Indira Gandhi National
Open University
School of Sciences

BBYCT-131
BIODIVERSITY (MICROBES, ALGAE, FUNGI AND ARCHEGONIATES)

Block

2

ALGAE

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BLOCK 2 : ALGAE

In the previous Block 1, you were introduced to the world of Microbes – Viruses and Bacteria. In the four units of this block you will be studying a heterogeneous group of organisms that are photosynthetic. Algae exert profound effects in today's world and they have been doing so for billions of years. For example, as a result of their photosynthetic activities, algae generate a very large fraction of oxygen present in Earth's atmosphere. They also produce an enormous quantity of organic carbon. Much of this organic carbon serves as food for several other organisms.

The variety and structural organisation as well as the general biology of algae have attracted biologists to choose algae for investigations as models for understanding the biological processes found in higher plants. Warburg chose a single-celled green alga, *Chlorella* for measuring light energy requirement for photosynthesis in relation to oxygen production. Calvin elucidated the path of carbon during carbon fixation. Emerson discovered the importance of accessory pigments in photosynthesis by using blue-green and red algae.

In the field of cellular differentiation, development and its control, *Fucus* eggs were expensively used. *Acetabularia* is still preferred alga for studying the relative roles of nucleus and cytoplasm at molecular level.

Chlorella, *Scenedesmus* and *Spirulina* are used for mass scale substitute for food and as a source of protein especially in times of war. Since time immemorial people have been either collecting algal seaweeds from nature or artificially farming them in coastal seawater. Algae are source of a wide variety of metabolic products. Through the extensive use of biotechnology such useful compounds are manufactured from algae and are being used in pharmaceutical, textile, beverage industries. Gelling agents like agar-agar, alginic acid for ice-creams and other products can be manufactured from algae.

Algae are also used as biofertilizer; for example, nitrogen fixing algae which farmers grow to enrich their soil.

The modern life style of man is heavily dependent on fossil fuels that were formed millions of years ago. Modern biotechnology and engineering are developing new ways to generate sustainable fuels by using algae. Such algae-originated biofuels may help reduce burden for fast depleting fossil fuels.

From the account given above we believe that you can appreciate why algae should be studied in detail.

There are four units in this Block.

Unit 5 Algae : Introduction

Unit 6 Algae : Organisation, Reproduction and Classification

Unit 7 Algae : Morphology and Life Cycles

Unit 8 Algae : Economic Importance

Objectives

After studying this block, you should be able to :

- describe the cellular and organisational characteristics in algae;
- discuss the range of thallus organisation in algae;
- compare the types of reproduction and life-cycle patterns in algae;
- explain the characteristics in the life cycles of representative algal forms;
- discuss various habitats and distribution of algae; and
- describe the importance of algae in human welfare.

UNIT 5

ALGAE: INTRODUCTION

Structure

5.1 INTRODUCTION

In this unit you would get an overview of algae, their habitat, distribution, morphology and cellular structure. The study of algae is known as Phycology, derived from Greek word *Phykos* meaning seaweed. As a group, algae show a lot of variation in their habit, habitat, morphology, mode of reproduction and life cycles. This diversity of form and structure make them competent to survive in a diverse range of environmental conditions. They are found in habitats such as crevices of rocks, deserts, fresh as well as marine water. Algae can exist as free living organisms and also in symbiotic association with fungi to form lichens.

Objectives

After studying this unit, you will be able to:

- list characteristic features of algae;
- comment on the type of plastids and photosynthetic pigments found in algae;
- describe the various types of habitats of algae and give examples of each;
- describe and give examples of different algal associations with plants and animals; and
- elaborate upon the ecological relevance of algae.

5.2 GENERAL CHARACTERISTICS

Algae comprise an assemblage of organisms that are chlorophyllous, autotrophic thallophytes. Their body is not differentiated into true root and shoot systems, and hence is called a thallus. They exist in a range of morphologically diverse forms. They are found as unicellular cyanobacteria to multicellular, complex, highly differentiated eukaryotic thalloid and polysiphonoid forms. At cellular level, algae exist as simple prokaryotes with no membrane bound organelles, and also as typical eukaryotic cells with well organised microanatomy and also possess flagella that confers motility upon some algae. To classify algae and assign them their correct taxonomic position, a combination of characteristics are used by phycologists such as composition of photosynthetic pigments, storage products, and organisation of organelle membranes. There is a lot of ambiguity in taxonomic position of algae as they show some affinities to Plant Kingdom (presence of photosynthetic pigments and autotrophic mode of nutrition) but at the same time they have some characteristics that make them near to Protists and hence in the Five-Kingdom System of classification all eukaryotic algae have been put in the Kingdom Protista. This is clearly an artificial grouping, for some of the green algae are more related to true plants than to other algae. Some algal members such as the unicellular euglenoids and cryptomonads are probably protozoans that have acquired plastids through endosymbiosis. Indeed of the 36 genera of euglenoids 25 genera do not possess chloroplasts and live as heterotrophs. You shall read in detail the classification of algae in Unit 6. There are about 24,000 species of algae described so far.

5.2.1 Habitat

Free living algae exist in diverse environmental conditions predominantly in aquatic conditions. However, they are found growing luxuriantly in damp areas with ample water. Fresh water species occur in ponds, streams, lakes and even inside water tanks. They grow on rocks, tree trunks, crevices and on damp soil. The marine forms are found growing attached to the sea rocks and on bed and are known as seaweeds. Some of the marine forms are also free floating. In fact the free floating, unicellular forms constitute the phytoplankton of oceans and lakes. Some forms exist in a symbiotic relationship with fungi to form lichens, e.g., *Nostoc, Gloeocapsa, Scytonema* and many others. They are also found living on other plants and are known as epiphytes, and on other animals and are known as epizoic. Some species such as *Anabaena* grow as endophytes in coralloid roots of *Cycas* and in leaves of *Azolla*. Algae that are attached to the bottom of lakes and oceans form Benthon. Distribution of algae in different habitats has been discussed in detail in Section 5.3.

5.2.2 Habit

The plant body ranges from simple prokaryotic unicellular forms (*Nostoc*) to highly differentiated thalloid forms *Fucus*. In fact Prokaryotic non motile unicellular forms are more closely related to bacteria and only on the basis of presence of chlorophyll they are grouped with algae. Some unicellular eukaryotic forms that exist as free-living forms are also motile, e.g., *Chlamydomonas*. These unicells are associated with each other and form colonies of various number of cells. The colonies may be motile or non motile and show variation in the number of cells and their arrangement. Sometimes the number of cells in a colony can be restricted, e.g., tetrasporal groups such as *Microcystis* that have only 4 cells per colony. The colonies can be arranged as a plate, e.g., *Gonium*, or are in mucilaginous spheres, e.g., *Volvox*. Some colonies are macroscopic and may be seen without the help of microscope. The unicellular forms may be non-motile that may be rhizoidal, e.g., *Rhizochrysis* or protococcoidal, e.g., *Synechococcus*. You shall read in detail about these in Unit 6.

Filamentous forms may exist as simple unbranched free living filaments as seen in *Nostoc* or may exist as unbranched filaments showing differentiation of the lower most cells into anchoring organs called holdfast as seen in *Oedogonium*. Genera such as *Coleochaete* and *Ectocarpus* show a heterotrichous form of habit, wherein the thallus has a prostrate system attached to the substratum and an erect system emanating from the former. Thalli of *Polysiphonia* and *Fucus* show a higher degree of differentiation. *Polysiphonia*, a marine red alga has an arrangement wherein the main plant body has a central siphon surrounded by pericentral siphons.

5.2.3 Cell Structure: Prokaryotic and Eukaryotic Forms

Based upon its internal organisation, algae are divided into two categories, i.e., prokaryotic and eukaryotic. Algae with prokaryotic cells have lack of well differentiated, membrane bound organelles. Organelles such as nucleus, mitochondria, dictyosomes and flagella are absent from the cells of prokaryotic algae, e.g., cyanobacteria. Except members of Cyanophyceae, all other divisions of algae have eukaryotic cells wherein cells possess nucleus, chloroplasts, mitochondria and pyrenoids. Detailed description of prokaryotic and eukaryotic algal cells has been given in Unit 6. In this Unit we shall discuss about general distribution of different types of plastids, photosynthetic pigments, storage products in algae.

5.2.4 Plastids

Plastids are membrane bound organelles that has different pigments and performs a range of functions such as photosynthesis and storage. Characteristic colours of different genera of algae are due to the presence of pigments such as cholorophylls, xanthophylls and many others. Microanatomy of the chloroplasts have membranous vesicles that are flattened and are known as thylakoids. These may be arranged in stacks or may be free. Phycobilisomes are present in these thylakoids and contains phycobili proteins, phycoerythrin and phycocyanins. Algae show various arrangements of phycobilisomes on the thylakoids. Different groups of algae show a lot of variation in the ultrastructure of the plastids (Fig. 5.1). Plastids in Cholorophyta and Rhodophyta are bound by double membrane. In some eukaryotic algae the choloroplast envelope membrane is surrounded by a choloroplast ER that has ribosomes attached to it. Members of Dinophyta and Euglenophyta have one choloroplast ER membrane. Two membranes of choloroplast ER are found in Cryptophyta and Heterokontophyta, in which the outer of the two membranes is continuous with outer membrane nuclear envelope.

5.2.5 Photosynthetic Pigments

Distribution of photosynthetic pigments in different groups of algae is an important feature of algae. Algae have a range of photosynthetic pigments such as chlorophyll a, b, c (c1 and c2) and d. Chlorophyll a is found in all photosynthetic algae and other forms of chlorophylls show skewed distribution in different groups. Members of Euglenophyta and Cholophyta have predominantly chlorophyll b, whereas those of Dinophyta and Cryptophyta and Heterokontophyta have chlorophyll c. Of the two forms of chlorophyll c, c2 is always present. Chlorophyll d is found only in some cyanobacteria and red algae. In addition to chlorophylls, brown and red algae have special antennae pigments that help them capture light of different wavelengths. Members of Phaeophyta have β-carotene and fucoxanthin along with chlorophyll a and c. Rhodophyta get their characteristic red color due to r-phycoerythrin, r-phycocyanin, carotenes and xanthophylls in addition to chlorophyll a and d.

5.2.6 Storage Products

Different groups of algae vary in the forms of their storage products. Algae convert their primary photosynthetic products into polysaccharide compounds such as starch, laminarin. Additionally, they also are low and high molecular weight glucans and low molecular weight compounds. Storage products of algae can be classified on the basis of the molecular weight of the compounds, and are categorised as low molecular weight and high molecular weight compounds. These are further divided into sub-types. Given below is the list of compounds and the groups of algae that store them.

1. Low Molecular Weight compounds
   a. Sugars, e.g., Sucrose – Chlorophyta
      Trehalose – Cyanophyta
   b. Glycosides – Rhodophyta
   c. Polyols, e.g., Mannitol – Rhodophyta and Phaeophyta

