist in both freshwater and marine habitats, although mostly marine. They are found in tropical, temperate, and cold-water environments. Rhodophyta tend to live at greater depths of water than Charophyta and Chlorophyta. This is because Rhodophyta pigments absorb blue light, which penetrates water to a greater depth than other wavelengths. Rhodophyta are primary producers. They provide habitats for other aquatic organisms. In addition, Rhodophyta play an important part in the establishment and maintenance of coral reefs. Those species found in coral reefs are called coralline algae; they secrete a shell of carbonite around themselves.

Rhodophyta are also farmed and harvested for use in food and gels. Sheets of red algae are toasted and used to wrap sushi. Rhodophyta are also used to make nori. Dried nori can be eaten alone, or used in sushi. Rodophyta are rich in protein and vitamins, which makes them especially useful for food. Cultivation of Rhodophyta is a fairly simple process which began in Japan over 300 years ago.

One of the ways in which Rhodophyta have to adapt to their aquatic environments is in terms of wave action. Previous research suggested that Rhodophyta are constant in strength when it comes to facing the drag caused by waves. In their examination of *Mastocarpuspapillatus*, Kitzes and Denny (2005) showed that these responses are not uniform. *Mastocarpuspapillatus* groups react based on whether or not their sites are exposed or protected. Rhodophyta do not all behave the same way; instead, they adjust their responses based on the immediate conditions of their environment.

Rhodophyta have medical purposes. Turhani et. al. (2005) studied hydroxyapatite ceramic granule, which was calcified from red algae, to see if it would have potential for bone tissue engineering. Their objective was to determine whether or not living cells would grow on the granule. The results of their experiment showed that the cells had high viability, meaning that this compound has capabilities for bone engineering. In addition, Rhodophyta are useful for the study of metabolic pathways, cell biological processes, and genetics. One species that is particularly useful for research is *Galdieriasulphuraria* because of its metabolic versatility.

9.4 RHODOPHYCAE PLANT CLASSIFICATION

The Rhodophyceae, or the red algae, are readily distinguished from other algae by the following salient characters:

(a) Presence of chromatophores with a red pigment, phycoerythrin, in addition to the usual photosynthetic pigments and rarely with a blue pigment, phycocyanin; the presence of phycoerythrin in a large quantity often gives the plant a distinctive red colour, though green, olive-green and golden-brown red algae are not uncommon;

(b) Total lack of flagellate asexual spores;

(c) Transportation of non-flagellate male gamete to the female sex organ, the carpogonium, and deposition against it at the time of sexual reproduction;

(d) Indirect formation of spores mostly takes place from the zygote, but in some cases the zygote directly divides to form spores.

Red Algae Plant Classification

Domain: Eukaryota

(unranked): Diaphoretickes

(unranked): Archaeplastida

Division: Rhodophyta

Morphology of Red Algae

Red algae can range in morphology from being unicellular to having complex parenchymatous and non-parenchymatous thallus. Red algae have doubled cell walls. The outer layers contain the polysaccharides agarose and agaropectin, which can be extracted from cell walls by boiling as agar. The majority of the inside walls are made of cellulose. Additionally, their plastid genomes are the most gene-rich ones yet found.

Cell Structure

Red algae do not have centrioles and do not have flagella during their whole life cycle. Red algal cell structure is defined by the presence of normal spindle fibres, microtubules, unstacked photosynthetic membranes, phycobilin pigment granules, pit connections between cells, filamentous genera, and the lack of chloroplast endoplasmic reticulum.

Chloroplast

The phycobilins (phycocyanobilin, phycoerythrobilin, phycourobilin, and phycobiliviolin), which are contained within phycobilisomes, give red algae their distinctive colour. In the chloroplast, thylakoids are evenly dispersed and ungrouped. Other pigments include lutein, zeaxanthin, a, and b-carotene, and chlorophyll. The double membrane of the chloroplast envelope encloses the chloroplast. The absence of grana and the attachment of phycobilisomes to the stromal surface of the thylakoid membrane are two further traits that set red algal chloroplasts apart from other types.

Pit Connections

Red algae can be identified by their pit connections and pit plugs, which develop during the cytokinesis process following mitosis. In red algae, cytokinesis is not present. In the majority of situations, the centre of the newly formed division is left with a small pore. The pit connection is created in the areas where the daughter cells are still in contact. Shortly after the pit connection is formed, a pit plug forms and is deposited in the wall gap that connects the cells, blocking cytoplasmic continuity. Cells that have a common parent cell form primary pit connections. Because apical development is the norm, the majority of red algal cells have two principal pit connections, one to each subsequent cell.

Storage Products

Among the most significant photosynthetic products are Floridoside (the main product), Disofloridoside, digeneaside, mannitol, sorbitol, dulcitol, and others. As a long-term storage product, floridean starch, which is analogous to amylopectin in land plants, is freely (scattered) deposited in the cytoplasm. The concentration of photosynthetic products is influenced by environmental variables such as pH, medium salinity, light intensity, dietary constraints, and others. As the salinity of the medium increases, the amount of floridoside produced grows, preventing water from leaving the algal cells.

9.5 DIFFERENCES BETWEEN RED ALGAE, BROWN ALGAE AND GREEN AGAE

Red Algae	Brown Algae	Green Algae
1. Red algae may be found in freshwater, brackish water, and, most notably, saltwater.	Brown algae can be found in freshwater, brackish water, and saltwater (occasionally).	The majority of green algae are found in freshwater, frequently adhering to submerged rocks and wood or as scum on stagnant water.
They include photosynthetic pigments such as chlorophyll a, d, and phycoerythrin.	They include photosynthetic pigments like as chlorophyll a, c, and fucoxanthin.	Blue-green algae and cyanobacteria contain the green pigment ‘chlorophyll a.
The food stored in them is floridean starch.	Mannitol or laminarin is stored in food in them.	Starch is a food that has been stored.
They are classified as algae in the Rhodophyceae family.	They are classified as algae of the Phaeophyceae family.	Green algae are members of the Chlorophyta phylum.
They do not have flagella.	They have two uneven, lateral flagella.	They also have flagellar apparatus.
Their cell wall is composed of cellulose, pectin, and poly sulphate esters.	They have cellulose and a pigment-aligned cell wall.	They have cellulose, hemicellulose, and pectin cell walls.

9.6 CLASSIFICATION OF RHODOPHYCEAE (RED ALGAE)

In biology, **taxonomy** (arrangement', and 'method) is the scientific study of naming, defining (circumscribing) and classifying groups of biological organisms based on shared characteristics. Organisms are grouped into taxa (singular: taxon) and these groups are given a taxonomic rank; groups of a given rank can be aggregated to form a more inclusive group of higher rank, thus creating a taxonomic hierarchy. The principal ranks in modern use are domain, kingdom, phylum (*division* is sometimes used in botany in place of *phylum*), class, order, family, genus, and species. The Swedish botanist Carl Linnaeus is regarded as the founder of the current system of taxonomy, as he developed a ranked system known as Linnaean taxonomy for categorizing organisms and binomial nomenclature for naming organisms. With advances in the theory, data and analytical technology of biological systematics, the Linnaean system has transformed into a system of modern biological classification intended to reflect the evolutionary relationships among organisms, both living and extinct.

Fritsch (1935, 45) classified the Class. Rhodophyceae into two sub-classes and seven orders.The outline of the classification is given:

Class. Rhodophyceae

Sub-class Bangioideae

Order. 1. Bangiales

Sub-class Florideae

Order. 1. Nemalionales

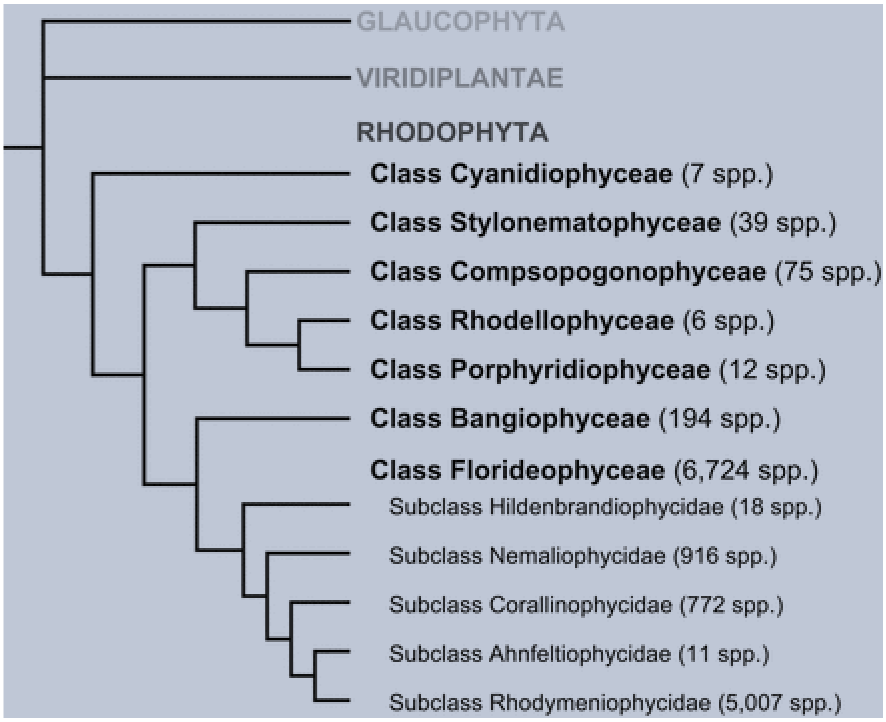
2. Gelidiales

3. Cryptonemiales

4. Gigartinales

5. Rhodymeniales

6. Ceramiales



Red algae/ Rhodophyceae

- ✓ Rhodophyceae is commonly known as red algae.
- ✓ Majority of them are marine and abundantly found in the warmer areas.
- ✓ They are red in colour due to the predominance of the red pigment, r-phycoerythrin.
- ✓ Red colour of algae is due to the presence of the red pigment, r-phycoerythrin that makes them unique among others.
- ✓ The red algae are mostly marine except Batrachospermum which is the only freshwater red alga.
- ✓ The red thalli of most of the red algae are multicellular. Some of them have complex body organization.
- ✓ Flagellated cells are completely absent in the life cycle.
- ✓ Cell wall is mucilaginous and contains cellulose, pectin and abundant sulphated phycocolloids (like agar, carrageenan, funori).
- ✓ Pigments – Chl-a, Chl-d carotenoid (-carotene) and phycobilins (r-phycoerythrin - red colour and r - phycocyanin - blue colour).
- ✓ They are found in both well-lighted regions close to the surface of the water and also at great depths in oceans where only little light penetrates.
- ✓ When growing deep, algae appears red due to the predominance of r-phycoerythrin that captures short-wavelength that is able to reach the maximum depth in water. These algae, therefore, reach the maximum depth (30-90 mt) in the sea where no other photosynthetic organism grows.
- ✓ They appear bluish-green when growing near the surface of the sea because of the little production of phycoerythrin. This property of change in color with depth is called chromatic

adaptation(Gaidukov's effect).

✓ The stored food is Floridean starch very similar to amylopectin and glycogen in structure.

✓ **Reproduction:**

i) Vegetative reproduction

Usually by fragmentation.

ii) Asexual reproduction

By many types of non-motile spores like monospores, carpospores,tetraspores.

iii) Sexual reproduction

It is the most advanced (Oogamous) type followed by complex post fertilization development.

✓ Some common examples of red algae are- Polysiphonia, Porphyra, Gracilaria and Gelidium.

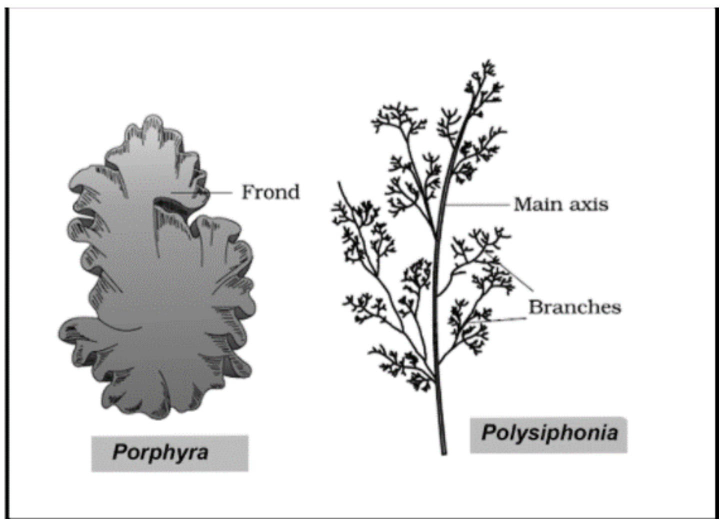


Fig.9.1 Diagrammatical presentation of *Porphyra* and *Polysiphonia*

9.7 Porphyra

Porphyra is representative of a diverse and important group, the red algae (Rhodophyta), one of three algal groups that have members that include multicellular, macroscopic forms (the other two are the brown algae (Phaeophyta) and the green algae (Chlorophyta)). Like the green algae, but not to the same extent, the red algae group also has members that are unicellular or filamentous. Some red algae deposit calcium carbonate in their cell walls and therefore produce a rigid structure that may be a crust on rocks or may form erect branching structures. Other red algae are significant because the cell wall contains polysaccharides that can be extracted from their cell walls and used to make gels (agar).

It is a genus of coldwater seaweeds that grow in cold, shallow seawater. More specifically, it belongs to red algae phylum of laver species (from which comes laverbread), comprising approximately 70 species. It grows in the intertidal zone, typically between the upper intertidal zone and the splash zone in cold waters of temperate oceans. In East Asia, it is used to produce the sea vegetable products nori (in Japan) and gim (in Korea). There are considered to be 60 to 70 species of *Porphyra* worldwide and seven around Britain and Ireland where it has been traditionally used to produce edible sea vegetables on the Irish Sea coast. The species Porphyra purpurea has one of the largest plastid genomes known, with 251 genes.