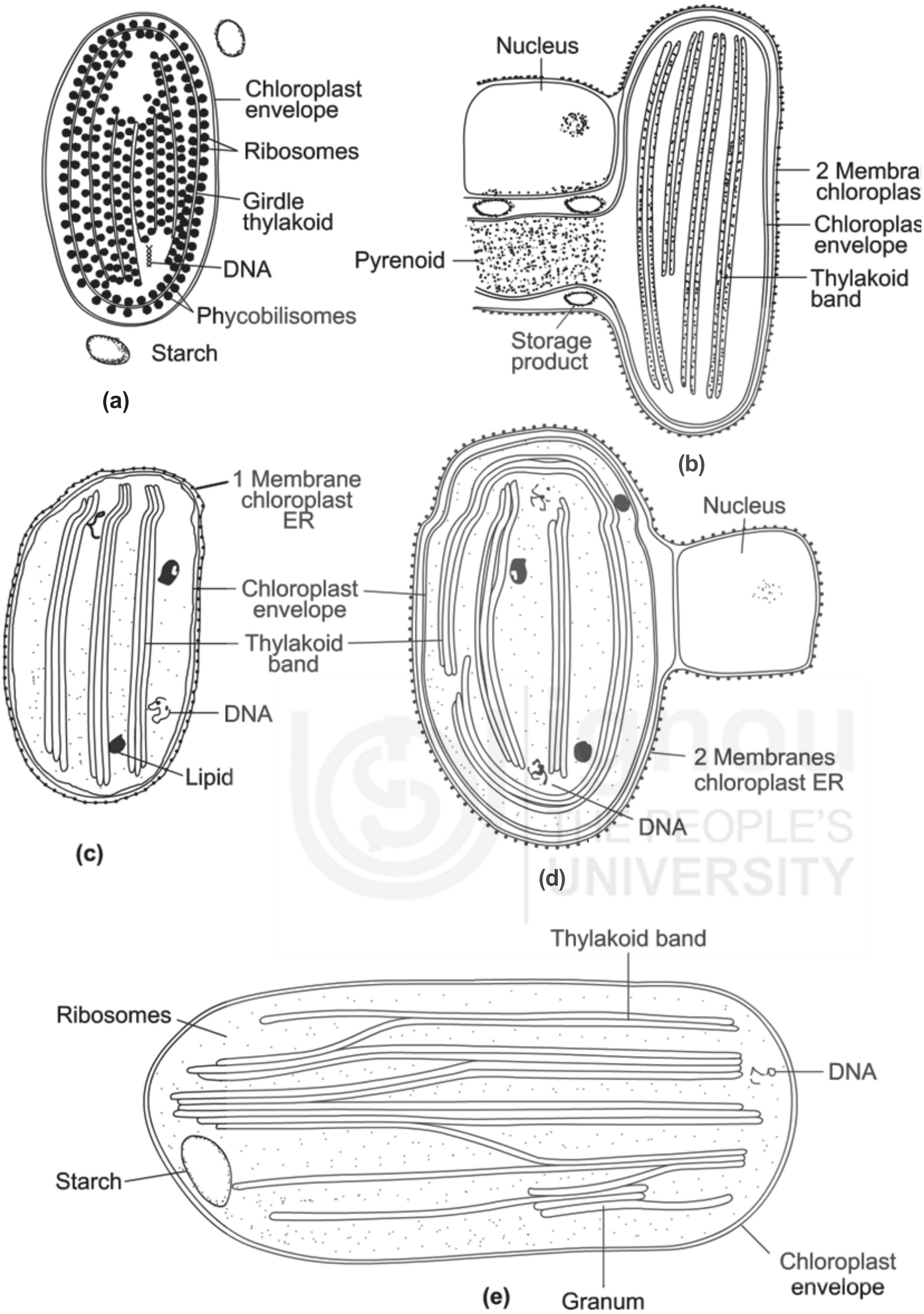

Fig. 5.1 (a-e) : Diagrammatic representation of different types of chloroplast structures found in eukaryotic algae. a) Rhodophyta: One thylakoid per band, absence of chloroplast endoplasmic reticulum (ER); b) Cryptophyta: Two thylakoids per band and two membranes of chloroplast ER; c) Dinophyta and Euglenophyta: Three thylakoids per band and one chloroplast ER membrane; d) Heterokontophyta: Three thylakoids per band and two membranes of chloroplast ER; e) Chlorophyta: 2-6 thylakoids per band and no chloroplast ER.

***Source*: Lee, 1989.**

2. High Molecular Weight compounds

   a. α, 1$\rightarrow$ 4-linked glucans

      - Floridean Starch – Rhodophyta
      - Myxophycean starch – Cyanophyta
      - Starch – Chlorophyta, Charophyta, both form amylose and amylopectin

   b. α, 1$\rightarrow$ 3-linked

      - Laminarins – Phaeophyta
      - Chrysolaminarin – Chlorophyceae and Bacillariophyceae
      - Paramylon – Euglenophyta, Xanthophyta
      - Fructosan – *Acetabularia*, a member of Chlorophyta

Table 5.1 : Some important Divisions of Algae and their Key Characteristic Features

Division	Cell Type	Type of Plastids	Pigments	Storage Product
Cyanophyta	Prokaryotic	NA	Chlorophyll a, c-phycocyanin, c-phycoerythrin, myxoxanthin, myxoxanthophyll	Myxophycean and cyanophycean starch
Chlorophyta	Eukaryotic	2-6 thylakoids per band and no chloroplast ER	Chlorophyll a and b	Starch
Euglenophyta	Eukaryotic	Three thylakoids per band and one Chloroplast ER membrane	Chlorophyll a and b, β-carotene, xanthophylls	Paramylum
Bacillariophyta	Eukaryotic	Chloroplasts surrounded by two membranes of chloroplast Endoplasmic Reticulum	Chlorophyll a c, β-carotene, xanthophylls, e-carotene	Leucosin

Division	Cell Type	Type of Plastids	Pigments	Storage Product
Phaeophyta	Eukaryotic	Chloroplasts surrounded by two membranes of chloroplast Endoplasmic Reticulum	Chlorophyll a,c, β-carotene, fucoxanthin	Laminarin, mannitol
Rhodophyta	Eukaryotic	One thylakoid per band, absence of chloroplast ER	Chlorophyll a, d, r-phycoerythrin, r-phycocyanin, xanthophylls lutein	Floridean starch

SAQ 1

Fill in the blanks:

i) Plastids in ………… possess 2-6 thylakoids per band and no endoplasmic reticulum (ER).

ii) ………… and ………… are characteristic photosynthetic pigments of Rhodophyta.

iii) Algal storage products with low molecular weight are …………, ………… and ………… .

iv) Members of Phaeophyta store their food in the form of high molecular weight compounds ………… .

v) Algae that grow on other animals are called ………… .

5.3 ECOLOGY AND DISTRIBUTION

When we say algae are found everywhere it is no exaggeration. Wherever there is water, a little moisture or water vapours, and light, however feeble, they are sure to appear as green, yellow, or brown patches, which in course of time cover the whole surface. Their occurrence and growth is controlled by several factors and is the subject of science, Ecology. When several types of algae grow together under similar natural conditions we call them as communities. The composition of a community is determined by the physical and chemical nature of the habitat. In many cases the algal community indicates to us about the nature of the habitat, whether it is rich or poor in nutrients or is polluted, in other words it serves as an ecological indicator. In this section you will also learn how algae have adapted to the environment in which they are found growing by having special morphological and physiological features. We list below some important algal habitats found in nature.

5.3.1 Aquatic

Most of the algae grow in water in the absence of which they quickly dry up and die; however, there are also sub-aerial algae, which are described further in this Unit. Depending on the concentration of salts there are various kinds of water bodies, such as fresh water, brackish water, sea water, brine-salt lakes and salt pans. Further, these habitats now a days may contain many types of pollutants, like excessive organic matter, heavy metals, pesticides, industrial effluents which are produced and dumped into them by humans. This greatly affects the algae and other organisms present in the water.

Fresh Water

Fresh water habitats comprise of rivers, mountain streams, lakes, ponds, tanks, and temporary rainwater puddles. In our country, rice fields where standing water is present for several months are rich in nitrogen-fixing cyanobacteria such as *Rivularia, Gloeotrichia, Nostoc, Anabaena,* and some green algae *Oedogonium, Draparnaldiopsis, Chaetophora, Coleochaete,* desmids and diatoms.

In slow flowing rivers with rocky shores one may find many filamentous algae like *Spirogyra, Oedogonium* and *Cladophora* as extensive floating mats generally attached to the under water rock boulders. The surface of submerged rocks also show various types of attached epiphytic algae like diatoms, desmids and cyanobacteria. Algal flora also shows seasonal variation depending on the turbidity and rate of flow of water and other seasonal factors.

The algal flora in a lake shows different communities at different regions. Near the shores and at the bottom (benthos) thick mats of *Spirogyra, Oedogonium, Chara, Nitella* and a number of epiphytic algae like *Chaetophora, Coleochaete,* desmids, diatoms, colonial Cyanobacteria, *Cladophora* growing as tufts on the shells of animals are frequently found. Suspended in the upper layers of water, unicellular and colonial algae *Chlamydomonas, Volvox, Pandorina, Scenedesmus, Euglena,* diatoms, *Microcystis, Anabaena, Anabaenopsis* occur as phytoplankton. These algae are generally small, phototactic – moving up and down depending on the light conditions – floating during the day and sinking at the night. At times, when the water is rich in nutrients with optimum temperature and sunshine, one particular algal type *(Microcystis, Euglena)* multiplies very rapidly to dominate the other algae, resulting in water blooms (flowering of water). Such blooms can be harmful to the fish and other animals that grow in the water because they may consume all the oxygen in the water during the night. While seasonal water blooms are more common in temperate countries, in India and other tropical countries, permanent blooms of colonial Cyanobacterium *Microcystis* is most frequent. It forms thick, bluish-green suspension in many temple tanks and lakes making the water unfit for human needs.

Marine

Sea inhabits largest number of algae collectively known as seaweeds. Although India has a very long shoreline, it is only the rocky areas as found in Gujarat, Tamil Nadu, Andhra Pradesh, and in the islands of Andamans and Lakshadweep that have rich marine flora. Open sea away from the coast is rich in planktonic algae. Marine phytoplankton is rich in variety and its composition depends on the geographical location and seasons. Diatoms form the main bulk of phytoplankton, Dinophyta, Cyanophyta, silicoflagellates and other groups also occur but in less quantities. Sometimes, the sea water becomes coloured due to thick pink blooms of *Noctiluca* and some other algae. A cyanobacterial bloom of *Trichodesmium* may cover large area of the sea giving a red colour as in Red Sea. Occasionally, some dinoflagellates (toxic) multiply very fast and form blooms generally known as red tides. Phytoplanktons of the sea play an important role in the primary production of organic matter, photosynthetic carbon fixation and serves as food for crustaceans, fingerlings of many fishes and even whales. All marine living organisms are directly or indirectly dependent on the growth and activities of the phytoplankton. In recent years very minute organisms collectively known as picoplankton including *Chlorella nana, Micromonas,* and *Dolichomastix* have been found to play a very important role in the biological productivity of oceans.

Brines and Salt Lakes

Inland lakes like Sambhar Salt Lake in Rajasthan contains sodium chloride and other salts in saturating concentrations (brines). One can see in them thick floating blue-green scums of permanently growing cyanobacteria *Anabaena, Anabaenopsis* and unicellular green alga *Dunaliella.* The metabolism of these halophilic organisms is active only at high salt concentration.

Table 5.2: List of some important littoral seaweed found on Indian coasts

East Coast	
Chlorophyta (Green Algae)	*Ulva, Cladophora, Bryopsis, Acetabularia*
Phaeophyta (Brown Algae)	*Ectocarpus, Padina, Dictyopteris, Dictyota, Sargassum*
Rhodophyta (Red Algae)	*Chondria, Polysiphonia, Grateloupia, Porphyra, Gracilaria, Ceramium*
West Coast	
Chlorophyta (Green Algae)	*Chamaedoris, Ulva, Bryopsis, Acetabularia*
Phaeophyta (Brown Algae)	*Dictyopteris, Dictyota, Nemacystis*
Rhodophyta (Red Algae)	*Dasya, Laurencia, Helminthocladia*

5.3.2 Special Habitats

Algae are also found in special habitats where environmental conditions are in extreme.

Thermal Regions

Among the lower Himalayas and other mountains (Himachal Pradesh, Bihar, Odisha and Maharashtra) are found hot water thermal springs with temperatures ranging from 40° to 70°C which inhabit quite a number of algae, mainly cyanobacteria, *Mastigocladus laminosus, Synechococcus lividus, Oscillatoria* and *Phormidium.* Unlike in other algae, the growth and metabolism of the thermal algae are most active only at high temperatures.

Polar Regions

Algae can also grow under extremely cold climate conditions that prevail at Arctic and Antarctic regions. Among Cyanobacteria, *Nostoc* is most common, besides *Schizothrix* and *Oscillatoria.* Lichens with algal symbionts *(Collema)* are of common occurrence. Cyanobacteria and lichens grow and fix nitrogen under polar conditions. Indian expeditions to Antarctic have collected several types of algae mostly diatoms and Cyanobacteria.

On permanent snow fields where the surface is stable at least for a few weeks, abundant growth of algae is found giving red, brown or yellow colour to the snow. Red snow is caused by algae *Chlamydomonas nivalis* and *C. flavo-virens.*

5.3.3 Soil and Sub-aerial

Surface layers of soils all over the world provide a favourable substratum when wet for the growth of several types of algae. Terrestrial algae play a major role as primary colonisers on newly exposed areas and help in the establishment of other plants in the accumulation of humus. After the destruction of all life by the eruption of a volcano on the island of Krakatoa in 1883, the first organisms that appeared were Cyanobacteria like *Anabaena, Tolypothrix, Symploca* and *Lyngbya.* Soil algae grow profusely on damp or moist soil, although many of them can withstand prolonged and severe dry conditions. Many cyanobacteria *(Nostoc, Cylindrospermum, Porphyrosiphon, Scytonema, Tolypothrix, Stigonema, Aphanocapsa, Lyngbya, Phormidium)* green algae *(Oedogonium, Oedocladium, Uronema,* and other algae *(Botrydium, Vaucheria,* diatoms) grow on the surface of the soil, which is temporarily moist at least for brief time during the seasons. They form a crust over the surface of the soil, particularly cyanobacteria which have mucilagenous sheaths and prevent erosion of the top soil.

SAQ 2

a) Which of the following algae is found in the rice fields?