Life cycle

Porphyra displays a heteromorphic alternation of generations. The thalluswe see is the haploid generation; it can reproduce asexually by forming spores which grow to replicate the original thallus. It can also reproduce sexually. Both male and female gametes are formed on the one thallus. The female gametes while still on the thallus are fertilized by the released male gametes, which are non-motile. The fertilized, now diploid, carposporangia after mitosis produce spores (carpospores) which settle, then bore into shells, germinate and form a filamentous stage. This stage was originally thought to be a different species of alga, and was referred to as *Conchocelis rosea*. That *Conchocelis* was the diploid stage of *Porphyra* was discovered in 1949 by the British phycologistKathleen Mary Drew-Baker for the European species Porphyraumbilicalis. It was later shown for species from other regions as well.

Food

Most human cultures with access to *Porphyra* use it as a food or somehow in the diet, making it perhaps the most domesticated of the marine algae, known as laver, *rong biển* (Vietnamese), The marine red alga *Porphyra* has been cultivated extensively in many Asian countries as an edible seaweed used to wrap the rice and fish that compose the Japanese food sushi and the Korean food gimbap. In Japan, the annual production of *Porphyra* species is valued at 100 billion yen (US$1 billion). *P. umbilicalis* is harvested from the coasts of Great Britain and Ireland, where it has a variety of culinary uses, including laverbread. In Hawaii, "the species *P. atropurpurea* is considered a delicacy, called *Limu luau*". Porphyra was also harvested by the Southern Kwakiutl, Haida, Seechelt, Squawmish, Nuu-chah-nulth, Nuxalk, Tsimshian, and Tlingitpeoples of the North American Pacific coast.

Vitamin B12

Porphyra contains vitamin B12 and one study suggests that it is the most suitable non-meat source of this essential vitamin. In the view of the Academy of Nutrition and Dietetics, however, it may not provide an adequate source of it for vegans.

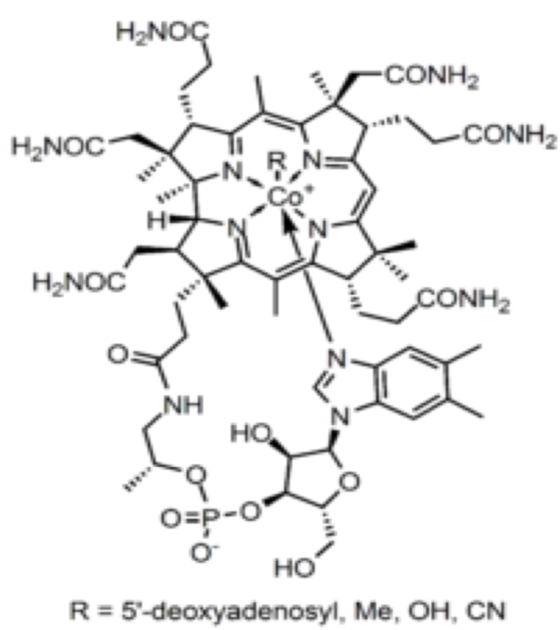


Fig.9.2 Vitamin B$_{12}$

For vegetarians *Porphyra* is thought to be a source of vitamin B_{12}, a nutrient usually derived from animal sources. There are some reports that chemical found in *Porphyra*, although similar to vitamin B_{12}, does not perform the necessary functions, but most researchers believe that *Porphyra* can be a source of vitamin B_{12}.

Species

- Porphyraakasakae A.Miura *1977*
- Porphyraangusta Okamura *&* Ueda *1932*
- Porphyraargentinensis M.L.Piriz *1981*
- Porphyraatropurpurea *(*Olivi*)* De Toni *1897*
- Porphyraaugustinae Kützing *1843*
- Porphyraautumnalis Zanardini *1860*
- Porphyrabangiaeformis Kützing *1849*
- Porphyrabulbopes *(*Yendo*)* Ueda *1932*

9.8 TAXONOMY AND PHYLOGENY

The red algae are eukaryotes and usually placed in their own phylum, the Rhodophyta. Their affinities with cyanobacteria are reflected in their chemistry (in particular their photosynthetic pigments), but they are clearly eukaryotic with nuclei, chloroplasts and mitochondria. Like the green algae, the chloroplasts of red algae have two membranes, one thought to be the remnant of the membrane of the cyanobacterium that was engulfed during the endosymbiotic event and a second membrane that was produced during phagocytosis when the cell was engulfed, the phagosomal membrane.

The chloroplasts of other photosynthetic groups of algae (e.g. diatoms, brown algae) are considered to have been the result of secondary endosymbiosis, a second engulfing (phagocytosis) event where an already eukaryotic cell consumed, but did not digest, another eukaryotic cell that was a red or green algae. These chloroplasts have four membranes, two from the chloroplast of the red/green algae, one from the plasma membrane of the (prim itive) red or green algae cell that was engulfed and a fourth membrane, again a remnant of a phagosomal membrane, derived from the engulfing cell.

Structure

Although large, often up to 20 cm in extent, *Porphyra* is not truly multicellular, i.e. parenchymatous (three-dimensional). It has a very simple two-dimensional form, existing as sheets which are either one or two cells thick. The alga does produce filamentous ‘rhizoids’ that attach one end of the sheet to a substrate.

Reproduction

Sexual reproduction in all the red algae is complex and involves alternation of generations, but instead of alternating between a haploid form and diploid form there are three fo rms: (1) a haploid (gamete producing) form that develops from haploid spores; (2) a diploid form that develops from a zygote, stays attached to its parental gametophyte and produces diploid spores that are dispersed; and (3) a diploid form that develops from these diploid spores and in turn produces haploid spores following meiosis.

Matter and energy

Porphyra is a typical photoautotroph, using the energy of sunlight to synthesize carbohydrates from carbon dioxide and then using the carbohydrates as an energy source in cellular respiration and as building materials to synthesize a variety of biomolecules. The red algae produce a distinct form of starch, floridian starch, that is not found in other eukaryotes.

Interactions

Porphyra is generally found in cool, marine waters. It is an important component of shallow marine waters into the intertidal zone. As an autotroph it is an important base to marine food chains. It is also a type of 'seaweed' that is commonly eaten by humans and is called 'nori' or 'laver'. More recently it has become popular in the U.S. in sushi. *Porphyra* is cultivated in the oceans off Japan and elsewhere, being grown on rope networks hung in the water. Other red algal species are important to humans to produce agar. Polysaccharides in the cell wall are extracted, purified and dried to a powder. This can then be used to make gels suitable for growing a variety of organisms.

9.9 NEMALION

Nemalion is a genus of red algae that contains approximately ten species, including *N. helminthoides*. Its members are known by a number of common names. It is the source of the subclass name "Nemaliophycidae". The Nemalionhelminthoides is a brown, mucousy, elongated and twisted alga that resembles a shoelace or spaghetti. Its holdfast clings to rock, and several filaments emanate from it. On rare occasions, dichotomous branching may be observed in the thallus. It is Cylindrical, reddish to purple brown, softly gelatinous thallus, simple or sparingly dichotomously branched, 2-3 mm wide, 250 mm long, with discoid base.

Scientific classification

Scientific classification	
(unranked):	Archaeplastida
Division:	Rhodophyta
Class:	Florideophyceae
Order:	Nemaliales
Family:	Nemaliaceae
Genus:	*Nemalion* Duby

Species

As of 2017, the species accepted taxonomically are:

- Nemalionamoenum
- Nemalionattenuatum
- Nemalioncari-cariense
- Nemalionhelminthoides
- Nemalionlongicolle
- Nemalionlubricum (type species)
- Nemalionmultifidum
- Nemalionmultifidum subsp. monoicum
- Nemalionperpusillum
- Nemalionvermiculare

Nemalionhelminthoides

Nemalionhelminthoides (Velley) Batters

Nemalionlubricum Duby

Rhodophyta: *Helminthocladiaceae*

Conservation status

Critically Endangered

Morphology and biology

Thallus cylindrical, rope-like, not branching or slightly branched, reaching up to 10–30(45) cm long and 1–3 mm wide; with brownish red or more often dark red colour. The thallus is strongly attached to the rocks by widened basal part, the hold-fast. The species is monoecious and its sexual organs could be seen only with a microscope. Occurs in spring and early summer.

Habitats and populations.

Epilithic in the tidal zone in clear waters. Not confirmed during the last few years.

Distribution in Bulgaria

Black Sea Coast (*Southern* – limited only in Ahtopol and Sozopol-Tsarevo subregions of the Sozopol region).

General distribution

Europe, N America, Africa (Morocco), Atlantic Islands, S America (Brazil, Uruguay), Asia (Japan), Australia and New Zealand.

Threats

Anthropogenic pollution of the Black Sea and direct collection by tourists.

Conservation measures taken

Included in the “Red List of Bulgarian algae. I. Macroalgae”.

Conservation measures needed

Decrease of anthropogenic pollution of the Black Sea; environmental education of the population.

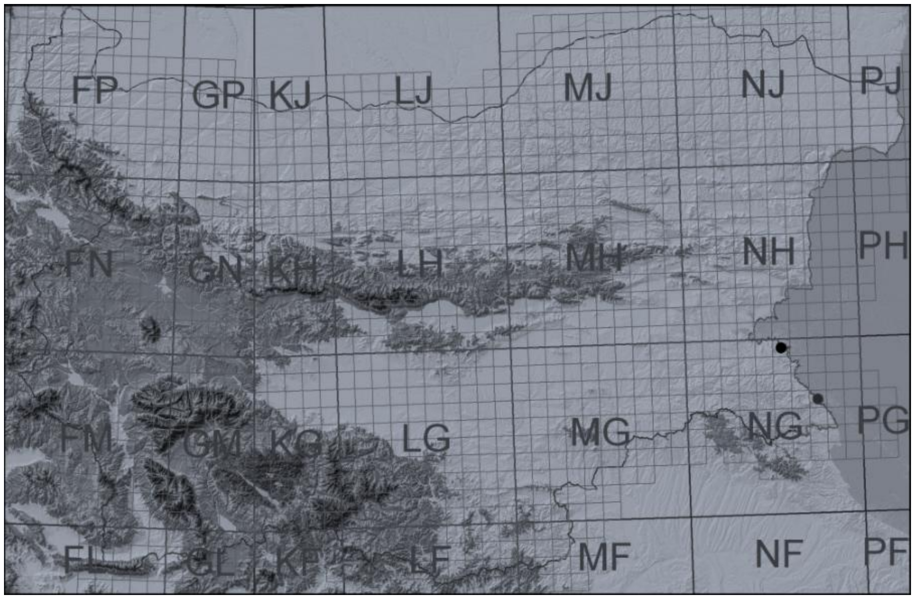


Fig.9.3 Distribution map of Nemalionhelminthoides

Some important Questions

Q. 1 What are red algae?

Red algae are the oldest group of eukaryotic algae containing over 6000 species. They fall under the kingdom Protista and phylum Rhodophyta. They contain chlorophyll and can prepare their own food by the process of photosynthesis.

Q. 2 Why red algae are named so?

Red algae are named so because of their red colour which they obtain from the pigment Phycoerythrin. The pigment reflects red light and absorbs blue light and hence give a reddish appearance to the algae.

Q. 3 What distinguishes the red algae from other algae?

The only difference between the red algae and other algae is that the red algae lack flagella, the whip-like structures that help in locomotion and perform sensory functions.

Q. 4 What is the importance of red algae?

Red algae form an important part of the ecosystem and are consumed by various organisms such as crustaceans, fish, worms and even humans. Red algae are also used to produce agar that is used as a food additive. They are rich in calcium and also used in vitamin supplements.

Q. 5 Give a few examples of red algae.

- Irish moss
- Dulse
- Laver (Nori)
- Coralline algae

Q. 6 Where are red algae found?

Red algae are commonly found in coral reefs and tide pools. They have the ability to survive at a greater depth than other algae because the pigment Phycoerythrin absorbs the blue light that can penetrate deeper than any other light wave. This allows red algae to carry out photosynthesis at a greater depth.

Q. 7 What are the different pigments present in red algae?

The different pigments present in red algae are:

- Red Phycoerythrin
- Blue Phycocyanin
- Zeaxanthin
- Carotenes
- Lutein

9.10 NEMALIONHELMINTHOIDES (VELLEY) BATTERS

Rhodophyta, Order: Nemaliales; Family: Liagoraceae=Nemalionaceae. Nema means a 'thread' or a 'filament', and helminthoid means 'worm-shaped', referring to its elongated and smooth thallus.

Description

The Nemalionhelminthoides is a brown, mucousy, elongated and twisted alga that resembles a shoelace or spaghetti. Its holdfast clings to rock, and several filaments emanate from it. On rare occasions, dichotomous branching may be observed in the thallus.

Size

The algal length ranges from several centimeters to 40 cm, and its width ranges between 1-6 mm.

Colour

The Nemalionhelminthoides is brown, usually dark.

Special features

The algal mucousy appearance resembles a brown filament of spaghetti. Its habitat is the upper regions of the abrasion platform, facing the sea. The width varies, as does the shade and texture of individuals, but the thalli on every individual are identical.

Habitat

The Nemalionhelminthoides grows at the upper reaches of the intertidal zone on the edge of the abrasion platform, in an upper area that usually forms the rim of the tidal pool (often in an area built by and populated by Serpula sp.). Often, the Nemalionhelminthoides is the only macro alga in the near vicinity, and its appearance in an area free of other algae is pertinent, since the area would otherwise be the site of competition. The species' 'loneliness' may be the result of either arresting substances that the alga secretes, which inhibit the colonization by other species, or due to the preference of herbivores that, for some reason, do not eat this specific alga. There may be other reasons. Without doubt, this does pose a fascinating subject for research. The Nemalionhelminthoides is exposed to the air most of the time.