Sargassum, *Porphyra*, *Anabaena*, *Ulva*

b) Fill in the blank with the correct choice from the ones given below:

Volvox, Diatoms, *Coleochaete*, *Microcystis*

………… forms thick, bluish-green suspension in tanks and lakes making the water unfit for human needs.

c) In the following sentences fill in the blank spaces with appropriate words.

i) The algae that are found in slow moving water are .... and ....

ii) .... forms the main bulk of marine phytoplanktons.

iii) The colour of Red Sea water is due to ....

iv) ....is a picoplankton.

v) The most common algae of Arctic and Antarctic region is ....

vi) The species of *Chlamydomans* that give red colour to the snow are ....

5.4 ALGAL ASSOCIATIONS

Algae live associated with other plants and inside animals as described below.

5.4.1 Algal-Plant Associations

Algae are known to be associated with other plants, some as epiphytes attached to the outer surface and some inside the tissues as endophytes. Epiphytes are common in all the groups of aquatic algae. One interesting case is a green endophytic alga, *Cephaleuros* that grows just below the cuticle of leaves of tea (red rust disease of tea), coffee, mango, guava and other fruit bearing trees, as rusty red coloured patches. Another endophytic alga *Chlorochytrium* is found in the intercellular spaces of water plants *Lemna, Ceratophyllum* and *Elodea.* Several species of brown algae *Ectocarpus* and *Sphacelaria* grow as endophytes in larger kelps – *Laminaria* and *Cystoseira.*

5.4.2 Algal-Animal Associations

There are number of instances where algae are found growing inside the animals (endozoic). Green alga *Chlorella* is found inside the unicellular *Paramecium,* in the tentacles of *Hydra* and in sponges. In marine habitats, sea anemones, and some corals contain unicellular algae – zooxanthellae (Cryptophyta) and also some Dinophyta members. *Platymonas* (green alga) is found inside a marine worm *Convoluta.*

5.4.3 Algal-Symbiotic Associations

When an alga lives in close association with a non-photosynthetic organism (fungus or an animal), because of its ability to fix carbon photosynthetically some of the carbon fixation products like sugars may be absorbed by the non-photosynthetic host, while the alga in turn may get some sort of protection. This kind of mutually beneficial association is known as symbiosis. Where the alga is also a nitrogen-fixer as in some cyanobacteria, nitrogenous compounds are also available to the host organism along with carbon compounds. Several cyanobacteria and also some green algae occur in symbiotic association with fungi as distinct group known as lichens. Nitrogen-fixing cyanobacteria are found in symbiotic association with photosynthetically active plants, bryophytes, pteridophytes, gymnosperms and angiosperms.

SAQ 3

In the following statements fill in the blank spaces with appropriate words.

i) The algae that are primary colonisers on volcanic soils belong to the Division ....

ii) Thick layers of Cyanobacteria on the soil prevent soil erosion because of the presence of ....

iii) The alga ....lives inside *Paramecium.*

iv) .... is an example of endophytic alga found in intercellular spaces of water plants.

v) The red rust of tea is due to an alga of genus ....

5.5 ECOLOGICAL SIGNIFICANCE OF ALGAE

Algae play an important role in ecosystem dynamics of their respective habitats. Since they are cosmopolitan in distribution, their effect is seen in a diverse range of environmental conditions. As a group, they show a wide range of ecological amplitude for various factors (such as light, temperature, salinity) that makes them competent enough to survive in mediocre as well as harsh conditions. Algae may have both positive as well as negative influence on the other biotic and abiotic factors around them. In the following Section, we shall discuss the various positive and negative interactions that algae have with the environment and other organisms.

5.5.1 Nitrogen Fixation

Blue green algae are capable of fixing atmospheric nitrogen into nitrites and nitrates that makes nitrogen available to the plants. This property of algae makes them extremely important in agricultural systems where they facilitate availability of N_2 to plants. This also leads to an increase in the fertility of soil. Some important Nitrogen fixing algae are *Oscillatoria princeps*, *O. formosa*, *Anabaena* and *Nostoc*. Quiet often algae are used as fertilizers in rice fields to enhance the nitrogen content of soil.

5.5.2 Carbon Sequestration

Algae contribute significantly towards carbon fixation and are primary producers, particularly in aquatic ecosystems. They fix inorganic CO_2 from the atmosphere and convert it into organic carbon as carbohydrates. Their role in carbon fixation is now used by scientists to mitigate climate change by using them as CO_2 trapping agents.

5.5.3 Diatomite

Under favourable conditions, the frustules of dead diatom cells remain intact and accumulate at the bottom of water bodies. These deposits of diatomaceous earth are known as diatomite, and are used in several industries. It is used as filters in chemical industry, as insulators in boilers and in automobile polishing industry.

5.5.4 Effect of Algae on Soil Fertility and Structure

Members of red and brown algae are used as manure as they are rich in potassium. They may be directly ploughed and used as fertilizers or may be burnt and converted to ash and sprayed on fields. Species of *Turbinaria* are often used as fertilizers for palms. Some seaweeds also have positive influence on soil structure. They are used to increase binding property of clayey soils. Species of *Chara* are rich in calcium as they are encrusted with calcium carbonate. In some countries they are used in place of lime.

5.5.5 Waste Water and Sewage Treatment

Domestic sewage is rich in organic and inorganic nutrients and is very poor in oxygen. Algae such as *Chlamydomonas, Euglena* and *Chlorella* are used to degrade the waste into simpler compounds and reduce odour. Also increased rate of photosynthesis by these algae leads to a higher level of oxygen in sewage.

5.5.6 Algal Blooms

Discharge of nutrient rich effluents from industries into water bodies lead to their enrichment in phosphorous. The process is called eutrophication. Increased availability of nutrients lead to a spurt in the growth of free-floating microscopic algae such as *Anabaena*, *Microcystis* and *Aphanizomenon* known as algal blooms. In such aquatic bodies algae form a mat like covering on the surface of the water body that leads to depletion in the oxygen levels in the water. This is detrimental to aquatic life particularly fish.

5.5.7 Toxic Effects of Algae

Some marine algae produce toxins that sicken or kill other organisms. These toxins may be neurotoxins e.g., anatoxins, saxitoxins, hepatotoxins, e.g., mycrocystin, nodularin. Some of the toxin producing algae are *Phaeocystis pouchetii*, *Dinophysis forti*, *Prymnesium parvum*. Some Dinoflgellates produce ion-channel disrupters, e.g., ciguatoxin and maitotoxins that lead to fish poisoning.

SAQ 4

a) Write short notes on:

   i) Role of algae in soil fertility,

   ii) Algal blooms, and

   ii) Toxic effects of algae.

b) Given an example of each:

   i) Nitrogen fixing algae,

   ii) An alga that produces toxins,

   iii) Algae used for treatment of sewage, and

   iv) Algae rich in calcium.

5.6 SUMMARY

In this unit you have learnt that:

- Algae are an assemblage of organisms that share common characteristics such as autotrophic, photosynthetic thallophytes.
- They are cosmopolitan in distribution and occur in all habitats on the surface of the Earth wherever water or water vapours and sunlight are reasonably available.
- They show astounding ability to adapt themselves to the environmental conditions where they grow.
- Different groups of algae show variation in the distribution of photosynthetic pigments and storage products.
- Algae are an integral component of the ecosystem and have profound influence on other ecosystem components.
- Algae play a significant role in enhancing soil fertility and sewage treatment.
- Eutrophication of water bodies lead to a spurt in growth of algae known as algal bloom.

5.7 TERMINAL QUESTIONS

1. Describe the different types of plastids found in algae. Support your answer with suitable examples.
2. List various photosynthetic and accessory pigments found in algae and the groups they are present in.
3. “Algae can occupy a diverse range of habitats”. Justify this statement.
4. Elaborate upon the ecological role played by algae.

5.8 ANSWERS

Self-Assessment Questions

1. i) Chlorophyta
   ii) r-phycoerythrin, r-phycocyanin
   iii) sugars, glycosides, polyols
   iv) laminarins
   v) Epizoic
2. a) *Anabaena*
   b) *Microcystis*
   c) i) *Spirogyra, Oedogonium*, *Cladophora* (any two)
      ii) Diatoms
      iii) *Trichodesmium*
      iv) *Chlorella nana*, *Micromonas* and *Dolichomastix* (any one)

v) *Nostoc*

vi) *Chlamydomonas nivalis*, *C. flavo-virens.*

3. i) Cyanobacteria

   ii) mucilagenous sheath

   iii) *Chlorella*

   iv) *Chlorochytrium*

   v) *Cephaleuros*

4. a) i) Refer to Subsection 5.5.4

   ii) Refer to Subsection 5.5.6

   iii) Refer to Subsection 5.5.7

   b) i) *Anabaena*

   ii) *Phaeocystis pouchetii*

   iii) *Chlamydomonas*, *Euglena* and *Chlorella*

   iv) *Chara*

Terminal Questions

1. Refer to Subsection 5.2.4
2. Refer to Subsection 5.2.5
3. Refer to Section 5.3
4. Refer to Section 5.5

5.9 GLOSSARY

Algal Blooms : Spurt in the growth of free-floating algae in nutrient rich water bodies.

Benthic : Any organism found on the base of the water body.

Epiphytic algae : Algae that lives on other plants.

Epizoic algae : Algae that lives on other animals.

Parasitic algae : Algae that lives on other organisms and is detrimental to the host.

Phycobilin : Water soluble blue green or pink pigment found in Cyanophyta, Rhodophyta and Cryptophyta.

Picoplankton : Microscopic planktons that are less than 2 microns in diameter.

Red tides : Increased number of dinoflagellates makes the water body red in colour.

5.10 FURTHER READING

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UNIT 6

ALGAE : ORGANIZATION, REPRODUCTION AND CLASSIFICATION

Structure

6.1 INTRODUCTION

Algae are a heterogeneous group of plants that share common characters such as they are thallophytes, possess photosynthetic pigments, synthesize a range of storage products viz. starch, laminarin, paramylon, fructosan and others. They lack typical differentiation into root, stem and leaves and possess chlorophyll *a* as their primary photosynthetic pigment. Reproductive cells in algae are not covered. Algae being photosynthetic autotrophs were classified as plants earlier. However, due to absence of protective cells around their reproductive organs, they are no longer classified as plants, and have been placed in the kingdom Protista along with Protozoa. The study of algae is termed as Phycology or Algology. The term Phycology is derived from the Greek word *phykos*, which means seaweeds.

Algae are widely distributed in nature and thrive well in areas where there is plenty of water and sunshine. They can survive well in fresh, marine as well as brackish waters. Algae that occur on shores and coasts and are attached to a substratum are called as Benthic, and those that occur as free-living or suspended are known as Planktonic. Some genera also inhabit harsh habitats and are found growing in snow, deserts and hot springs. Although simple in structure, they exhibit great diversity in size and appearance. Their size ranges from simple microscopic to giant thallus extending several metres in length as in kelps. Algal morphology varies from simple unicellular form to complex thallus as found in seaweed. Algae are basically of two types: Prokaryotic and Eukaryotic. Ultrastructural investigations have revealed that blue-green algae have prokaryotic type of cellular organization and are more closely associated to bacteria than to other algae with which they were traditionally grouped. All other algae have eukaryotic cells. The reproductive processes found in algae are also discussed in this unit.

Objectives

After studying this unit you will be able to:

- list key identifying features of algae;
- describe the range of morphological forms of algae;
- list the distinguishing features of prokaryotic and eukaryotic algae;
- discuss the phenomenon of origin and evolution of sex in algae;
- describe and differentiate between the different types of asexual spores in algae;
- differentiate between isogamous, anisogamous and oogamous types of sexual reproduction in algae;
- draw and label the parts as seen in ultrastructure of cells of prokaryotic and eukaryotic algae;
- describe briefly the basic features of various cell organelles present in prokaryotic and eukaryotic algae;
- give salient features of classification in algae; and
- enumerate the key characteristics of various divisions of algae.