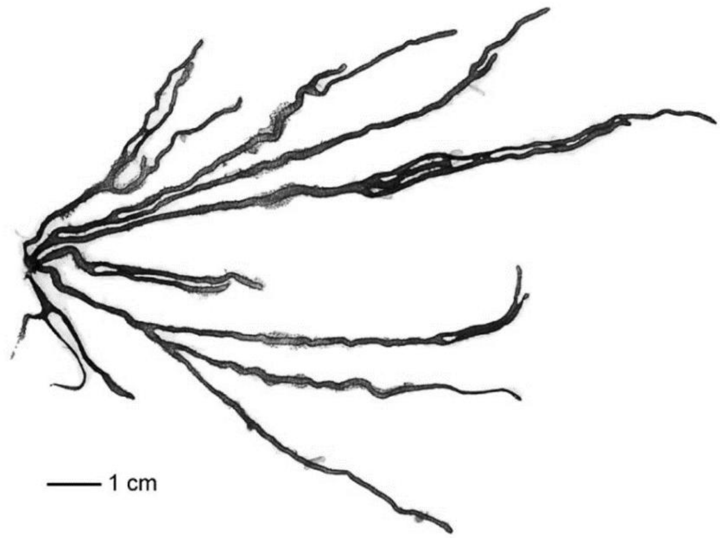


Fig.9.4 Structure of*Nemalionhelminthoides*

Biology and reproduction

The outer layer of cells is rich in pigmentation, and the inner ones are colourless. The Nemalionhelminthoides is monoecious. The male and female reproductive cells (gametes) are generated in the same individual. Research into the induction of reproductive cell generation in Nemalion reveals that the production of reproductive cells is affected by environmental conditions, especially day length. The ability to control the reproductive mechanism is important, if for no other reason than the Nemalionhelminthoides' economic importance as a source of agar.

Seasonality and distribution

The Nemalionhelminthoides can be found along rocky beaches for a short period in Spring and early Summer.

Additional species

An additional species of Nemalion reported in the Eastern Mediterranean is Nemalionmultifidum (Weber and Mohr) J. Agardh, mostly noted in Turkey. Nemalionmultifidum differs from the above in its higher level of branching. Some researchers claim that the characteristic is not significant, and that this is actually the same species. Nemalions are marketed as consumables in Japan and in Western organic food outlets, where imports from the Far East are sold. Since the alga can be found in the Mediterranean and is quite tasty, one may expect it eventually to be produced for consumption here, as well.

9.11 Uses of red algae

Red Algae has great ecological importance. They form a vital part of the food chain and are also involved in producing about 40 to 60 per cent of the total global oxygen for both terrestrial habitat and other aquatic habitats. Listed below are a few ecological and commercial importance of red algae.

- Algae provide natural food for fish and other aquatic animals.
- Red alga is the most important commercial food in Japan and in the region of North Atlantic.

- Agar or agar-agar, a jelly-like substance which is used in puddings, dairy toppings and other instant food products is extracted from Red algae.
- Red algae are used as the source of food for thousands of years as they are high in vitamins, minerals, a rich source of calcium, magnesium, and antioxidants.
- They are sources of dietary fibre as they have the ability to promote healthy circulation, lower bad cholesterol and regulate blood sugar levels.
- They are also involved in nourishing your skin, boosting the immune system and contributing to bone health.

9.12 Economic Importance of Rhodophycae

Red algae are crucial for the environment. They are an essential link in the food chain and contribute between 40 and 60% of the world's oxygen supply, which is used in both terrestrial and other aquatic settings. Several red algae's ecological and commercial values are listed below.

- Fish and other aquatic creatures may eat algae naturally.
- The most significant commercial food in Japan and the North Atlantic area is red algae.
- Red algae are used to make agar, also known as agar-agar, a jelly-like material that is used in puddings, dairy toppings, and other fast food products.
- Due to their high vitamin and mineral content, as well as their abundance of calcium, magnesium, and antioxidants, red algae have been utilised as a food source for thousands of years.
- They are sources of dietary fibre because they can cut bad cholesterol, improve circulation, and control blood sugar levels.
- They support the health of your bones and skin, as well as your immune system and skin.

Examples of Rhodophyceae

Example of Rhodophyceae includes Gracilaria, Gelidium, Porphyra, and Polysiphonia.

9.13 Summary

Under this unit we have summarized the characteristics of red algae, **classification, cell structure & metabolism of** Rhodophyceae. The red algae form a distinct group characterized by having eukaryotic cells without flagella and centrioles, chloroplasts that lack external endoplasmic reticulum and contain unstacked (stroma) thylakoids, and use phycobiliproteins as accessory pigments, which give them their red color. But despite their name, red algae can vary greatly in color from bright green, soft pink, resembling brown algae, to shades of red and purple, and may be almost black at greater depths. Unlike green algae, red algae store sugars outside the chloroplasts as floridean starch, a type of starch that consists of highly branched amylopectin without amylose, as food reserves outside their plastids. Most red algae are also multicellular, macroscopic, marine, and reproduce sexually. The life history of red algae is typically an alternation of generations that may have three generations rather than two. The coralline algae, which secrete calcium carbonate and play a major role in building coral reefs, belong here. Red algae such as Palmariapalmata (dulse) and Porphyra species are a traditional part of European and Asian cuisines and are used to make other products such as agar, carrageenans and other food additives.

Porphyra displays a heteromorphic alternation of generations.[6] The thallus we see is the haploid generation; it can reproduce asexually by forming spores which grow to replicate the original thallus. It can also reproduce sexually. Both male and female gametes are formed on the one thallus. The female gametes while still on the thallus are fertilized by the released male gametes, which are non-motile. The Nemalionhelminthoides is a brown, mucousy, elongated and twisted alga that resembles a shoelace or spaghetti. Its holdfast clings to rock, and several filaments emanate from it. On rare occasions, dichotomous branching may be observed in the thallus.

9.14 Terminal questions

Q.1 What do you mean by characteristics of Rhodophyceae**?**

Answer:--

Q.2 Describe cell structure and metabolism in Rhodophyceae.

Answer:--

Q.3 Describe the Differences between Red Algae, Brown Algae and Green Agae.

Answer:--

Q.4 Write short notes on the following.

(a) Brown algae

(b) Red algae

(c) Green algae

Answer:--

Q.5 Describe the economic importance of Rhodophycae.

Answer:--

Q.6 Write short notes on the following.

(a) Nemalion

(b) Porphyra

Answer:--

Q. 7 Write short notes on uses of red algae.

Answer:--

FURTHER READINGS

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 10: Rhodophyceae–II

Structure

10.1 INTRODUCTION

The Rhodophyta, the red algae, constitute a division of organisms that share the following combination of attributes: eukaryotic cells, lack of flagella, floridean starch, phycobiliprotein pigments (red and blue), un-stacked thylakoids, and chloroplasts lacking an external endoplasmic reticulum. They are primarily marine in distribution, with only approximately 3% of the over 5000 species occurring in truly freshwater habitats. Most of the inland species of Rhodophyta are restricted to streams and rivers (lotic forms), although a few species are found in lakes and ponds (lentic forms). A small number of inland Rhodophytes occurs in habitats other than typical freshwaters, such as hot springs. Freshwater red algae in North America represent a widespread division, with members that range from the high Arctic to the tropical rainforest. The number of species increases from the tundra to the tropics (6 to 25), similar to the trend seen for marine species of Rhodophyta.

Red algae are primarily multicellular and found in marine and freshwater environments. In addition, rhodophytes lack flagella and centrioles. The few unicellular red algae are primarily extremophiles inhabiting acid hot springs and make up a group called the Cyanidiophytina which include the genera Cyanidium, Cyanidioschyzon, and *Galdieria*. Closely related to the rhodophytes are the *Rhodelphis* and picozoans. *Rhodelphis* and picozoans form a clade with the rhodophytes but lack some of the key features of rhodophytes. For example, *Rhodelphis* and picozoan species are non-photosynthetic heterotrophsand both are flagellated. *Rhodelphis* has a remnant of a plastid and the picozoans appear to have lost their plastid. Both exhibit phagotrophy -- a trait largely absent in the archaeplastids – making them protozoan-like.

Objectives

This is the tenth unit on Rhodophyceae -II of block-II (Algae-II). Under this unit, we have following objectives. These are as under:

- To know about general characteristics of red algae
- To know its life histories and external features
- To know about taxonomy and nomenclature of Gelidium
- To discuss distribution and reproduction of Polysiphonia

10.2 LIFE HISTORIES & EXTERNAL FEATURES

Rhodophyta or red algae represent a division that is characterized by chloroplasts that have no external endoplasmic reticulum and unstacked thylakoids, phycobiliprotein pigments, floridean starch, and lack of flagella. They are predominantly marine in distribution; only approximately 3% of over 5000 species occur in truly freshwater habitats. In North America, 25 genera are recognized in inland habitats. Freshwater red algae are largely restricted to streams and rivers, but also can occur in other inland habitats, such as lakes, hot springs, soils, caves, and even sloth hair.

The Red algae or Rhodophytes are a rich and diverse group of algae, comprising of seven classes with enormous species number. These inhabit in a range of aquatic environments, mostly marine. Other niches include freshwater habitats and hot water springs. As a terrestrial niche, they have been reported to grow in tropical rainforests as well. Fossil evidence indicates rhodophytes as one of the founding multicellular lineages and ancient groups of photoautotrophic eukaryotes (Archaeplastida). It is now a proven fact that genes with nuclear as well as plastid origin from the ancestral red algae have contributed significantly to enhance eukaryotic evolution and diversity. The size of red algae ranges from single cellular forms to multicellular forms to several feet in length. Rhodophytes are broadly classified into mesophiles, extremophiles, and economically important seaweeds.

Rhodophytes are prominently red in color due to the presence of water-soluble pigments phycobiliprotein and PE. Other colors are imparted by phycocyanin (blue) and blue-greenish allophycocyanin. The pigment responsible for photosynthesis is chlorophyll a, and it is associated by accessory phycobiliproteins, forming a light-harvesting complex known as phycobilisome, present on the surface of thylakoids. There are a number of common structural and biochemical characteristics that these Rhodophytes share with other lineages of algae. But, definitely, they have a certain unique set of cellular features which are confined to this class only, for example, presence of light-harvesting complex, phycobilisomes, unstacked thylakoids, pit connections between adjacent cells and are marked by the absence of parenchyma. They play a major role as carbon sync along with the synthesis of many fatty acids and metabolites. The biogeochemical influence of rhodophytes on the ecological aquatic foodwebs and global climate is indispensable. Red algae have a valuable role in producing oxygen in the seawater. Various species of red algae are a source of food for many aquatic organisms like fishes, worms, etc. Not only this, certain algal species are responsible for the formation of tropical reefs. In fact, red algae have far more contributed to the reef structure than any other organism.

The commercial value of representatives of rhodophytes is undeniable. They are used as an important economic resource for humans. Red seaweeds are used as a food source for human consumption and several industries are based on food processing of nori (Porphyra *spp*) and many other algae. The high and rich content of vitamins, carotenoids, proteins, and antioxidants of red algae-derived foods has made them an attractive and popular choice in the health food industry for more than a thousand years. Other industries are based on phycocolloid production, which harvests a range of red seaweeds like carrageenophytes and agarophytes for the production of agar and carrageen gels. Aquaculture based industries use algae as additives to feed. Phycobiliproteins have also been used as a fluorescent tag for the localization and quantification of antigens.

Brown algae or Phaeophyceae is characteristically defined by golden-brownish color due to the presence of fucoxanthin, a carotenoid pigment and in few species, tannins. Taxonomically, this group belongs to multicellular species group, Stramenopiles. Brown algae are mostly found in marine segments and dominant seaweeds in rocky coastal ecosystems. Less than 1% of the approximately 2000 brown algal species occur in freshwater ecosystems. These include various seaweeds, which play an important role in marine ecosystems as they are a source of food to so many diverse organisms and facilitate habitats for others.

The size of brown algae ranges from small filamentous forms to large and complex marcroscopic kelps, which could range from 1 m to more than 100 m. Brown algae hold valuable economical aspect in food and pharmaceutical industries. Seaweeds are commercially important for the production of alginates, fucoids, etc. Despite their ecological, evolutionary, and economical value, very few brown algal genomes have been sequenced so far. The useful whole-genome sequencing is need of the hour and more brown algal genomes are required to be sequenced in order to explore their versatility and sustainability toward ecological conditions.

10.3 TYPES OF ALGAE

These diverse group of aquatic organisms is neither plant nor animals. Based on their general features, algae are grouped into **Kingdom Protista.** According to the records, there are more than 50,000's known species of Algae and based on their habitat, presence of biological pigments and other characteristics they are classified into seven different types.

1. Pyrrophyta
2. Euglenophyta
3. Red algae or Rhodophyta
4. Brown algae or Phaeophyta
5. Green algae or Chlorophyta
6. Yellow-green algae or Xanthophyta
7. Golden-brown algae or Chrysophyceae

Here, let us we will discuss more about the red algae, its general characteristics and uses.

10.4 GENERAL CHARACTERISTICS OF RED ALGAE

Red algae are different from other groups except for diatoms. Listed below are general characteristics of red algae.

- Lack of flagella and centrioles
- Presence of photosynthetic pigments
- Found both in marine and freshwater
- They show biphasic or triphasic life cycle patterns.
- They are a multicellular, filament, blade structure.
- Stored food is in the form of starch and polymers of galactan sulphate
- A pit connection (hole in the septum) is formed between two algal cells.
- Have a diffuse growth pattern- Apical growth, Complex oogamy (triphasic)
- These group of red algae is generally found in tropical marine locations
- The mode of nutrition may either be saprophytic, parasitic or also epiphytic.
- Their cell walls consist of cellulose and many different types of carbohydrates.
- Grow on solid surfaces independently or sometimes found attached to other algae.
- Presence of pit in the cell walls, through which cytoplasmic connections are maintained.
- The male sex organs are known as spermatangium and the female sex organs are called carpogonia or procarp.
- Mode of Reproduction: It takes place by all the three means: vegetative, asexual and sexual. Asexual mode of reproduction is by monospores and during the sexual mode of reproduction, they undergo alternation of generations.

10.5 GELIDIUM

Gelidium is a genus of thalloid red algae comprising 134 species. Its members are known by a number of common names.

10.5.1 Taxonomy and Nomenclature

Gelidiaceae has 159 species, considered to be the largest family inGelidiales with four major genera: *Capreolia, Gelidium,Gelidiophycus,* and *Ptilophora.Gelidium* was first described by Lamouroux in 1813 and is regarded to be one the genus with the most species. Species diversity has been established by previous studies, whereas, molecular analysis reveals biogeographic relations that concerns its current distribution pattern in oceans. Identification of species has been a challenge as sexual plants are somewhat difficult to find in nature, therefore, other physiological features are examined instead, such as branching patterns and vegetative traits, but subsequent studies revealed that these are also affected by its development and environmental factors highlighting the need for genetic studies utilizing genetic markers.

10.5.2 Morphology

Specimens can reach around 2–40 cm (0.79–16 in) in size. Branching is irregular, or occurs in rows on either side of the main stem. *Gelidium* produces tetraspores. Many of the algae in this genus are used to make agar. ***Chaetangium*** is a synonym.

10.5.3 Distribution

Gelidium are widely distributed globally, specifically in tropical to temperate regions, but lacking in polar regions. In the ocean, *Gelidium* can be found inhabiting the intertidal to subtidal zone. Species from the genus require further studies to distinguish boundaries among members, as recent molecular research have shown that there are cryptic, unidentified species assumed to be regionally endemic and isolated but may also be ubiquitous in nature. Some species are common in the Atlantic and Pacific Ocean (*G. crinale)* while some are confined in North Atlantic waters (*G. pussillum).* Reports of *G. pussillum* occurrence outside of its specified range may be questionable and requires further verification.

10.5.4 Ecology

Gelidiales consists of many species that are economically important as they produce agar while some serve ecologically significant functions such as substrate cover. The growth of *Gelidium* can primarily be affected by nutrient availability and light. In turn, these factors are also regulated by temperature and water movement, respectively. Santelices (1991) evaluated how eight factors may affect *Gelidium* productivity, all of which are important in understanding how different interactions correlate to production yield. Some of these factors include seasonality, phenotypic characters, age, reproductive state, and even the source of the algae.

10.5.5 Life History

Gelidium is assumed to follow the *Polysiphonia* life cycle, with sexual and tetrasporangial generations. Tetrasporangia formation is also known to be affected by temperature and other environmental factors including light, salinity and moisture, although germination rates remain unaffected based on an earlier study. In 1993, *Gelidiumrobustum* in Santa Barbara, California was investigated for 16-months showing tetrasporangial abundance throughout the year, but may not have the ability to germinate despite maximum spore output.

10.5.6 Cultivation and Exploitation

An important agarophyte, *Gelidium* has been cultured in Korea and China since the early 1990s, with some cultivation efforts noted in Europe, specifically in Spain and Portugal. In South Africa, *G. pristoides* (Turner) has been cultivated in the field while laboratory trials on *G. crinale* (Turner) and *Pterocladiellacapillacea* (Gmel.) Santelices and Hommersand were tested in Israel.

Gelidium has been found to be over-exploited in Japan, depleting algal beds which in part, affects agar production, pushing the need for even more efforts in cultivation, replacing the practice of harvesting wild *Gelidium*. In 2017, global data have shown that Norway, China, and Chile are among the countries that lead the overharvesting of seaweeds, mostly kelp. Advances in *Gelidium* cultivation have been put forth including the use of floaters at sea and marine ponds for free-float technology in cultivation. At its core, environmental factors are needed to be controlled for favorable growth of *Gelidium* revealing how ponds may be the better option among the set-ups.

10.5. Chemical Composition

Agar is primarily extracted from *Gelidium* especially among North African Atlantic and South European species based on specific gel properties with water. In Morocco, *Gelidiumsesquipidale* is known to be harvested during summer time to extract agar used commercially, making the country among the top producers in the world. Agarocolloids are known to be extracted in algae belonging to the orders Gracilariales and Gelidiales with certain applications in the food and cosmetics. Gelling properties often differ among species, seasons, seaweed age, and substitutions between sulphate esters, among other compounds. Sulphate composition often dictates gel strength, while methyl esters determine gelling and elasticity.

10.5.8 Utilization and Management

In Portugal, *G. sesquipedale* are commonly harvested for agar since the 1960s. Management strategies are yet to be implemented especially among big commercial companies that should be responsible in harvesting the resource, similar to South Africa where the decrease in annual *Gelidium* landings show how fisher folk shifted to collecting kelp for abalone feeds instead of *Gelidium* harvesting.

10.5.9 Gelidium as environmental records

Gelidium species have been collected, pressed and maintained in herbaria and personal collections from the 1850s onwards since seaweed collecting became a popular pastime for the middle classes as well as scientists in Europe and North America. These numerous well-documented specimens can provide information beyond taxonomy.

Sensitive measurement of stable nitrogen isotope ratios in *Gelidium* species collected in southern Monterey Bay between 1878 and 2018 showed a pattern of changes that matched with changes in the California current and provided support for a theory about the end of the local fishing industry. Nitrogen isotope ratios are well established as a measure of nutrient productivity in aquatic ecosystems. The California current runs along coastal California and correlation with information on fish catches indicates that an increase in nutrient-rich cold water is important for fish productivity, notably sardines. The California current has only been measured since 1946. The correlations with the *Gelidium* nitrogen ratios allowed the California current to be projected back into the nineteenth century and compared with historical records of fish catches.

10.6 POLYSIPHONIA

While there are more than 4,000 catalogued species of red algae worldwide, most are found in tropical marine waters, and only a few are freshwater species. ***Polysiphonia***, a common genus of marine red algae, is red in color because of the pigment **phycobilin**, which masks the green color of the chlorophyll responsible for photosynthesis. As a red-colored plant, ***Polysiphonia*** is well suited to absorb the green and blue-green light that typically penetrates the deeper seawater where these red algae thrive.***Polysiphonia*** is a genus of filamentous red algae with about 19 species on the coasts of the British Isles and about 200 species worldwide, including Crete in Greece, Antarctica and Greenland. Its members are known by a number of common names. It is in the order Ceramiales and family Rhodomelaceae.

10.6.1 Description

Polysiphonia is a red algae, polysiphonousand usually well branched, with some plants reaching a length of about 30 cm. They are attached by rhizoidsor haptera to a rocky surface or other alga. The thallus (tissue) consists of fine branched filaments each with a central axial filament supporting pericentral cells.

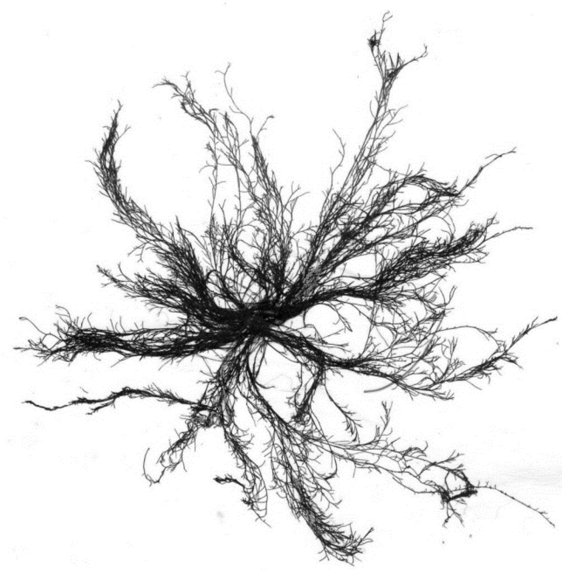


Fig.10.1 Strucure of Polysiphonia urceolata

Scientific classification	
Kingdom:	Protista
Division:	Rhodophyta
Class:	Florideophyceae
Order:	Ceramiales
Family:	Rhodomelaceae
Genus:	*Polysiphonia* Greville, 1823

The number of these pericentral cells (4–24) is used in identification. Polysiphoniaelongata shows a central axial cell with 4 periaxial cells with cortical cells growing over the outside on the older fronds. Its cuticle contains bromine. Features used in identification include the number of pericentral cells, the cortication of main branches, constriction of young branches at their base, whether the branching dichotomous or spiral, and the width and length of thalli.

Red algae often attach to submerged stones or anchor to other marine plants and are able to withstand the wave and tidal forces of the intertidal zone. Because of their durability, fragments of red algae that survive the winter, or are buried under sand for months, can grow again into healthy plants under favorable environmental conditions. Valued as a food plant, ***Polysiphonia*** retain their red coloring and gelatinous form, even when heated. These red algae are often used as a vegetable substitute for gelatin in puddings, ice cream, and toothpaste. As its generic name implies, ***Polysiphonia*** forms many "pipes" or branches in its typical configuration. Branch-like structures consist of a line of elongated cells that displays a segmented appearance, and produces secondary branches that radiate from the algae body. Long hairs known as trichoblasts are often observed growing from the branches.

10.6.2 Distribution and ecology

Species have been recorded from Europe, Australia and New Zealand, North America and South America, islands in the Pacific Ocean, South Africa, southwest Asia, Japan, Greenland and Antarctica. The species are entirely marine, found growing on rock, other algae, mussels or limpets and artificial substrata etc. from mid-littoral to at least 27 m depth. Many species are abundant in rock pools. Polysiphonia lanosa is commonly found growing on Ascophyllum nodosum.

10.6.3 Reproduction and life cycle

The life-cycle of the red algae has three stages (triphasic). In *Polysiphonia* it consists of a sequence of a gametangial, carpospoangial and tetrasporangial phases. Male (haploid) plants (the male gametophytes) produce spermatia and the female plants (the female gametophytes) produce the carpogonium (the haploid carpogonium) which remains attached to the parent female plant. After fertilization the diploid nucleus migrates and fuses with an auxiliary cell. A complex series of fusions and developments follow as the diploid zygote develops to become the carposporophyte, this is a separate phase of the life-cycle and is entirely parasitic on the female, it is surrounded by the haploid pericarp of the parent female plant. The diploid carpospores produced in the carposporangium when released are non-motile, they settle and grow to form filamentous diploid plants similar to the gametophyte. This diploid plant is the tetrasporophyte which when adult produced spores in fours after meiosis. These spores settle and grow to become the male and female plants thus completing the cycle.

Sexual reproduction is complicated and commands its own lexicon of terms to describe the numerous red algae life stages or phases. The **tetrasporophyte** is a small ***Polysiphonia*** plant with the diploid number (**2N**) of chromosomes. Round balls, or **tetrasporangia**, form on each segment and are easily seen on the branches. Dividing into four parts, the tetrasporangia form four haploid (**N**) spores that develop into the male and female plants or gametophytes. Nonflagellated spermatia are released to the water currents from the spermatangia formed on the top branches of the gametophyte. The spermatium moves to the **carpogonium**, the female reproductive organ, and they merge. Through a tube of the **trichogyne**, a hair-like receptive protuberance of the carpogonium, the nucleus of the male cell moves towards the egg cell, creating a zygote that develops into a **cystocarp**. In the cystocarp, diploid **carpospores** (**2N**) form and escape through a hole, eventually growing into new tetrasporophytes.

10.6.4 Species

The species currently recognized are:

- ✓ P. abscissa
- ✓ P. abscissoides
- ✓ P. acanthina
- ✓ P. acuminata
- ✓ P. adamsiae
- ✓ P. adriatica
- ✓ P. amphibolis
- ✓ P. anisogona

The economic importance of algae

Algae have diverse economic uses. They perform half of the total carbon dioxide fixation on earth by photosynthesis, acting as the primary producers in aquatic habitats.

(a) Food source:

Many species of marine algae such as Porphyra, Sargassum, and Laminaria are edible. Chlorella and Spirulina are rich in proteins. Thus, they are used as food supplements.

(b) Commercial importance:

Agar is used in the preparation of jellies and ice creams. It is obtained from Gelidium and Gracilaria. Carrageenin is used as an emulsifier in chocolates, paints, and toothpastes. It is obtained from the red algae.

(c) Medicines:

Many red algae such as Corallina are used in treating worm infections.

10.7 SUMMARY

Under this unit we have summarized Rhodophyceae by its concept in concern to characteristics, classification and importnce.Red algae are mostly found in a marine environment. A number of species is unicellular, but most species are multicellular. Red algae possess pigments of the phycoerythrine (red) and Phycocyanine (blue) group, involved in photosynthesis. Phycoerythrine reflects red light; hence the perception of the red color for us. The pigment absorbs rays in the blue-green-yellow range of the spectrum. Under this unit we have discussed the taxonomy and nomenclature of *Gelidiu.* They are widely distributed globally, specifically in tropical to temperate regions, but lacking in polar regions. In the ocean, *Gelidium* can be found inhabiting the intertidal to subtidal zone. Species from the genus require further studies to distinguish boundaries among members, as recent molecular research have shown that there are cryptic, unidentified species assumed to be regionally endemic and isolated but may also be ubiquitous in nature.

Polysiphonia is composed of dark-reddish filaments with a single tier of pericentral cells around the axial cell. No freshwater collections have an additional layer of cortication but a few marine species do. Delicately branched hairs (trichoblasts) are formed in upper portions of the plant. Rhizoidal branches arise from pericentral cells. Freshwater samples have not been observed as being either sexual or tetrasporic. Species have been recorded from Europe, Australia and New Zealand, North America and South America, islands in the Pacific Ocean, South Africa, southwest Asia, Japan, Greenland and Antarctica .

10.8 TERMINAL QUESTIONS

Q.1 What do you mean bytaxonomy and nomenclature of Gelidium?