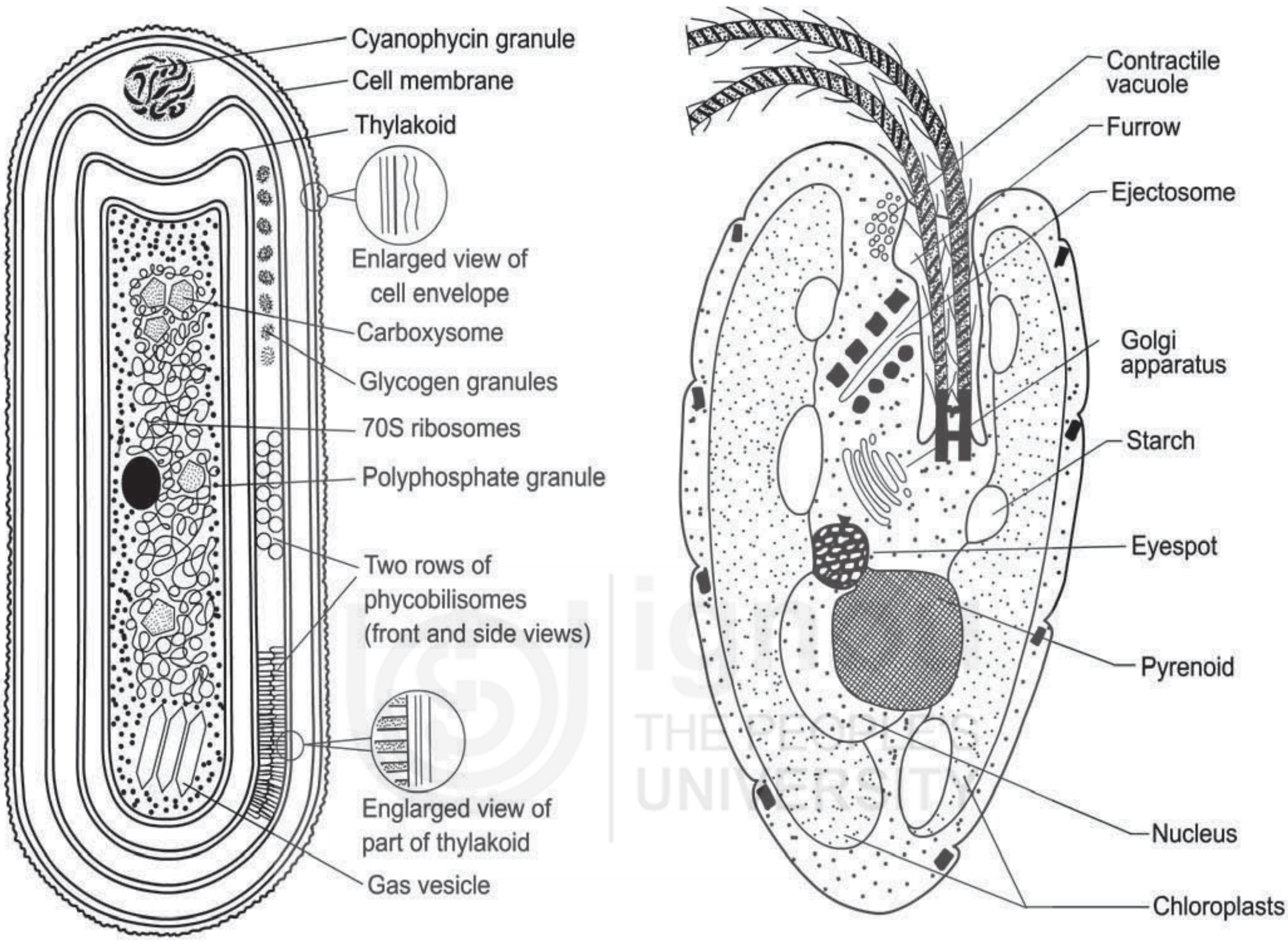
6.2 RANGE OF ORGANIZATION

6.2.1 Structure of an Algal Cell: Prokaryotic and Eukaryotic forms

Based upon its internal organization, algal cell is divided into two categories, prokaryotic and eukaryotic. Prokaryotic cells are characterized by the lack of well differentiated, membrane bound organelles. Organelles such as nucleus, mitochondria, dictyosomes and flagella are absent from the cells of prokaryotic algae. Blue green algae have prokaryotic cells.

Prokaryotic algal cell

Cyanobacteria or blue-green alga is a group of algae that have only prokaryotic cells. They have cell enclosed by plasma membrane containing non-membrane bound organelles (Fig. 6.1).



(a) (b)

Fig. 6.1 (a, b) : Diagrammatic representation of the ultrastructure of: a) a prokaryotic; and b) eukaryotic algal cell. Source: (a) Stanier and Cohen-Bazire, 1997; and (b) Dodge, 1973.

Cell Wall and Cell Sheath: The cells of Cyanobacteria are enveloped by a peptidogylcan layer outside the cell membrane. It has a complex structure made of a polymer of N-acetylmuramic acid and N-acetylglucosamine that are cross linked by peptides and other compounds. A periplasmic space surrounds the peptidoglycan layer that is further surrounded by an outer membrane. In many Cyanobacteria such as *Anabaena*, cell wall is enveloped by an additional mucilage sheath that helps them in gliding. In sub-aerial forms the sheath is thick, firm and colored yellow or orange brown and is multilayered. Some aquatic forms such as *Scytonema* and *Petalonema* may also have multilayered and coloured sheath.

Photosynthetic Lamellae: Cyanobacteria have no chloroplasts but only pigmented membranes which occupy the peripheral region of the cells called chroniatoplasm. In this area photosynthetic lamellae or thylakoids are present which are folded double membranes having photosynthetic pigments chlorophyll *a* and phycobiliproteins. On surface of the thylakoids are found rows of granules called phycobilisomes that contain phycocyanin, allophycocyanin and sometimes also phycoerythrin characteristic of Cyanobacteria. It has been found that the thylakoids also contain enzymes required for respiration.

Granular Inclusions of Cytoplasm: The ultrastructure of cyanobacterial cytoplasm shows several types of granules. Between the thylakoids glycogen granules of different size are present. Protein-like polymers occur as non-membrane bound granules and are called cyanophycin granules. They are made up of polymer of two amino acids aspartic acid and arginine and act as temporary storage sites of nitrogen. Another type of granule common in algae growing in waters rich in phosphate are polyphosphate granules, a storage form of phosphate. Some blue green algae also contain granules of polybetahydroxybutyrate as big crystals. Polyglucan granules, rich in polymers of glucose are found in space between thylakoids of actively photosynthesizing algae. Another unique granules found in cyanobacteria are polyhedral crystalline bodies known as carboxysomes. They are made up of ribulose-biphosphatecarboxylase (Rubisco) enzyme which is required for photosynthetic fixation of carbon dioxide. Like all bacterial cells Cyanobacteria also contain 70S ribosomes dispersed in the cytoplasm and are needed for protein synthesis.

Gas Vesicles: Also known as gas vacuoles, they are vesicles whose walls are made up of single layer of protein molecules and are permeable to gases but not to water. They are found in many planktonic Cyanobacteria such as *Microcystis*. They occur as elongated, cylindrical vesicles singly or in bundles and make cells float on the surface of water. When gas escapes they collapse, become flat, and the cells sink to the bottom of water body.

Nucleoplasm: The central portion of a prokaryotic cell is usually referred to as nucleoplasm and it contains the genetic material DNA. It appears as a network of fibrils, and like that of bacteria it is a long thread in the shape of a ring, generally referred to as circular chromosome. There may be multiple copies of it in a cell.

Specialised Cells of Cyanobacteria

As you have learnt that besides the common vegetative cells, filamentous Cyanobacteria show two other types of structures, heterocysts and akinetes.

Heterocyst: Look at the structure of heterocyst given in Figure 6.2. Unlike a vegetative cell, heterocyst has a thick wall with three layers which are structurally different. The inner most layer contains certain glycolipids which make the heterocyst impermeable to oxygen, otherwise O_2 inhibits the action of nitrogenase and prevents nitrogen fixation.The heterocysts are connected with the adjacent cells through fine protoplasmic strands, plasmodesmata at the poles and also with large shiny granules - polar granules made up of cyanophycin.The heterocysts also contain many photosynthetic lamellae, but these are less dense than in the vegetative cells. The lamellae contain chlorophyll *a* and carotenoids. However, phycocyanin is lost when a vegetative cell changes into a heterocyst. Therefore, mature heterocysts cannot fix carbon dioxide, so O_2 is not liberated in light. Polyphosphate and glycogen granules, carboxysomes and gas vesicles are entirely absent in the cytoplasm of the heterocyst.

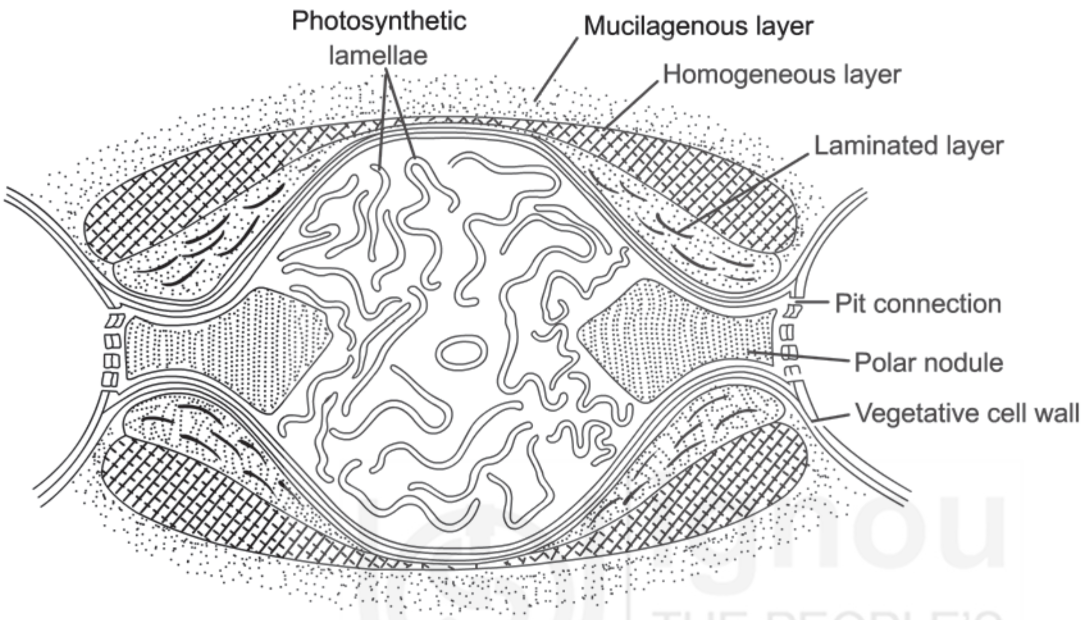


Fig. 6.2 : Diagrammatic represntation of structure of mature heterocyst. Source: Singh et al., 2016.

Eukaryotic algal cell

Except members of Cyanophyta, all divisions of algae have eukaryotic cells. A typical eukaryotic algal cell has a plasma membrane and cell wall. It also contains a nucleus, chloroplasts, mitochondria and pyrenoids. In the following text, you would learn in detail about the structure of eukaryotic algal cell. Ultrastructure of a typical eukaryotic algal cell has been discussed in the following Section (Fig. 6.1b).

Cell wall: Cell wall of algae is made up of a fibrillar structure that forms the skeleton and the amorphous component in which the fibrillar component is embedded. Cellulose is the most common polysaccharide found in algal cell wall. Additionally different groups of algae have different structural polysaccharides in their cell walls. In siphonaceous algae such as *Porphyra* and *Bangia*, mannan is the most common polysaccharide. Cells of Division Chrysophyta have no proper cell wall. They are covered by scales of silica, e.g., *Mallomonas*. In coccolithophorides elaborate scales contain calcium carbonate (calcite). The cell wall of red algae contains polysulphate esters of carbohydrates in addition to cellulose and pectin.

Chloroplast: The ultrastructure of algal chloroplast is similar to that of higher plants. It is enveloped by double membrane and encloses a number of thylakoid lamellae that are spread in a matrix - the stroma. The lamellae are made of lipoprotein complexes interspersed with molecules of chlorophylls and carotenoids. When phycobilins are present as in the case of red algae, they are present in the form of granules known as phycobilisomes, attached to the membrane surface in linear rows. The stroma of chloroplast contains several enzymes connected with photosynthetic carbon fixation.The arrangement of thylakoids in chloroplasts varies in different algae. They may be very closely stacked to form grana (sing, granum), as in green algae, brown algae and euglenophytes. In red algae they are widely separated from each other.

Location of chloroplast within the cell can be axile: at the centre or parietal: towards the periphery. Their number also varies from one to many, but is fixed for a species. Under the microscope, the following shapes of chloroplasts can be easily recognized: cup like *(Chlamydomonas),* girdle like *(Ulothrix),* spiral band *(Spirogyra)* and stellate or star-shaped (*Zygonema*), reticulate net-like (*Oedogonium*). These are shown in the Fig. 6.3 given below. One important feature of chloroplast is the presence of circular or ring like DNA. Plastids of *Euglena, Acetabularia, Chlamydomonas,* diatoms, members of Chrysophyceae, Xanthophyceae, Phaeophyceae all have been shown to contain circular DNA. Chloroplasts give rise to new plastids by simple division. Chloroplasts contain ribosomes of 70s type unlike those present in the cytoplasm, and synthesize proteins. Ribosomes of 70s type are characteristic of prokaryotes like Cyanobacteria and hence, it is believed that chloroplasts of eukaryotes were indeed Cyanobacteria which became endosymbiotic during the course of evolution.