Answer:---

Q.2 Describe the distribution and ecology of Gelidium.

Answer:---

Q. 3 Describe the general characteristics of red algae.

Answer:---

Q. 4 Write short notes on the following.

(a) Algae

(b) Rhodophyceae

Answer:---

Q. 5 Write short notes on the following.

(a) Reproduction in Polysiphonia

(b) Life cycle of Polysiphonia

Answer:---

Q. 6 Describe the distribution, ecology and reproduction in Polysiphonia.

Answer:---

Q. 7 Write short notes on the following.

(a) Speciesof Polysiphonia

(b) Chemical composition in Gelidium

Answer:---

FURTHER READINGS

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 11: XANTHOPHYCEAE

Structure

11.1 INTRODUCTION

The Xanthophyceae is a clade of stramenopilan photoautotrophs containing about 118 genera and 600 species. Morphology ranges from free-living or attached unicells to colonies and unbranched or branched filaments and siphons. A large majority are found in freshwater and soil, while some occur in brackish and marine habitats. Although abundant growth of a few species can occur in nature, none are known to be of practical importance. They are characterized by possession of chlorophylls *a*, c_1, and c_2 and a range of xanthophylls, but not fucoxanthin, in generally yellowish-green, discoidal, parietal chloroplasts. Thylakoids are in groups of three, and most species investigated have a single thylakoid forming a girdle band around the periphery of the chloroplast. Chloroplasts are surrounded by chloroplast endoplasmic reticulum. Pyrenoids, when present, are typically semi-immersed and are not associated with granules of storage products. A cell wall consisting of two overlapping parts occurs in some coccoid and filamentous species. Reproduction is generally asexual but some, e.g., *Vaucheria*, exhibit sexual reproduction.

The taxonomic status of a significant number of species is uncertain, especially those that are rarely observed, e.g., species of Chloramoebales, Heterogloeales, and Rhizochloridales. Transfer of species to the Eustigmatophyceae and other groups is likely. There is molecular phylogenetic data for fewer than 20 % of species. Four major clades are recognized. Two of these contain both coccoid and filamentous species. Many traditional orders, families, and genera are paraphyletic or polyphyletic. It is presently convenient to retain the traditional classification of seven orders based on morphology until these difficulties are resolved following the inclusion of more species in phylogenetic analyse

Objectives

lose. They appear to be the clThis is the eleventh unit on Xanthophyceae of block-II (Algae-II). Under this unit, we have following objectives. These are as under:

- To know about Xanthophyceae, characteristics, significance.
- To discuss the life cycles of *Gelidium* and *Vaucheria.*
- To discuss genome structure and metabolism in Gelidium.
- To know about economic importance of Xanthophyceae.

Yellow-green algae, (class Xanthophyceae), class of approximately 600 species of algae in the division Chromophyta, most of which inhabit fresh water. Yellow-green algae vary in form and size from single-celled organisms to small filamentous forms or simple colonies. They were once classified with the green algae (division Chlorophyta) on the basis of similarity of body organization. Molecular evidence, however, has led to a revision of that taxonomy; the group is likely closely related to the brown algae (class Phaeophyceae). The Xanthophyceae are distinguished by their food reserve (oil), the quantity of β-carotene in their plastids, and motile cells with unequal flagella. Frequently their cell walls are two overlapping halves. The usual method of asexual reproduction is by motile zoospores or nonmotile resting aplanospores. Sexual reproduction is rare; the genus *Vaucheria* is an important exception.

Yellow-green algae or the Xanthophyceae (xanthophytes) are an important group of heterokont algae. Most live in fresh water, but some are found in marine and soil habitats. They vary from single-celled flagellates to simple colonial and filamentous forms. Xanthophyte chloroplasts contain the photosynthetic pigments chlorophyll a, chlorophyll c, β-carotene, and the carotenoid diadinoxanthin. Unlike other Stramenopiles (heterokonts), their chloroplasts do not contain fucoxanthin, which accounts for their lighter colour. Their storage polysaccharide is chrysolaminarin. Xanthophyte cell walls are produced of cellulose and hemicelluosest relatives of the brown algae.

11.2 MAIN CHARACTERISTICS OF XANTHOPHYCEAE (YELLOW GREEN ALGAE)

These are yellow green algae which contain chlorophyll a but lack chlorophyll b. Instead of chlorophyll b they possess chlorophyll e or c. Besides chlorophylls they possess xanthophylls and beta carotene. The class Xanthophyceae is divided into four orders: Heterochloridales, Heterococcidales, Heterotrichales and Heterosiphonales

Pigments in Xanthophyceae

- Chief pigment consists of Chlorophyll a, Chl c, β carotene, diatoxanthin, diadinoxanthin and heteroxanthin
- Chlorophyll b is absent
- Xanthophyll (dominant pigments)
- Lutein, violaxanthin, neoxanthin, flavacin and flavoxanthin are present.
- Unlike other heterokonts, their chloroplast do not contain fuxoxanthin, which account for lighter color.

- Unlike other Chromista, Xanthophyta completely lack the brown pigment Fucoxanthine.
- Yellow-green color is due to Chlorophyll c, as opposed to the golden color or their relatives, which may make them difficult to recognized as chromists.

11.3 CLASSIFICATIONS

The species now placed in the Xanthophyceae were formerly included in the Chlorophyceae. In 1899, Lüther created the group Heterokontae for green algae with unequal flagella. Pascher included the Heterokontae in the Chrysophyta. In 1930, Allorge renamed the group as Xanthophyceae. The monadoid (unicellular flagellates) and also sometimes the amoeboid species have been included by some authors in the Protozoa or Protista, as order Heterochloridina, as class Xanthomonadina, with orders Heterochloridea and Rhizochloridea, as order Heterochlorida, as order Heteromonadida, or as subclass Heterochloridia. These groups are called ambiregnal protists, as names for these have been published under either or both of the ICZN and the ICN.

Higher order taxa:

Eukaryota; stramenopiles

Genera

Vaucheria, Tribonema, Botrydium

11.4 DESCRIPTION AND SIGNIFICANCE

Commonly called the yellow-green algae. There are about 600 species of Xanthophyceae, all but three *(*Botrydium*, Tribonema* and *Vaucheria*) of the species are very rare. Before 1899 there were so few species known that they were categorized with the Chlorophyta (green algae). They are often confused with green algae because it is pigmented by chlorophyll and lacks the fucoxanthin that is present in other Chyrsophyta. In fact, Xanthophyceae are "secondary endosymbionts" -- they evolved from protists that engulfed algae and assimilated their chloroplasts. The two main varieties appear as large green vesicles up to several mm in diameter.

11.5 GENOME STRUCTURE

There has not been a genome project on Xanthophyceae yet, however there have been some experiments studying how the organism can morph to adapt to frigid waters. There is also evidence from DNA sequence comparison that Xanthophyceae is genetically related to Raphidophyceae .

11.6 CELL STRUCTURE AND METABOLISM

Xanthophyceae are a photosynthetic group of yellow-green algae. Their photosynthate is stored as oils and the storage polymer chrysolaminarin. Most Xanthophyta are coccoid or filamentous, but some are siphonous, meaning that they are composed of multiple tubular cells with several nuclei. What makes up the cell wall is unknown but inside some there are two silica valves similar to those in diatoms. For the species that are filamentous the interlocking halves are in the shape of a H. While not much is known about the life cycle of xathnophyta generally their reproduction is asexual, in which the cell divides bilaterally and creates and produces an endogenous cyst. Reproduction has only been observed in two xanothophtyes: in *Vaucheria*, it was found to be oogamous, and *Botrydium* reproduces by means of bimastigote zoospores or aplanospores.

Ecology

Xanthophyta are generally found in freshwater, wet soil and tree trunks, but there are several marine species. Most of the species occur singly and are found around other algae, making it difficult to find the same species twice. They do very well at low pH in habitats that are rich in iron. It was also found that Xanthophyceae loses its cytoplasmic streaming ability and organization of other vegetative filaments, when it is in an aluminum-rich environment. Many of them are found in late winter among floating mats in still water.

The species *Vaucherialongicaulis* has a unique characteristic in that it will send a larvae of *Alderuamodesta* into spontaneous metamorphorosis when the larvae comes in contact with it. The adults can create two kinds of larvae, planktotrophic or lecithotrophic. Lecithotrophic clutches contain a mix of larvae, some which settle spontaneously, and others that need to be exposed to *Vaucherialongicaulis*.There were other experiments done to test and see if other algae would have the same effect and out of the 17 none did except for *Vaucherialongicaulis*.

11.7 EOOLOGY ALGAE BASE (2020)

Xanthophyceae have been divided into the following five orders in some classification systems.

- Dictyosphaeriopsis
- Groenlandiella
- Halosphaeropsis
- Pelagocystis
- Polyedrium
- Pseudopleurochloris

Lüther (1899)

Classification according to Lüther (1899)

- Class Heterokontae
    - Order Chloromonadales
    - Order Confervales

Pascher (1912)

Classification according to Pascher (1912).

- Class Heterokontae
    - Heterochloridales
    - Heterocapsales
    - Heterococcales
    - Heterotrichales
    - Heterosiphonales

Fritsch (1935)

Fritsch (1935) recognizes the following orders in the class Xanthophyceae

- Order Heterochloridales
    - Family Heterochloridaceae (e.g., Heterochloris)

  - Family Heterocapsaceae (e.g., Chlorogloea)
  - Family Mischococcaceae (e.g., Mischococcus)
  - Family Heterorhizidaceae (e.g., Rhizolekane)
- Order Heterococcales
  - Family Halosphaeraceae (e.g., Halosphaera)
  - Family Myxochloridaceae (e.g., Myxochloris)
  - Family Chlorobotrydaceae(e.g., Chlorobotrys)
  - Family Chlorotheciaceae (e.g., Chlorothecium)
  - Family Ophiocytiaceae (e.g., Ophiocytium)
- Order Heterotrichales
  - Family Tribonemataceae (e.g., Tribonema)
  - Family Heterocloniaceae (e.g., Heterodendron
- Order Heterosiphonales
  - Family Botrydiaceae (e.g., Botrydium)

Smith (1938)

In the classification of Smith (1938), there are six orders in the class Xanthophyceae, placed in the division Chrysophyta:

- Order Heterochloridales (e.g., Chlorochromonas)
- Order Rhizochloridales (e.g., Chlorarachnion)
- Order Heterocapsales (e.g., Chlorosaccus)
- Order Heterotrichales (e.g., Tribonema)
- Order Heterococcales (e.g., Botrydiopsis)
- Order Heterosiphonales (e.g., Botrydium)

Pascher (1939)

Pascher (1939) recognizes 6 classes in Heterokontae:

- Class Heterochloridineae
- Class Rhizochloridineae
- Class Hetcrocapsineae
- Class Heterococcincae
- Class Hetcrotrichineae
- Class Heterosiphonineae

11.8 BOTRIDIUM

The yellow-green alga *Botridium* has clusters of small, saclike, coenocytic vesicles. Coenocytic or siphonous organisms do not have cross walls separating individual cells, creating tube-like thalli with many nuclei. The genus grows on damp soil and has colorless rhizoids that attach underground. The vesicles can be very large - as much as several millimeters in diameter - and therefore can sometimes be seen without the aid of a microscope. A thin peripheral layer of cytoplasm contains the multiple nuclei and discoid plastids.

11.8.1 Species

Some currently recognized species:

- *Botrydium becherianum*
- *Botrydium corniforme*
- *Botrydium cystosum*
- *Botrydium divisum*
- *Botrydium granulatum*
- *Botrydium intermedium*
- *Botrydium milleri*
- *Botrydium pachydermum*

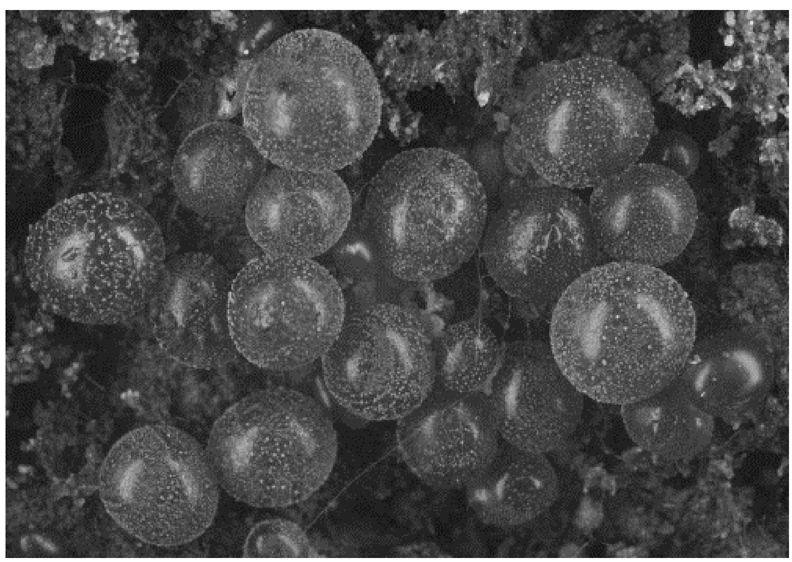


Fig.11.1 Structure of Botrydium granulatum media

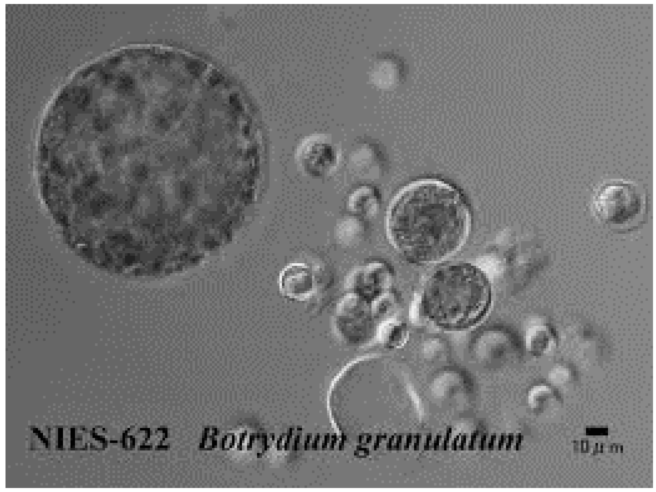


Fig.11.2 Structure of Botrydium granulatum

Botrydium granulatum is a species of yellow-green algae in the family Botrydiaceae. When sufficient water is present, *Botridium* releases biflagellate zoospores or gametes with a single nucleus. When there is less water the parent cells instead produce aplanospores (nonmotile spores that sometimes develop flagella) or resistant cysts. *Botridium* reproduces sexually via isogametes or anisogametes. Like other yellow-green algae, *Botridium* can sometimes reproduce asexually through fragmentation, bilateral division, and the development of akinetes.In Botrydium sexual reproduction is by means of bimastigote isogametes. Sexual reproduction in Vaucheria is oogamous. Antheridia and oogonia are formed either on special lateral branches of the main filament or are sessile. They are separated from the main filament by a cross-wall.