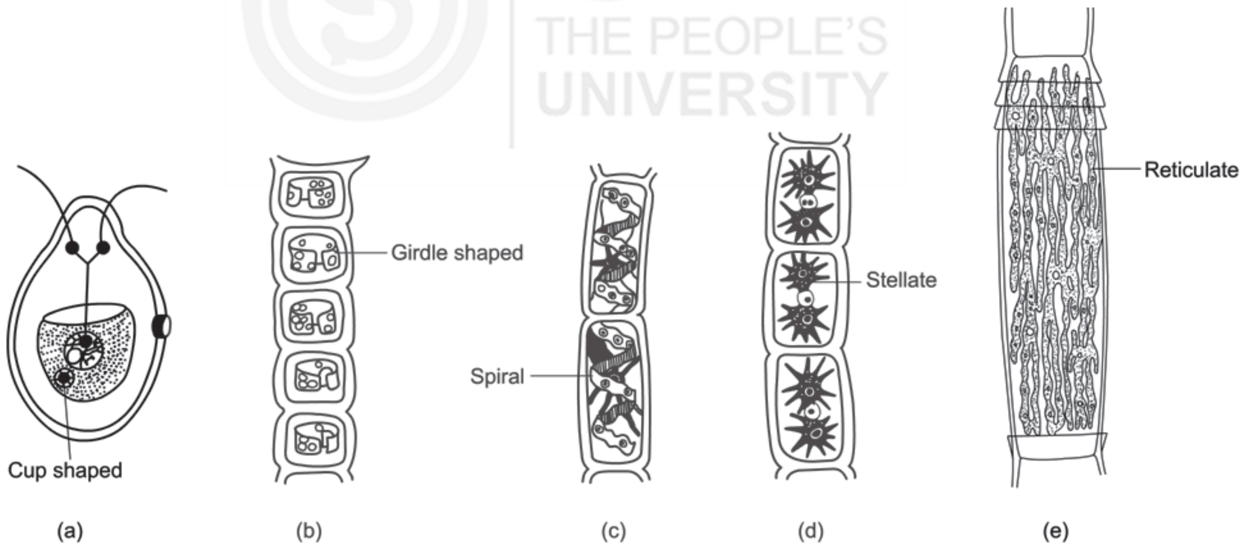


Fig. 6.3 (a-e) : Types of chloroplasts in algae : a) Cup-shaped, *Chlamydomonas*; b) Spiral, *Spirogyra*; (c) Parietal, *Ulothrix*; d) Stellate, *Zygnema*; and e) Reticulate, *Oedogonium*. Source: (e) Hoek et al., 1997.

Pyrenoids: Plastids of many green algae have prominent proteinaceous granules called pyrenoids around which starch is deposited. In many cases one can see photosynthetic thylakoids traversing the matrix of the pyrenoid or at least closely associated with it. When the chloroplasts divide, pyrenoids also divide to give rise to new pyrenoids.

Nucleus: The number of nuclei per cell varies with genera. Many algae contain only one nucleus per cell. However, green alga *Cladophora* is multicellular multinucleate *Caulerpa* is multinucleate coenocytic and *Vaucheria* contains more than one nucleus and is multinucleate. Like the eukaryotic plant and animal nuclei, algal nucleus is enveloped by a distinct double membrane punctured by pores. During the interphase (not dividing, resting nucleus) uncoiled, fine chromatin-threads are visible in the nucleus. Chromatin is complex of DNA, histone and non-histone proteins that condenses to form the chromosomes during cell division. Many algal nuclei contain globular nucleoli, one or more in number, sometimes attached to the specific region of the chromosome nucleolus organizer. Nucleolus may degenerate and disappear during the cell division but reappear during the interphase. It is now known that the nucleolus is involved in the synthesis of cytoplasmic ribosomes. The structure of nucleus in the algal groups Euglenophyta and Dinophyta is quite unique and is different from all other eukaryotes. During the interphase, the nucleus inside its membrane shows not uncoiled chromatin fibres but highly condensed chromosomes. Further, unlike in other organisms, they do not contain histone proteins.

The number of chromosomes present in each genus or species of an alga has no relation with its systematic position. The smallest number recorded is n=2 and the highest may be 600 or more. The size of individual chromosomes is also variable. Large chromosomes are found in *Oedogonium, Cladophora* and *Chara.*

Mitochondria: The number of mitochondria in algal cells varies from one to many. Their size and shape also varies widely. The ultrastructure shows a double membrane, the inner one is folded inwardly forming cristae protruding into the lumen. It is believed that mitochondria originated from endosymbiotic bacteria adapted to intracellular existence inside the ancestral host eukaryotic cells. Like the chloroplasts, they also contain circular DNA, RNA, 70S ribosomes that facilitate protein synthesis.

Golgi bodies: These are also known as dictyosomes and are widely found in algal cells. They are made up of 2-20 lamellae or membranes arranged in stacks. They play an important role in the formation of cell wall and in secretion.

Flagella: Flagella are important organelles that confer motility upon the algae. A typical flagellum consists of two main parts: an axoneme, and a column. The axoneme has a typical 9+2 arrangement of microtubules and is covered by a plasma membrane. The flagellar column is a tunnel-like structure in the cell wall through which the flagellum enters the cell. There are different types of flagellae based upon the presence or absence of hairs. Flagellae without tiny hair on its surface are known as whiplash or acronematic flagella, and those with hair (mastigonemes) are known as Tinsel or pantonematic. Depending upon the length of the flagella they may be: isokont, i.e., flagella of equal length, and anisokont, i.e., flagella of unequal length. They are means of locomotion for the motile cells of algae found in all divisions except Rhodophyta. The alga may itself be motile (as in unicellular and colonial algae) or at some stage in its life cycle produce reproductive motile cells - zoospores and gametes. Some green algae and the members of Phaeophyta, Chrysophyta, Dinophyta show two flagella, one with smooth surface and the other with fine hairs.

Eyespots: Motile cells of algae belonging to Chlorophyta, Phaeophyta, Euglenophyta, Chrysophyta contain orange-red coloured eyespots. In some algae eyespot may form a part of the chloroplast and it is located at the base of the flagellum, but in *Euglena* it is quite distinct and away from the chloroplasts. The common type of eyespot as found in green algae, e.g., *Chlamydomonas* appears to have a row of orange coloured lipid granules as a part of thylakoids at the anterior portion of the chloroplast that contain carotenoids.

6.2.2 Morphology

Algae show a wide range of diversity in the organization of their thallus. The algal thallus ranges from being a simple unicellular form to a multicellular well differentiated form. In between the two extremes there is a range of colonial filamentous forms. In the following text you would study in detail about the different types of thalli in algae.

Based upon the number of cells, their association and degree of differentiation with each other the algal thallus can be classified into the following types:

Unicellular: Unicellular Forms - The thallus in these forms are reduced to one cell. These can be of the following sub types:

Rhizoidal – These cells lack rigid cell wall and form cytoplasmic projections, e.g., *Rhizochrysis* (Fig. 6.4a).

Protococcoidal – These are simplest non-motile cells and lack organized nucleus and plastids. Found in Cyanophyta – *Synechococcus*, Chlorophyta – *Chlorella* (Fig. 6.4b), the shapes of the protococcoidal unicell may range from circular as in Bacillariophyta; to triangular – *Tetrgonidium*, *Goniochloris* (Xanthophyceae); or elongate with basal attachment disc as in *Characium* (Chlorophyceae).

Flagellate Unicellular Forms – These cells have flagella that facilitate them to move. *Chlamydomonas* (Fig. 6.4c) of Chlorophyceae is a typical example of unicellular motile algae.

Colonial: When a cell divides and the daughter cells formed remain together within common mucilage mass, it is known as a colony. A colony may contain large number of cells. Sometimes it may be so big that one can see it with unaided eyes. In this type of thallus organization, motile flagellate cells aggregate to form simple colonies in which the daughter cells remain together within mucilage. The colonies may occur as plate like – *Gonium* (Fig. 6.4d) or spherical groups – *Pandorina* (Fig. 6.4e) or mucilage spheres in which cells are arranged below the surface and are interconnected by protoplasmic threads, e.g., *Volvox.* In some members such as *Pediastrum* (Fig. 6.4f) and *Scenedesmus* (Fig. 6.4g) cells are arranged as non-flagellate coenobia wherein they occur together as aggregates.

Tetrasporal groups: This kind of an organization is seen in members of Cyanophyta such as *Microcystis*. In these genera cells are embedded in mucilage to form non-motile colonies. The term is not true in description as not all the colonies have only four cells.

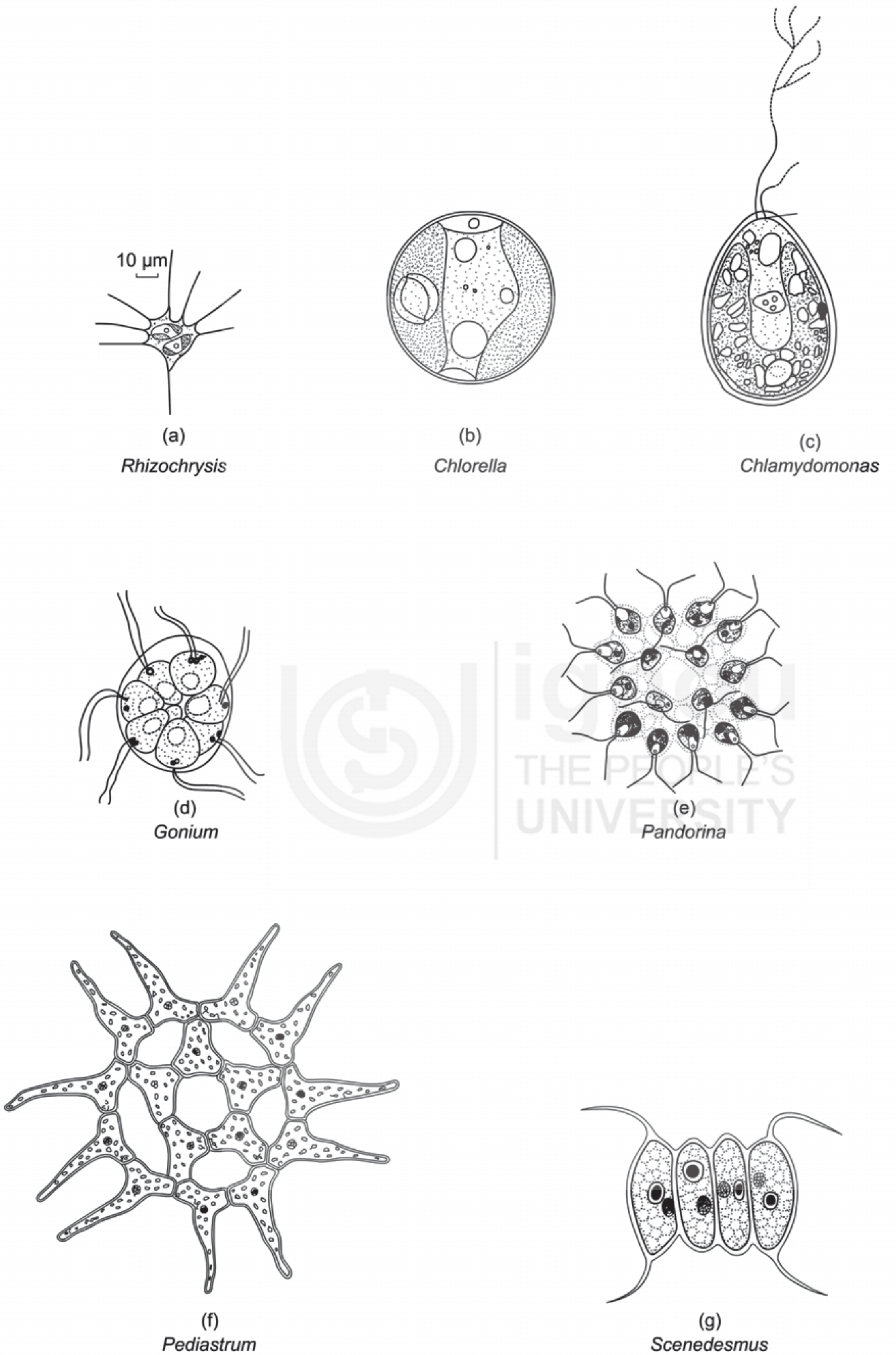


Fig. 6.4 (a-g): Diagrammatic representation of different unicellular (a-c) and colonial (d-g) forms of algae. a) *Rhizochrysis*, b) *Chlorella*; c) *Chlamydomonas*; d) *Gonium*; e) *Pandorina*, f) *Pediastrum*, g) *Scenedesmus*. Sources: (a,b) Hoek et al., 1997; (c) Santra et al., 1993; (d,e) Lee, 1989; (f) Barsanti & Gualtieri, 2006; and Singh et al., 2016.

Filamentous: Filamentous type of thallus is obtained when an algal cell divides only cross wise, without being separated from each other to form a linear row of cells. Filamentous type of organization is quite common in algae and there are levels of structural and organizational differentiation in these forms. These may range from single unbranched, free living, or attached; you will now read about a few of these forms in detail.

Unbranched Filaments – In this type of thallus the filaments do not branch and remain as a single row of cells. These single filaments may comprise of a uniseriate row of cells embedded in mucilage as seen in *Nostoc* and *Ulothrix* (Fig. 6.5 a,b). It may show a very simple model of differentiation as some intermediary cells are modified into heterocysts. You would study in detail about *Nostoc* in Sub-section 7.2.1.

Filamentous, attached – In some genera of filamentous algae the basal cell is differentiated into a specialized structure called holdfast that facilitates attachment of the filament to the substratum such as rock. Such an arrangement is observed in *Ulothrix* (Fig. 6.5b). In this even the apical cells are morphologically distinct from rest of the cells and are broader in shape. The vegetative cells undergo several divisions to form zoospores that act as a mode of asexual reproduction.

In unbranched filamentous forms, genus *Oedogonium* of Chlorophyceae shows a still higher level of structural and functional differentiation (Fig. 6.5c). It is an unbranched filamentous thallus that remains attached to the substratum with the help of a holdfast. Growth of the filaments is due to certain specialized cells in the filaments known as cap cells, which are so called as they have ring like structures / cap on their walls. These cells may divide several times and the numbers of caps indicate the number of times they have divided.

Branched Filaments: Branching is seen in several genera of alga it is primarily of two types: False Branching and True Branching, e.g., *Vaucheria*. False Branching is observed in members of Cyanophyta when the trichome breaks within the mucilaginous sheath and one (or both) the ends show lateral growth to form a false branch. It is also formed when trichome (filament) continues growing beneath the heterocyst so that both the rows of cells appear as a false branch. In genera such as *Cladophora*, filaments are branched that give a dense fluffy appearance to the thalli (Fig. 6.6a). It also shows acropetal mode of branch formation, i.e., the youngest branch is closest to the apex.

Heterotrichous form: When some cells of a filament divide vertically it results in a branch. Many filamentous forms show extensive branching of the main filament giving it a bushy appearance. In some algae the branches at the base remain horizontal, attached to the substratum known as prostrate system from which erect system of vertical branched filaments arise. This type of body is known as heterotrichous habit. Heterotrichous habit is the most developed filamentous construction in algae. It is observed in *Coleochaete* and *Ectocarpus* (Fig. 6.6b).

Thalloid: When the cells of a filament divide in more than one plane, i.e., not only cross-wise but also lengthwise, it results in a sheet of cells. The thallus may be one cell or many cells in thickness. It is found in *Fucus*, *Ulva* (Fig. 6.6c).

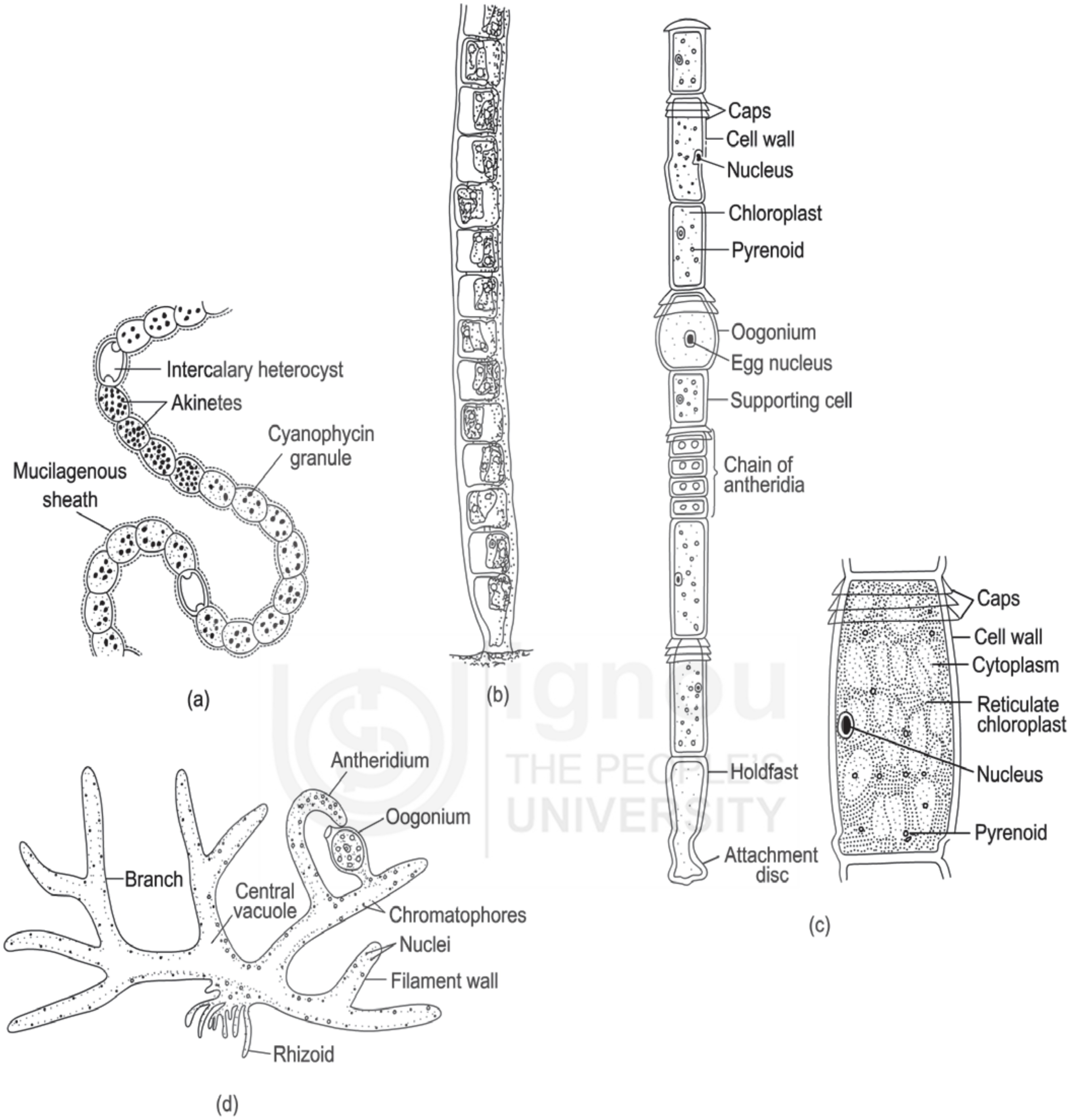


Fig. 6.5 (a-d) : Filamentous unbranched (a-c) and branched (d) algae. a) *Nostoc*; b) *Ulothrix*; c) *Oedogonium*; d) *Vaucheria*. Source: (a,c,d) Singh et al., 2016; and (b) Barsanti & Gualtieri, 2006.

Polysiphonoid: This form of algae is more complex than the earlier described forms. It is found in the red alga *Polysiphonia* (Fig. 6.6d) which is marine in habitat. The algae show in general heterotrichous habit. The prostrate system is in the form of an elongated rhizoid which attaches the algae to the substratum. The erect system is highly branched. The branches are of two kinds, some are long and some short and hair-like. The main filament grows by the division of a single apical cell. The mature plant body is made up of central row of cells - central siphon, surrounded by vertical rows of cells, 4 to 24-pericentral siphons and hence the name *Polysiphonia*. All the pericentral cells are connected with the cells of central siphon and are also connected with each other.

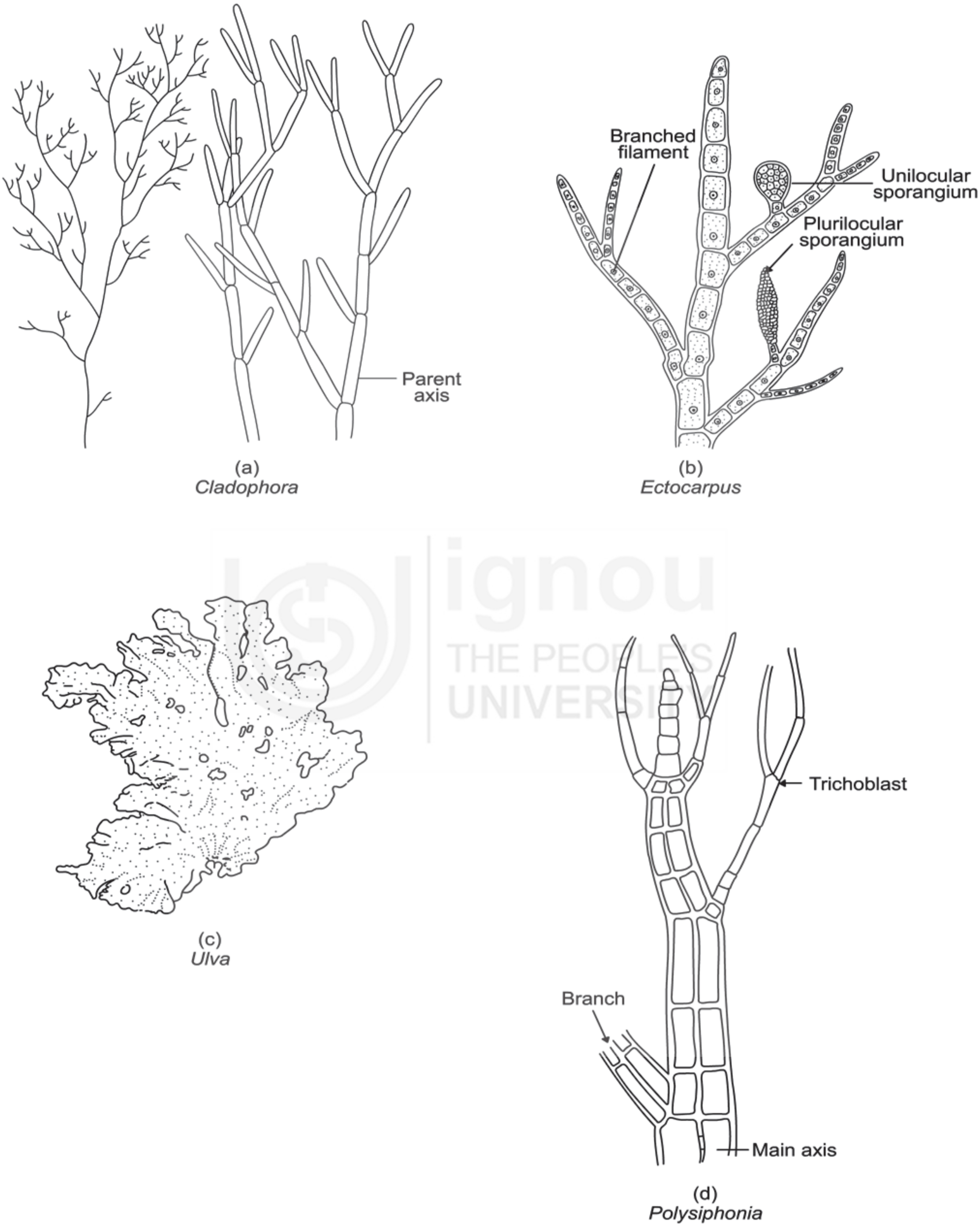


Fig. 6.6 (a-d): Diagrammatic representation of Branched – *Cladophora:* a) Heterotrichous –*Ectocarpus* b); thalloid – *Ulva*; c) and Polysiphonoid – *Polysiphonia*; d) forms of algae. Source: (a,b) Singh et al., 2016; (c) Hoek et al., 1997; and (d) Pandey & Trivedi, 1996.

SAQ 1

a) Indicate which of the following statements are true or false.

i) Cyanobacteria have prokaryotic cellular structure.

ii) Holdfast is found in *Nostoc.*

iii) *Chlamydomonas* floats because of the presence of gas vesicles.

iv) Pyrenoids are made up of proteinaceous deposits.

b) Choose the correct answer in the following.

i) Which of the following alga is colonial in form?

1) *Microcystis*

2) *Anacystis*

3) *Chlorella*

4) *Chlamydomonas*

ii) Heterocysts are present in:

1) *Microcystis*

2) *Nostoc*

3) *Volvox*

4) *Ulothrix*

c) In the following statements fill in the blank spaces with appropriate words:

i) .... is an unicellular alga.

ii) In younger colonies of *Volvox,* the cells of the colony are connected with ....

iii) The colony of .... floats on the surface of water because the individual cells have gas vesicles.

d) Briefly discuss the following and give suitable examples.

(i) Cell wall in eukaryotic algae.

(ii) Heterocysts.