11.9 VAUCHERIA

Vaucheria is a yellow-green alga that belongs to the class Xanthophyceae. It is commonly known as the water felt. This species is found worldwide, most existing in freshwater and marine environments. Some of the species are terrestrial as well. They can be commonly seen in estuaries, salt marshes, ponds and wet farmlands. Around 54 species of the genus are known, out of which 9 are found in India.

Classification of *Vaucheria*

Kingdom	Chromista
Division	Xanthophyta
Class	Xanthophyceae
Order	Vaucheriales
Family	Vauchericeae
Genus	*Vaucheria*

Structure of *Vaucheria*

- The plant body of *Vaucheria* is filamentous, branched, coenocytic, and siphonaceous thallus.
- They are mostly aseptate in structure, but septa may form during injury or development of sex organs.
- The terrestrial species of *Vaucheria* are found attached to the soil substrate by rhizoids. However, the floating species have no or ill-developed rhizoids.
- The filamentous body of *Vaucheria* has a thin outer wall, which is less elastic in nature.
- It has an outer layer made of pectin and an inner layer made up of cellulose.
- Inside the filament, a central vacuole is present with cell sap at the apices.
- The filament has a protoplast that is present between the cell and the vacuole. The protoplast houses nuclei, chromatophores and other organelles.
- Chromatophores are elliptical or disc-shaped chloroplasts that contain pigments but lack pyrenoids.
- It contains pigments, such as chlorophyll a, chlorophyll e, xanthophylls and carotenoids.
- Food is stored in the form of oil and can be seen as colourless droplets in the cytoplasm.

Reproduction in *Vaucheria*

Vaucheria reproduces by vegetative, asexual and sexual means. Let us look at them one by one.

Vegetative Reproduction in *Vaucheria*

Vegetative reproduction in *Vaucheria* takes place by fragmentation. The filaments of the genus may break due to mechanical injury by insect bites. Septa is formed at the site of injury, and the broken fragments develop into a new thallus.

Asexual Reproduction In *Vaucheria*

Asexual reproduction in *Vaucheria* takes place in three ways:

1. **Aplanospores:** Aplanospores are non-motile spores that are formed singly inside structures called aplanosporangium. They are formed during unfavourable conditions at the apical side of aerial hyphae. The aplanosporangium are club-shaped and non-flagellated structures that are separated from the rest of the thallus by a transverse septum. The aplanospores rupture the cell wall of the aplanosporangium and develop into new filaments.
2. **Zoospores:** Zoospores are flagellated asexual spores that are borne singly inside zoosporangium. Zoosporangia are green-coloured and club-shaped structures that are formed at the apical region of the filaments by forming a cross-wall from the rest of the filament.

   At the time of the liberation of the spore, the protoplast of the zoosporangium contracts, forming a narrow aperture, from which the zoospores are released. The zoospores become flagellated after liberation. The zoospores are yellowish-green, multiflagellate, multinucleate and ovoid structures that have a small central vacuole. They are also referred to as compound zoospores.
3. **Akinetes:** Akinetes are formed by the division of filaments into small segments by a thick gelatinous wall during unfavourable conditions. The akinetes are small, multinucleate and thick-walled segments that are also known as cysts or hypnospores. Since the segmented filament resembles the genus of *Gongrosira* algae, this stage is also known as the Gongrosira

stage.

Sexual Reproduction In *Vaucheria*

Sexual reproduction in *Vaucheria* is of oogamous type. The male sex organ is known as antheridium, and the female sex organ is known as oogonium. The plant body of *Vaucheria* can either be homothallic, meaning both the male and female sex organs are borne close to each other, on the same filament, or heterothallic, such that male and female sex organs are borne on different plants.

Development of Antheridium

For the development of antheridium, a short lateral branch projects out of the *Vaucheria* filament. The branch is aggregated with nuclei and chromatophores in the apical region. The apical region of the branch then bends into a horn shape, and a septum is formed. This separates the antheridium from the rest of the filament. Inside the antheridium, the nuclei divide mitotically and give rise to biflagellated and spindle-shaped antherozoids. The flagella are dissimilar, i.e. one is whiplash and one is tinsel. The antheridium opens at the apex, and antherozoids are released.

Development of Oogonium

The base of the antheridial branch develops a protuberance due to the accumulation of cytoplasm. This region of cytoplasm is colourless, has abundant nuclei and lacks chromatophores; this multinucleated mass is referred to as wanderplasm. The wall of the wanderplasm bulges out to form an oogonial initial, which enlarges eventually, and a number of chromatophores migrate in this area. The oogonial initial further develops into an ovoid or round-shaped structure with a beak at the apex. They get separated by the formation of transverse septa. During development, all of the nuclei in the oogonium, except one: degenerate. This one nucleus forms the ovum or the egg.

Fertilisation

At the time of fertilisation, the beak of the oogonium ruptures, and an aperture is formed in the antheridium. The oogonium releases a small amount of cytoplasm through the ruptured beak, and as a result, many antherozoids get stuck in the liquid, but only one enters the oogonium. The antherozoids lose their flagella upon coming in contact with the ovum and fuse with it to form a diploid zygote.

Germination

The zygote that is formed inside the oogonium comes out and remains dormant for some time. Upon the arrival of favourable conditions, the zygote divides meiotically and mitotically to form a coenocytic structure. The zygote wall cracks at some point, and the protoplasm elongates to give rise to rhizoidal initial and aerial hyphae.

11.10 ECONOMIC IMPORTANCE OF XANTHOPHYCEAE

Xanthophyta are important contaminants of source of water or drinking water supplies.These are able to change the quality of water but these are so small that mostly scientist ignore their role which they play for water. • Some species of xanthophyte are presumably in response to elevate nutrients from fertilizers. Some species produce substantial biomass in waster treatment suggests they may have promise for nutrients or heavy metal removal. • Freshwater Xanthophyta algae are not known to be toxin producers, but marine species produce potent ichtytoxins that lead to massive fish kill during blooms.

11.11 SUMMARY

Under this unit we have summarized Xanthophyceae by its concept in concern to characteristics, cell structure and metabolism.Xanthophyceae is a class comprised of xanthophytes or the yellow-green algae. The color is due to the presence of pigments such as xanthophylls and beta carotene.The color is due to the presence of pigments such as xanthophylls and beta carotene. They also have chlorophyll pigments. They have chlorophyll a and c. They also have chlorophyll pigments. Most live in fresh water, but some are found in marine and soil habitats.

Gelidium are widely distributed globally, specifically in tropical to temperate regions, but lacking in polar regions. In the ocean, *Gelidium* can be found inhabiting the intertidal to subtidal zone. Species from the genus require further studies to distinguish boundaries among members, as recent molecular research have shown that there are cryptic, unidentified species assumed to be regionally endemic and isolated but may also be ubiquitous in nature Best known as a solidifying component of bacteriological culture media.

Vegetative reproduction in *Vaucheria* takes place by fragmentation. The filaments of the genus may break due to mechanical injury by insect bites. Septa is formed at the site of injury, and the broken fragments develop into a new thallus. It is also used in canning meat, fish, and poultry; in cosmetics, medicines, and dentistry; as a clarifying agent in brewing and wine making; as a thickening agent in ice. Due to its high content in chlorophyll and β-carotene, it is highly useful in the production of oxygen. Countries like Japan are consuming some forms of this algae. In some agricultural practices, algaes are used as biofertilizer.

11.12 TERMINAL QUESTIONS

Q.1 What do you mean bymain characteristics of Xanthophyceae (Yellow Green algae) ?

Answer:---

Q.2 Describe the cell structure and metabolism in Xanthophyceae.

Answer:---

Q.3 Describe the description and significance of Xanthophyceae.

Answer:---

Q.4 Write short notes on the followings.

(a) Yellow green algae

(b) Vaucheria

Answer:---

Q.5 Write short on the followings.

(a) Botrydium

(b) Genome structure in Xanthophyceae

Answer:--

Q.6 What type of flagella is found in Vaucheria? Explain it.

Answer:--

Q.7 Describe the classification of Xanthophyceae?

Answer:--

Q.8 Describe economic importance of Xanthophyceae.

Answer:--

FURTHER READINGS

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker

UNIT 12: BACILLARIOPHYCEAE

Structure

12.1 INTRODUCTION

Bacillariophyceae (diatoms) Class of unicellular algae, usually occurring singly, but may be colonial or filamentous. Cell size ranges from 5 to 2000 µm. The cell wall (frustule) is impregnated with silica and consists of two valves, one of which overlaps the other like the lid on a box. The frustule is commonly delicately ornamented and pierced by tiny holes (punctae) which may be covered by porous sieve membranes. There are two orders. The Centrales (centric diatoms) are circular, with radial symmetry, and are predominantly marine. The Pennales (pennate diatoms) are elliptical, with bilateral symmetry, and dominate freshwater environments. The frustules have formed an important constituent of deep-sea deposits since the Cretaceous. The oldest known diatom is usually taken to be *Pyxidiculabollensis* from the Jurassic.

Objectives

This is the twelfth unit on Bacillariophyceae of block-II (Algae-II). Under this unit, we have following objectives. These are as under:

- To know about Bacillariophyceae, characteristics and distribution
- To discuss reproduction and economic importance of Bacillariophyceae
- To discuss *Peridinium* and its life cycle
- To discuss*Ceratium*and its life cycle

12.2 MAIN CHARACTERISTICS OF DIATOMS (BACILLARIOPHYCEAE)

The bacillariophyceae, popularly called diatoms, form a very important group of both fresh water and marine unicellular algae. There are about 16000 species of algae present in this group.The shape and size of these algae vary greatly. This may be in the form of boots, circles, triangles, squares etc. Sometimes the unicellular forms unite by a gelatinous material to form small colonies.

12.3SALIENT FEATURES OF BACILLARIOPHYCEAE

The Bacillariophyta, commonly known as the diatoms, are ubiquitous algae of both fresh- and salt-water and of damp places including aerial habitats as, old walls, rocky cliffs, bark of trees, and damp soils. Some are submerged in water growing attached to various substrata like aquatic algae and submerged objects. It is a large group of algae consisting of 200 genera and over 16,000 species, out of which 92 genera and about 569 species are reported from India. Most common Indian genus are Navicula and Pinnularia. They are commonly known as Diatoms. The diatoms are the most beautiful microscopic algae due to their structure and sculpturing of their walls.

The members of this class are either unicellular or form colonies. All are characterized by the presence of golden-brown chromatophores which, besides the usual pigments, contain some brown pigments of obscure nature. The cell wall is made up of both pectic substances and silica, and usually consists of two halves with rich ornamentations on their surface. The cells are either radially or bilaterally symmetrical. The members of Pennales show special type of sexual union between protoplasts of vegetative cells. They are probably all diploid. Diatoms are widely distributed both in fresh and salt water of all kinds. Some are also terrestrial.

General Characters of Bacillariophyceae:

The Bacillariophyceae, popularly known as diatoms, constitute a very large assemblage of unicellular algae. Owing to the colour of their chromatophores they appear to be brown algae, but they are usually considered as a separate and distinct group.

They are readily distinguished from other algae by the following salient features:

(a) The plant is usually unicellular and always non-flagellate, the silicified wall consisting of two overlapping halves;

(b) The photosynthetic reserve materials are fats and volutin but never starch;

(c) The photosynthetic pigments of the chromatophores are masked by the presence of a golden-brown pigment known as diatomin;

(d) Special type of large rejuvenescent cells (auxospores) are formed, either directly from the vegetative protoplast or as a result of sexual union, a feature not found in other groups of algae.

12.4 OCCURRENCE AND DISTRIBUTION OF BACILLARIOPHYCEAE

Diatoms are inhabitants of both fresh and salt water, being usually associated together in great abundance. Some diatoms are either strictly marine or strictly freshwater. Both freshwater and marine diatoms may be sessile in habit or free-floating (plankton); when sessile, they are attached to other types of algae or affixed to rocks or other solid inanimate objects under water.

After the death of individual cells, the silicified wall of a diatom remains unaltered and great numbers of these walls are deposited at the bottom of ponds, lakes or any other body of water in which diatoms thrive. If the conditions are favourable, deposition goes on unimpeded for ages, and as a result, accumulation may attain a considerable thickness. Deposits of such fossil diatoms are known as the diatomaceous earth, which are found distributed all over the world.