(iii) Diversity of chloroplasts in algae.

e) Match the following:

	I		II
	Forms of algae		Example
1	Rhizoidal	(a)	*Volvox*
2	Colonial	(b)	*Rhizochrysis*
3	Filamentous	(c)	*Polysiphonia*
4	Polysiphonous	(d)	*Oedogonium*

6.3 REPRODUCTION IN ALGAE

In this section you would learn about the various means of reproduction in algae. As in their form and structure, algae show a lot of diversity in their means of reproduction. They show all three major means of reproduction, i.e., vegetative, asexual and sexual. Also you would learn about the origin of sex in algae and the factors / signals that control sexual differentiation, attraction and fusion of gametes.

Reproduction in algae can be divided into three types:

Vegetative Reproduction – In which cells of the thallus or filaments simply divide to form a new individual. No special spores are formed in vegetative reproduction.

Asexual Reproduction – In this type of reproduction vegetative cells from one thallus/ filament (other than reproductive cells) of the filament/ thallus produce spores that germinate to form new individuals.

Sexual reproduction – In this type of reproduction, specialized cells or reproductive organs form gametes (from two filaments/ thallus of opposite strains/ mating types/ male or female) that fuse to form a zygospore which eventually germinates to form a new individual.

6.3.1 Vegetative Reproduction

Shows variation in unicellular and multicellular forms. In unicellular algae such as *Anacystis*, desmids and diatoms a cell divides by binary fission after it reaches an appropriate size. In some species of *Euglena* cells become enclosed in mucilage sheath and divide repeatedly to form palmelloid stage. In certain flagellate forms cells divide longitudinally to form two daughter cells and organelles are distributed among them. In filamentous forms such as *Nostoc*, vegetative reproduction is brought about by simple breaking / fragmentation of cells / filaments that eventually divide to form a new filament. In Cyanophyceae, trichomes are cut off from the main filament due to simple breaks. These short filaments are known as hormogonia that are motile and give rise to new daughter filaments.

6.3.2 Asexual Reproduction

When reproduction takes place through vegetative specialized cells (other than sex cells) is known as asexual reproduction. Vegetative cells of thallus are modified in order to form specialized structures called spores that disseminate to form a new thallus / organism. Depending upon physiological and environmental conditions spores can be of several types such as akinetes, zoospores and aplanospores. You would now study in detail about them in the following subsection.

Akinetes – In members of Cyanophyceae such as *Anabaena, Nostoc* and *Gloeotrichia* during unfavourable environment conditions (drought, extreme temperature, nutrient deficiency phosphate), some vegetative cells accumulate reserve food and become thick walled in order to survive extreme conditions (Fig. 6.7). These contains cyanophycin polypeptides and Cyanophyceae starch. At the onset of favourable conditions, these germinate to form daughter filaments. These may remain in quiescent stage upto 64 years (in *Anabena*).

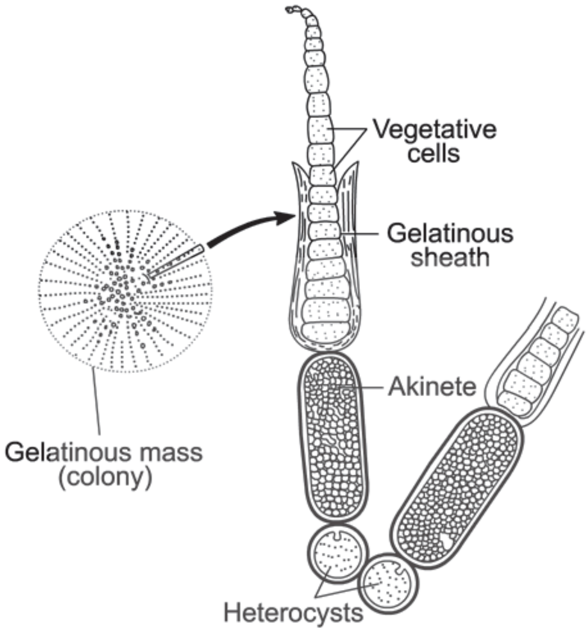


Fig. 6.7: Akinetes in *Gloeotrichia*. Source: Singh et al., 2016.

Zoospores: These are motile spores that facilitate reproduction in several genera of algae. Zoospores are produced both by unicellular, e.g., *Chlamyomonas*, or multicelluar, e.g., *Ulothrix, Oedogonium* algal forms. The specialized cell in a multicelluar green alga that produces zoospores is called zoosporangium. In *Chlamyomonas* the entire vegetative plant body functions as a zoosporangium. The zoospores may be biflagellate as in *Chlamyomonas* (Fig. 6.8 a). Tetraflagellate zoospores are formed by a green alga *Cladophora* (Fig. 6.8 b). The zoospores of *Oedogonium* and *Vaucheria* are multiflagellate. In *Oedogonium* (Fig. 6.8 c) a large number of flagellae are arranged in a ring surrounding a beak-like projection. It is referred to as a stephanokont. However, in *Vaucheria* (Fig. 6.8 d) the flagellae are distributed throughout the entire body of the zoospore. Such a zoospore represents a number of zoospores and hence is called as coenozoospore. Although all the zoospores formed in an alga are of uniform size as in *Chlamyomonas*, the alga *Ulothrix* may form large quadriflagellate macrozoospores or small biflagellate microzoospores.

After liberation from the parent thallus, flagellate zoospores swim for some time and settle by their anterior end. It divides to form a basal cell that further forms the holdfast and the upper cell forms the filaments by several subsequent divisions. On moist soil when zoospores of *Chlamydomonas* cannot be released due to lack of free water, they get embedded within a gelatinous material formed from parent cell wall. Such cells do not have flagella but whenever they become flooded with water they develop flagella and swim away in the water. These gelatinous masses containing thousands of non-motile cells are known as palmella stage of *Chlamydomonas* (Fig. 6.9).

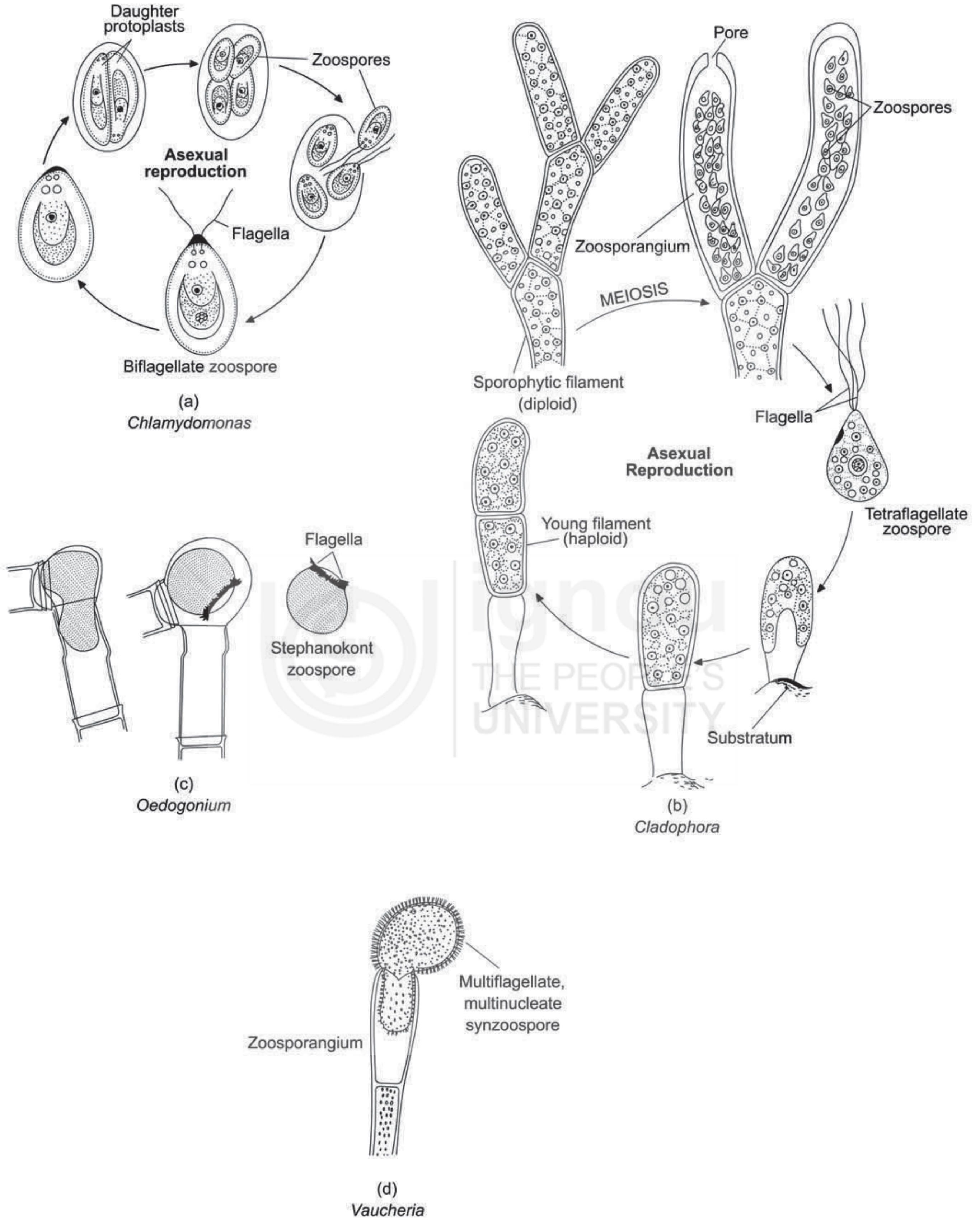


Fig. 6.8 (a-d) : Different types of zoospores found in algae : a) Biflagellate – *Chlamydomonas*; b) Tetraflagellate – *Cladophora*; c) Stephanokont – *Oedogonium*; and d) Multiflagellate, multinucleate – *Vaucheria*. Source: (a,b,d) Singh et al., 2016; and (c) Hoek et al., 1997.

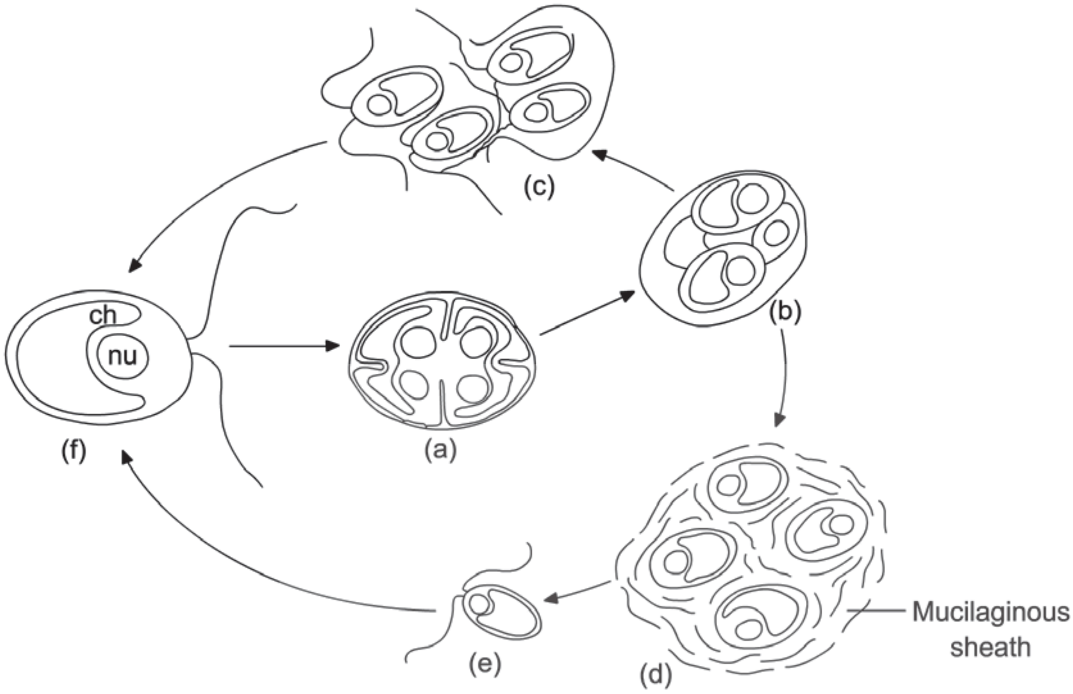


Fig. 6.9 (a-e) : Formation of palmella stage in *Chlamydomonas*. a) Division of parent cell; b) Formation of wall around daughter cells; c) Four daughter cells seen in figure, but the number may vary with species, release of daughter cells by break down of parent wall; d) Formation of a palmelloid stage in the absence of water. The daughter cells remain in mucilaginous sheath. (e) Cells develop flagella when flooded. Source: Philip, 1986.