12.5 VEGETATIVE BODY OF BACILLARIOPHYCEAE

Diatoms are usually unicellular and display a great diversity of forms, but sometimes cells are united together to form simple filamentous or branched colonies. Each cell of a living diatom or its wall alone is called a frustule, which consists of two overlapping halves or valves that fit together like a pair of Petri dishes. The outer valve is called epitheca and the inner, hypotheca. Each frustule thus presents two different views, namely girdle view and valve view, according to the position in which it is observed. Both the valves of a frustule have their outer walls strongly silicified and made up of an organic matrix chiefly consisting of pectin, there being no micro chemical reaction for cellulose. The siliceous deposit on a valve is not uniform but in the form of numerous fine transverse markings or ribs and also as small protuberances and areolae. The areolae may consist of minute vertical pores as incomplete canals which do not perforate the wall completely.

They are seldom perforated by minute pores through which mucilaginous secretion comes out. The ornamentation is either radially symmetrical with reference to a central point (Centric diatoms), or bilaterally symmetrical or asymmetrical with respect to a long axis (Pennate diatoms). Lying internal to the cell wall, there is a thick layer of cytoplasm as a primordial utricle surrounding a conspicuous central vacuole and containing one or more chromatophores, with or without one to several pyrenoids. There is only one spherical to ovoid nucleus of the normal type embedded in the peripheral layer of cytoplasm of it is suspended in a mass of cytoplasm at the centre of the vacuole and is connected to the peripheral layer by means of broad cytoplasmic strands.

The chromatophores are mostly rich golden brown in colour and vary in shape and number from species to species. This particular colour of the chromatophores is due to the presence of a special pigment, known as diatomin, which masks the photosynthetic pigments, chlorophyll and the associated carotenoids. Food reserves are in the form of fatty oil accumulated as droplets of variable size in the cytoplasm or in the chromatophores. Many planktonic unicellular diatoms -exhibit spontaneous movements, either as a series of jerks directed along the long axis of the cell or as forward and backward progression and retrogression, and these are also seen in some of the colonial forms. The common Indian species of Centric diatoms are Melosira varians, M. jurgensii, Coscinopiscus radiatus, etc., while those of Pennate ones are Synedra ulna, S. acus, Naviculastauroptera, N. viridis, Gomphonema acuminatum, Rhopalodiagibba, Asterionellaformosa, etc.

12.6 BACILLARIOPHYTA

Class : Bacillariophyceae

- This class is represented by approximately 200 genera and 600 species.
- Members are commonly known as diatoms and are commonly found in fresh water, water, in air or on soil.
- Thallus is unicellular, uninucleate diploid and show radial or bilateral symmetry.
- Cell wall is silicified. It shows characteristic secondary structures. It is often called the she or frustule.
- Frustule is made up of two overlapping halves. The upper larger half is called as the

epitheca, and the lower smaller overlapped half is called hypotheca.

- Cells generally possess many discoid or two plate like chromatophores.
- Members of this class are also called as golden brown algae because of their characteristic pigments which include carotenoids, fucoxanthin, diatomin (diatoxanthin, diadinoxanthin), beside chlorophyll a and chlorophyll C.
- The stored food products are in the form of oil, volutin chrysolaminarin.
- Cell shows gliding movement.
- Reproduction occurs by cell division and auxospore formation.
- Motile stages possess a single, anterior pantonematic flagellum.

Classification of Bacillariophyta:

The Bacillariophyta include the single class Bacillariophyceae which has been subdivided into two orders:

Pennales and Centrales.

Order: Centrales:

1. Thallus radially symmetrical.

2. Gliding movement absent.

3. Sexual reproduction anisogamous or oogamous.

Order Pennales is further divided into:

Family: Naviculoideae:

(i) Members are fresh water in habitat.

(ii) Valve view is boat shaped.

(iii) Raphe is present in both the valves.

Navicula:

Systematic Position:

Class: Bacillariophyceae

Order: Pennales

Family: Naviculoideae

Genus: Navicula

The Bacillariophyta include the single class Bacillariophyceae which has been subdivided into two orders:

Centrales

Valves circular, polygonal or irregular in outline and with an ornamentation on the wall; ornamentation radial or concentric about a central point; valves never have a raphe or pseudoraphe; protoplast with many chromatophores; statospores or microspores may be formed; auxospore formation mainly by oogamy. Ex.- Melosira.

Pennales

Valves bilaterally symmetrical or asymmetrical in surface view; wall ornamentation bilateral with respect to a line; valve always with a raphe or pseudoraphe; protoplast with one or two chromatophores; statospores or microspores are never formed; auxospore formation mainly by isogamy.Ex.- Navicula.

Occurrence:

Diatoms are found in all possible habitats. Commonly they are found in fresh water (Denticula tenuis, Naviculapupula, Meridioncirculare, Cymbellaventricosa, Melosiravariens, Amorpha ovalis etc.), sea water (Corethron, Biddulphia, Sceletonema, Fragilaria etc.) and soil (Pinnularia, Navicula, Frustulia etc.). The terrestrial species (Amorpha, Navicula, Pinnularia etc.) are able to withstand desiccation for a long period. Some diatoms (Gomphonima, Cymbella etc.) can grow as epiphyte. Licmophora, a member of diatom, grows endozoically.

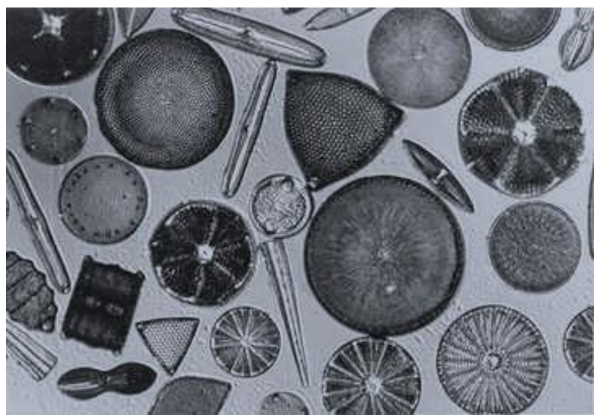


Fig.12.1 Ornamental shapes of different diatoms

Cell structure:

The cell consists of cell wall and protoplast. The cells are covered by a siliceous wall, the frustule. It consists of two overlapping halves, the theca. The upper one is epitheca and lower one is hypotheca. Both the theca consist of two portions: Valve- the upper flattened top and Connecting band or cingulum- the incurved region. The common region of the connecting bands, where both the theca remains fitted together, is the girdle. When the diatoms are observed from the valve side i.e., valve side is uppermost, called the valve view, but when viewed from the connecting band, it is the girdle view. Depending on symmetry, the cells are divided into two orders: Pennales (bilaterally symmetry) and Centrales (radially symmetry).

In some pinnate diatoms (Cybellacistula, Pinnulariaviridis etc.) an elongated slit is present on their valves, called raphe. The raphe is interrupted at its midpoint by thickening of the wall called central nodule. Similar thickening is also present at the ends called polar nodules. Some members like Tabellaria fenestrate etc. of the order Pennales, do not have raphe, called pseudoraphe. Besides raphe or pseudoraphe, the cell walls have other types of openings, called pores and locules. The cell wall is mainly made up of pectic substances, impregnated with silica. The content of silica varies from 1% (Phaeodactylumtricornutum) to about 50% on the basis of dry weight of the cell.

The entire content present inside the cell wall is the protoplast. The cell membrane encloses a large central vacuole surrounded by cytoplasm. The cytoplasm contains single nucleus, mitochondria, golgi bodies and chloroplasts. The chloroplasts may be of different shapes like stellate, H-shaped, discoid etc. In some species the chloroplasts contain pyrenoids. Depending on the mode of nutrition they may be photosynthetic autotrophs or photosynthetic symbionts or heterotrophs. The photosynthetic pigments are chlorophyll a, c1 and c2, β-carotene, fucoxanthin, diatoxanthin and diadinoxanthin. The latter two are present in small quantity. (The golden-brown colour of diatom cells is due to the presence of xanthophylls like fucoxanthin, diatoxanthin and diadinoxanthin. The term diatomin is used for the mixture of chlorophyll and carotenoids, particularly carotene and several brown xanthophylls pigments.) The reserve food of diatoms is chrysolaminarin and oil droplets (they do not store in the form of starch).

Movement:

All diatoms with raphe are motile. Most of the members of the order Pennales contain raphe and perform gliding movement. The gliding movement is caused by the circulation of cytoplasm within the raphe by the release of mucilage. The rate of movement varies from 02-25 μm/sec. The locomotion is affected by temperature, light etc.

Reproduction:

Diatoms reproduce vegetatively by cell division. During the process the protoplast of the mother cell swells up and the valves are slightly pushed apart. The nucleus now divides by mitosis into two daughter nuclei. Cytoplasm undergoes cleavage in such a way that each valve receives a daughter nucleus and a portion of cytoplasm. Then a new valve is secreted outside the daughter protoplast within each old valve. In this way two daughter cells are formed. These two daughter cells are unequal in size and one of the valves belongs to the parent cell and the other is newly formed. In the subsequent cell divisions, the sizes of the daughter cells successively become smaller and smaller.

When a certain definite minimum size is reached, a special mode of reproduction takes place by the formation of a special large rejuvenation takes place by the formation of a special large rejuvenating cell called auxospore such that the original size of the cell is regained. In Centric diatoms, the protoplast becomes about three times bulky by the absorption of water and the valves are widely pushed apart. This increased bulk of protoplast now secretes two overlapping valves and the entire structure thus formed is known as an auxospore. The auxospore divides vegetatively and gives rise to vegetative cells.

In Pennate diatoms, the auxospore is formed from the zygote which is the product of fusion of gametes produced by a single of two vegetative cells. Two conjugating diatoms come to lie close together and become enveloped by a common mucilaginous sheath. The diploid nucleus of each now divides by meiosis to form four haploid nuclei of which a single or two haploid daughter nuclei persist in each vegetative cell. Cytoplasm now collects around each of these daughter nuclei and in this way each vegetative cell gives rise to a single or two gametes. The gametes fuse sexually and give rise to a single or two zygotes and function as auxospores. Sometimes, two gametes are produced from a single vegetative cell, which fuse together to form zygote and auxospore.

12.7ECONOMIC IMPORTANCE OF BACILLARIOPHYCEAE:

The uses of the diatomaceous earth are very varied, viz. as a filtering material, as a substance used in insulation of boilers, blast furnaces, etc., as a cementing material, as a mild abrasive in metal polishes and toothpastes, as an absorbent for liquid nitroglycerine (the explosive material of the dynamite), and as a material for painting the ship to protect it against the attack of sea barnacles.

12.8 PERIDINIUM

Peridinium, genus of cosmopolitan freshwater dinoflagellates in the family Peridiniaceae, consisting of at least 62 species. Most are found in freshwater lakes, ponds, and pools, though some inhabit brackish environments. The genus was initially described in the early 1830s by German scientist Christian Gottfried Ehrenberg, making it one of the first known groups of dinoflagellates.***Peridinium*** is a genus of motile, marine and freshwaterdinoflagellates. Their morphology is considered typical of the armoured dinoflagellates, and their form is commonly used in diagrams of a dinoflagellate's structure. *Peridinium* can range from 30 to 70 μm in diameter, and has very thick thecal plates.

Most *Peridinium* are circular or oval-shaped, range in colour from green to yellow or brown, and vary from about 0.01 to more than 0.1 mm (0.0004–0.004 inch) in diameter. The cell has a theca (tough outer covering) that is divided into two parts, an epitheca and a hypotheca, which are roughly equal in size and are separated by a deep groove known as the cingulum (or girdle); the cingulum frequently is offset, forming a jagged band across the cell. Extending from the cingulum through the h

ypotheca is a second large groove, the sulcus (which sometimes projects a short distance into the epitheca). Some species have short apical horns (at the top of the epitheca) or antapical horns (on the bottom of hypotheca). Both the epitheca and the hypotheca are divided into angular plates, the specific arrangement and ornamentation of which are key features of the genus. Characteristic of dinoflagellates, from the cingulum and sulcus of *Peridinium* emerge two flagella, which help to control movement through the water. Though motile, *Peridinium* also exist in planktonic (free-floating) and nonmotile states.

Morphology

Peridinium is enclosed by cellulose theca and with two flagellates. The composition of the theca is laminaribiose and laminaritriose linking by $\beta - 1,\ 4$ and $\beta - 1,\ 3$ linkages.[4] The cell body of *Peridinium* is highly polarized and is distinguishable from apical and antapical sides or dorsal and ventral sides. Their theca is divided into epicone and hypocone by the middle region (also called girdle or cingulum). The flagellates have two different directions, one is surrounding the middle region while the other are in the longitudinal groove of hypocone. The chloroplast in *Peridinium* is triple membrane, and some plastid-derived organelles like pyrenoid or eyespot also. This provides the evidence that these organelles originated from secondary endosymbiosis. The inner membrane of mitochondrion is tubular. Trichocyst is a specialized organelle in dinoflagellate which help them defense to predators.

Life cycle

Peridinium is a haplontic algae. Most time of *Peridinium* are haploid vegetative cells and undergoing asexual or sexual cycle. They only form zygote before dormancy. In asexual cycle, the haploid vegetative cell throws the theca before mitosis and produces two daughter cells by mitosis. During mitosis, the chromosome in their nucleus condenses but the nucleus of endosymbiont doesn't. After the cleavage furrow starts to separate their nucleus, the nucleus of endosymbiont then passes through the gaps between cleavage furrow and their nucleus. Then the nucleus of endosymbiont was divided by cleavage furrow together.

In sexual cycle, they produce gametes as isogamete and the gametes fuse to form planozygotes to get dormancy. After dormancy, the zygote starts to undergo meiosis. The first meiosis produces a two diploid nuclei cell without cytokinesis. An asynchronized nucleus division then occurs in one of the two nuclei. One nucleus undergoing second meiosis before cytokinesis in first meiosis and turns into a trinucleate stage. After it, the cytokinesis of first meiosis is completed, and the trinucleate cell is divided into a diploid nucleus cell and a double haploid nuclei cell. When the cytokinesis of second meiosis is completed, finally, it produces four haploid daughter cells.

Overall, *Peridinium* dominants in mobile haploid generation. Between spring and summer, the haploid venerative cells produce gametes by mitosis and fuse gametes into a diploid planozygote. The diploid planozygotes then transform into immobile hypnozygotes and deposit to get dormancy in winter. After a year, the hypnozygotes germinate in spring and release haploid vegetative cells.

Ecology

Peridiniumgatunense blooms in the Lake Kinneret in Israel which changing the color of the lake is discovered in 1960. The blooming event occurs because the organic mineral is flushed into the sea every year in spring. Organic mineral nourishes the diatom and increases their population. Thus, the planozygotes of *Peridinium* break dormancy and release thousands of vegetative cells into the sea by feeding on diatom. From 1960 to 1996, the annual pattern was regularly peaked at spring in each year. But starting from 1996, the blooming was broken. The break of blooming is related to high temperature, other phytoplanktonic competitor (*Chytrid* or *Microcystis*), and human activities in the aquatic system by managing the water flow of the river.

12.9 CERATIUM

The genus ***Ceratium*** is restricted to a small number (about 7) of freshwater dinoflagellate species. Previously the genus contained also a large number of marine dinoflagellate species. However, these marine species have now been assigned to a new genus called Tripos. *Ceratium* dinoflagellates are characterized by their armored plates, two flagella, and horns. They are found worldwide and are of concern due to their blooms.

Taxonomy

The genus was originally published in 1793 by Shrank, F. von Paula. The taxonomy of C*eratium* varies among several sources. One source states the taxonomy as: Kingdom Chromista, Phylum Miozoa, Class Dinophyceae, Order Gonyaulacales, and Family Ceratiaceae. Another source lists the taxonomy as Kingdom Protozoa, Phylum Dinoflagellata, Class Dinophyceae, Order Gonyaulacales, and Family Ceratiaceae. The taxonomic information listed on the right includes Kingdom Chromalveolate. Thus, sources disagree on the higher levels of classification, but agree on lower levels.

C. furcoides was originally named C. hirundinella var. *furcoides* Levander 1894, but is now *C. furcoides* (Levander) Langhans 1925. It - and *C. hirundinella* - are invasives in several river basins in South America.

Appearance

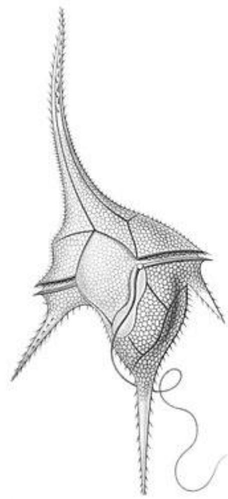


Fig.*12.2 Ceratiumhirundinella*. *Ceratium* species are characterized by their horns and two flagella located in the transverse and longitudinal positions.

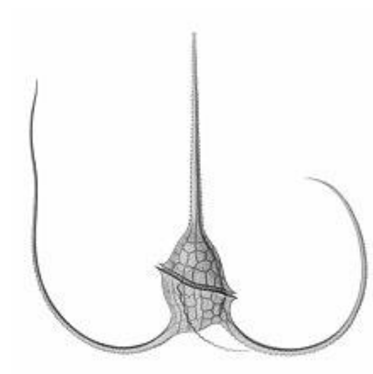


Fig.12.3 *Ceratium tripos* is recognisable by its U-shaped horns

Ceratium species belong to the group of dinoflagellates known as dinophysiales, meaning they contain armored plates.[2] They contain a pellicle, which is a shell, that is made from the cell membrane and vesicles; vesicles are composed of cross-linked cellulose, forming the plates. The pellicle divides into two structures known as the epicone and hypocone that lie above and below the transverse groove, the cingulum, respectively. Two rows of plates surround the epicone and hypocone in a particular pattern that may be inherited by offspring. These patterns may be used to identify groups of dinoflagellates or even species of *Ceratium.*

The plates contain expanded horns, which is a characteristic feature of *Ceratium* species. Species tend to have different shaped horns depending whether they are freshwater or marine species. Their morphology depends on the temperature and salinity of the surrounding environment. Species can be identified based on the shape of their horns. For instance, the species Ceratium tripos has horns that are U-shaped.

Species of *Ceratium* contain two flagella of different lengths that are orientated in the transverse and longitudinal positions. The transverse flagellum is structurally complex and wraps around the cingulum. The movement of the flagellum is described as "wave-like" and allows the organism to spin as it swims. The longitudinal flagellum extends from a groove known as the sulcus, and this flagellum is simpler in structure than the transverse flagellum. The movement of this flagellum pulls the organism forward, but ultimately its movement is controlled by the viscosity of the water.

Species of *Ceratium* have other structures called chromatophores, which contain red, brown, and yellow pigments used for photosynthesis. The average size of a *Ceratium* dinoflagellate is between 20–200 μm in length, which classifies it as belonging to the microplankton size category.

Life cycle

Reproduction

Ceratiums have zygotic meiosis in their alternation of generation. *Ceratium* dinoflagellates may reproduce sexually (two parent cells) or asexually (one parent cell). In asexual reproduction, the pellicle (shell) pulls apart and exposes the naked cell. The cell then increases in size and divides, creating 4–8 daughter cells, each with two flagella. The nuclear membrane is present throughout the process and the centrioles are not present, unlike many other eukaryotic organisms. The nuclear membrane only divides when the waist of the organism constricts.

In sexual reproduction, the cells of two organisms couple close to their sulci (longitudinal groove). Meiosis occurs, which allows the chromosomes given by the haploid parents to pair. Then diploid offspring, known as "swarmers", are released.

Growth

Species of *Ceratium* are mixotrophic, meaning they are both photosyntheticand heterotrophic, consuming other plankton. *Ceratium*dinoflagellates have a unique adaptation that allows them to store compounds in a vacuole that they can use for growth when nutrients become unavailable. They are also known to move actively in the water column to receive maximum sunlight and nutrients for growth. Another adaptation that helps growth includes the ability to extend appendages during the day which contain chloroplasts to absorb light for photosynthesis. At night, these organisms retract these appendages and move to deeper layers of the water column.

Distribution and habitat

Geographic

Species of *Ceratium* are found across high and low latitudes, but are commonly found in temperate latitudes. Marine species found in warmer tropical seas in lower latitudes tend to have more branched horns than marine species found in the cold waters of higher latitudes. The warm water of the tropics is less viscous, so marine species of *Ceratium* contain more branched horns in order to remain suspended in the water column. The main function for the horns is to maintain buoyancy.

Seasonal

As lakes and ponds stratify in the summer due to a decrease in mixing, freshwater species of *Ceratium* tend to dominate the water column.

Ecology

Ceratium sp. are generally considered harmless and produce non-toxic chemicals. Under certain conditions that promote rapid growth of the population, *Ceratium* sp. blooms known as Red Tides can deplete the resources and nutrients of the surrounding environment. These blooms also deplete the dissolved oxygen in the water, which is known to cause fish kills.

Fig.12.4 Fish kills result from depleting oxygen levels caused by *Ceratium* blooms.

These dinoflagellates play important roles at the base of the food web. They are sources of nutrients for larger organisms and also prey on smaller organisms such as diatoms.

12.10 HUMAN USE AND IMPACT

Worldwide, especially in higher latitudes, the frequency of red tides has increased, which may be due to human impacts on the coasts in terms of pollution. As a result, dead fish from the oxygen-depleted water wash up on beaches, much to the dismay of people at resorts and hotels.The migration of these species has been impacted by global warming. Because the surface temperature of the ocean rises, these organisms move to deeper layers of the water column as they are temperature sensitive. Due to this behavior, species of *Ceratium* are used as biological indicators because the deeper they are found in the water column, the greater the impact from global warming.

12.11 SUMMARY

Under this unit we have summarized the characteristics of Bacillariophyceae, **occurrence, distribution and its economic importance.**.The diatoms (Bacillariophyta) are the most species-rich group of autotrophic algae, found in fresh, brackish, and marine waters worldwide, and also in damp terrestrial habitats. They are well represented in marine phytoplankton and may account for 20% of global photosynthetic carbon fixation. However, the vast majority of the estimated 100,000 species are benthic, living attached to surfaces or gliding over sediments using a unique organelle, the raphe system.Further we have discussed *Peridinium* and *Ceratium* in this unit.*Peridinium* is a dinoflagellate with thick, armored plates that are often lobed and ornamented. The sutures are quite noticeable, and the cingulum is nearly at the cell median. The cells may be generally round to oval-shaped or flattened, with a convex dorsal surface and a concave ventral surface. Some species (such as *Peridinium limbatum*) have distinctive horns. The genus has over 30 species, most of which are photosynthetic.

Ceratium is a unicellular organism and a member of the family Ceratiaceae, commonly known as dinoflagellates. Dinoflagellates are usually considered algae but mostly are marine planktons. Ceratiumgenus comprises a rather small number of about 7 freshwater dinoflagellate species. The characteristics of Ceratium dinoflagellates include their horns, two flagella and armoured plates.Diatoms are a vital food source for aquatic species. It's also used in dental pastes and metal polishes as a cleaning agent. They are used in the production of alcohols, sugar filtering, antibiotics, and syrups. Refrigerators, furnaces, and boilers use them as insulating materials.

12.12 TERMINAL QUESTIONS

Q.1 What do you mean bymain characteristics of Bacillariophyceae ?

Answer:---

Q.2 Describe the salient features of Bacillariophyceae.

Answer:---

Q.3 Describe the occurrence and distribution of Bacillariophyceae.

Answer:---

Q.4 Write short notes on the followings.

(a) Peridinium

(b) Ceratium

Answer:---

Q.5 Write short on the followings.

(a) Bacillariophyta

(b) Economic importance of Bacillariophyceae.

Answer:---

Q.6 Explain economic importance of Bacillariophyceae.

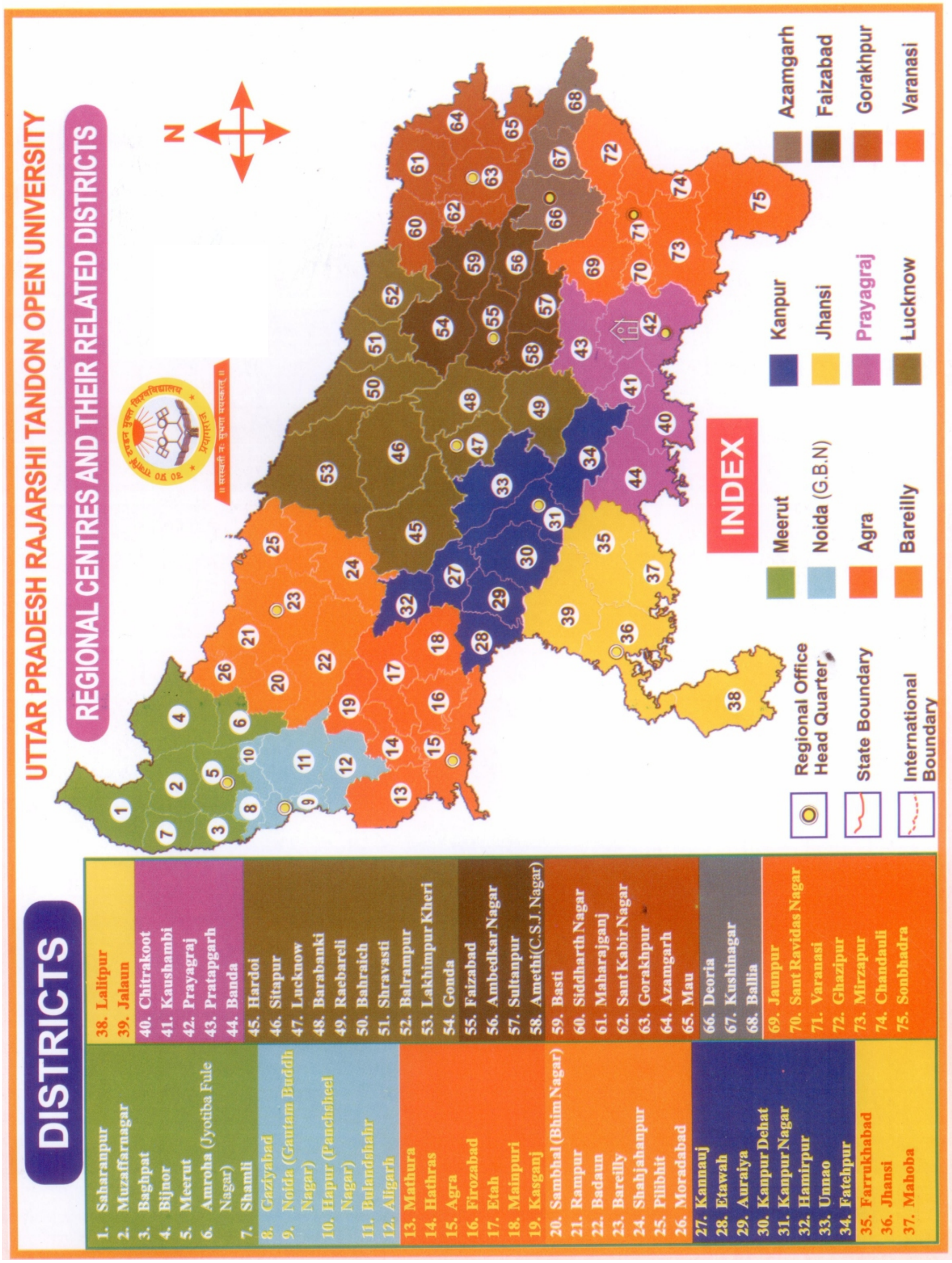
Answer:---

Q.7 Describe the classification of Bacillariophyceae.

Answer:---

FURTHER READINGS

- Text book of Botany – Singh -Pande-Jain.
- The elements of Botany- James Hewetson Wilson
- Textbook of Biotechnology –H. K. Das
- Biochemistry- Lehninger A.L.
- Biochemistry and molecular biology- Wilson Walker



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