Aplanospores: Aplanospores are non-flagellate spores and have a wall distinct from the parent cell wall. They have an eyespot and contractile vacuole. They have the ability to form new thalli after germination. They are sometimes also considered as abortive zoospores.

Autospores: They are non-motile spores that lack an eyespot and vacuole. They resemble the vegetative cell in shape and are found in several members of chlorococcales such as *Chlorococcum*.

Hypnospores: In adverse environment conditions aplanospores develop a thick wall around themselves. These are in resting stage and germinate when conditions are favourable. *Chlorococcum echinozygotum* shows the presence of both aplanospores as well as zoospores.

6.3.3 Sexual Reproduction

In algae, like in other organisms, sexual reproduction is characterized by the fusion of male and female gametes, i.e., two cells of opposite sex or mating types. Fusion of gametes leads to formation of a zygote which is the first cell of the next generation. Sexual reproduction in algae is not a universal phenomenon and is not seen in the members of Cyanophyta. It involves fusion of nuclear material and often cytoplasm of the cell / gametes of two organisms of the same species. These gametes may be simply morphologically similar cells, or may be derived from specialized reproductive structures in highly differentiated algal thalli. Gametes are always haploid and if not morphologically distinct, they belong to different mating types or strains. In such cases, the male strain is represented as a positive (+) strain and female is called negative (-) strain. Gametes may arise from a single parent plant or from different plants. If both gametes arise from the same parent plant the condition is known as monoecious or homothallic. When gametes come from different thalli, i.e., either positive (+) or negative (-), or from male and female plant the condition is known as dioecious.

Depending upon the size and morphology of gametes, gametic fusion is broadly classified into three types (Fig. 6.10).

- Isogamy – When both the gametes are morphologically identical or are of same size and shape.
- Anisogamy – When the two gametes are distinctly different in size or shape or motility and the larger of the two is negative (–) or female type.
- Oogamy – Oogamous state is when the female gamete is non-motile, i.e., without flagella. The male gametes are motile and are flagellate. They are also known as antherzoids or spermatozoids.
- Autogamy – This type of fusion is reported in some diatoms wherein the daughter nuclei fuse with each other without being released from the parent thallus.

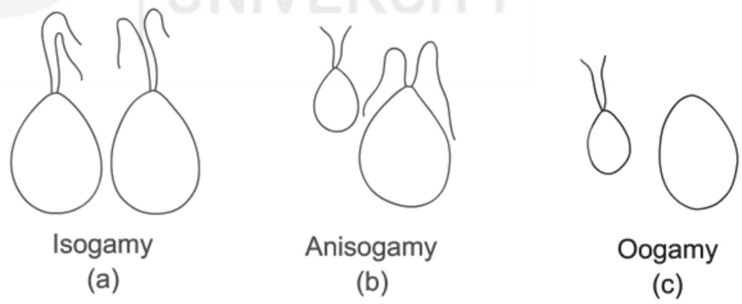


Fig. 6.10 (a-c) : Diagrammatic representation of isogamy a) anisogamy ; b) and oogamy; c) in *Chlamydomonas* spp. Only gametes are shown in the figures. Source: Raven et al., 2003.

In the process of fusion, the step of recognition of fertile sperms and eggs and the attraction between them is very important. In *Fucus* sperms are attracted to the eggs by fucoserratin which is a pheromone. Species specific recognition between the gametes is facilitated by the oligosaccharides on eggs and sperms. In some members of Phaeophyceae such as *Ectocarpus siliculosus* pheromones are responsible for attraction. Fusion of gametes leads to the formation of zygote that may germinate immediately if environment conditions are suitable. If conditions are unfavourable then a thick wall develops around it and leads to the formation of a resting zygospore. The resting zygospore germinates to form daughter thallus when the conditions are favourable.

6.3.4 Origin and Evolution of Sex in Algae

The basic feature of sex is the fusion of two cells - gametes which are of two types, male (plus) and female (minus). What factors lead to the fusion of cells as such is not clear but fusion brings about mixing of two different (but related) genomes together, one probably compensating for the deficiencies of the other. This particular feature is a biological advantage for the survival of the species.

Sexual reproduction gives variability and vitality to the daughter generations. Algae as a group shows the presence of all types of gametic fusion. These types are temporally separated and have evolved at different times. The transition from vegetative to sexual mode of reproduction has been in phases, and algae shows the presence of all these stages. The earliest method of sexual reproduction is isogamy in which the gametes are identical and originate from the same part or similar mating types, homothallion. This type of sexual mode of reproduction is closest to vegetative mode. Morphologically identical gametes show some changes / different behaviour and are obtained either from a negative (–) or a positive (+) thallus, i.e., they show heterothallic isogamy. In the next stage in evolution of sexual reproduction male (♂) or female (♀) gametes show morphological distinction. These variations are primarily in their size and/or motility. The bigger gamete is the female (♀) gamete and the smaller one is the male (♂) gamete. Anisogamy can also be physiological wherein the two gametes are morphologically identical but show physiological distinction. The next type of gametic fusion, i.e., oogamous is the most evolved and shows the presence of very distinctly differentiated gametes. The female (♀) gamete, i.e., the egg is non-motile and larger in size, whereas the male (♂) gamete is flagellate, small and fast. In higher and more evolved algae the egg and antherozoids are borne on morphologically specialized structures oogonia and antheridia, respectively. The maximum number of egg cells may go up to eight (8) whereas the number of sperm cells is very high.

In isogamous as well as advanced forms of sexual reproduction in algae, species-specific identification, attraction and fusion is mediated through chemotaxis that is facilitated by the release of certain chemicals such as gamones, sirenins and pheromones. In a brown alga *Ectocarpus*, these sirenins are identified as optically active dextrorotatory substances, the ectocarpen. While in *Fucus*, another brown alga it is identified as an octotriene, the fucoserraten. In a green alga, *Oedogonium* at least four different types of pheromones are reportedly involved in the process of sexual reproduction.

These responses to such chemotactic signals during gametic attraction of two gametes belonging to opposite genders is illustrated in Fig. 6.11.

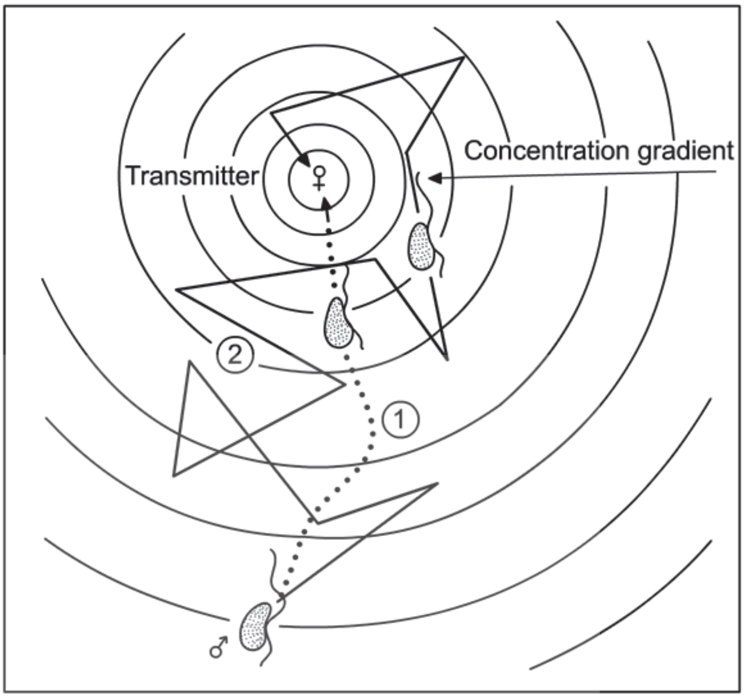


Fig. 6.11 : Diagrammatic representation of response to a chemotactical signal. With the help of specific receptors, the male gamete recognizes a temporal or spatial difference in the concentration of attracting substances. It can either follow the concentration gradient directly to its goal, the female gamete or transmitter, this process is known as *chemotopotaxis* (see 1). Or show a shock reaction to the reduction in concentration of attracting substance, this process is termed as *chemophobotactic* reaction (see 2). The shock reaction expresses itself in a change in the direction of movement of the male gamete. The male gamete slowly approaches the transmitter or the female gamete. The path of male gamete is complicated (see the figure). It is in the direction of the gradient, and due to sudden changes the direction of its movement takes place. Source: Mohr & Schopfer, 1995.

In addition to production of volatile substances as to attract opposite mating types in *Chlamydomonas*, glycoproteins on their surface of egg and sperm cells also play an important role in the process of fusion especially in advanced genera such as *Fucus*. Membrane polarization mediated by ions such as Calcium (Ca^{2+}) and Sodium (Na^{+}) also plays an important role in gametic fusion.

The role of nutritional and environmental conditions has been demonstrated in the process of gametogenesis in green alga, *Chlamydomonas* under experimental conditions. For example, depletion of nitrogen ions from the medium is a suitable signal for the induction of gamete formation. It is also reported that exposure of light is indispensable for the induction of gametogenesis, even if the *Chlamydomonas* cells have been transferred to a nitrogen-free medium. In *Chlamydomonas moevusii*, the effective radiation is absorbed by a retinal protein (rhodopsin) the photosynthesis plays no role.

In all eukaryotic algae as in all plants and animals, fusion of cells is the method by which sexual reproduction takes place. The question is how this fusion of cells originated and further how this phenomenon was preserved and refined during evolution. The study of the sexual processes found in the present day algae provide some answers to the above questions.

In *Chlamydomonas, Ulothrix* and others asexual reproduction takes place through motile swarmers called zoospores. In *Ulothrix* depending on the number of divisions that a cell undergoes, at least two types of zoospores are produced, small microzoospores and large macrozoospores. The microzoospores often fail to germinate to produce new plants, probably due to deficiency or low level of some vital substances needed for cell division and growth. However, such swarmers are found to fuse in pairs occasionally and then develop into *Ulothrix* filaments. It appears that macrozoospores are self-sufficient and do not require any such fusion (Fig. 6.10).

In many algae one cannot make out any difference in between the structure of a zoospore and a gamete, except for their behaviour - a zoospore directly develops into a filament whereas a gamete needs fusion with another gamete for further regeneration. You would read in detail about the different methods / modes of reproduction with suitable examples in Unit 7.

SAQ 2

a) Which of the following algae reproduces asexually through zoospores?

i) *Volvox*

ii) *Chlamydomonas*

iii) *Anabaena*

iv) *Microcystis*

b) In the following statements fill in the blank spaces with appropriate words:

i) ....is an enlarged cell in blue-green algae which accumulates food reserves, develops a thick wall and functions as a resting spore.

ii) Under unfavourable conditions the zoospores lose their flagellae and round up, they are called... .

iii) When a filamentous alga is accidently broken it develops into ....

iv) The stage when thousands of non-motile spores of *Chlamydomonas* cluster together in a gelatinous mass is called....................... .

v) When both plus (+) and minus (–) strains are produced by the same parent the condition is called................................. .

vi) When two gametes of plus and minus strains arise from different parent algae the condition is called ....

vii) Fusion of gametes of same size and morphology is called ....

viii) In .... the two gametes are of different shapes and sizes.

c) In the following statements choose appropriate alternative word given in the parentheses:

   i) In algae gametes are always (haploid/diploid).

   ii) In algae the product of fusion of male and female gametes is called (zoospore/zygospore).

6.3.5 Life Histories

In sexual mode of reproduction; after the male and female gametes fuse the resulting zygote has double the number of chromosomes. The number of chromosomes should reach to the basal level so that the next cycle of sexual reproduction can take place. Life history in algae depends upon the stage at which the reductional division takes place. Meiosis may be zygotic, i.e., the first division in the diploid zygote is reductional so the new thallus is haploid, or it may be gametic, i.e., the thallus is diploid and when the egg and antherozoids are to be formed, then reductional division takes place in the specialized cells, so that the gametes are haploid. Although, algae are less complex as compared to other plant groups, they show basic alternation of the haploid and diploid phases in their life cycle. There are different types of alternation of generations. The type of life cycle of an organism in which reproduction alternates in each generation between sexual reproduction and asexual reproduction is called alternation of generations. The two generations are termed as gametophytic and sporophytic generations. The gametophytic generation is haploid (n) and the sporophytic generation is diploid (2n). The fusion of two gametes (n) results in zygote (2n) which on germination forms the plant / thallus called sporophyte. The sporophyte in turn produces haploid spores by meiosis. When a spore germinates it develops into gametophyte which bears male or female gametes or both on the same plant / thallus. In some bryophytes the gametophytic generation is more conspicuous. While in ferns the sporophytic generation is more prominent. In angiosperms, main plant body is sporophyte and the gametophytic generation is reduced to a few cells. You will see that all types of situations prevail in algae. In some algae gametophyte is prominent while in others sporophyte is prominent. The four main types of life cycles are summarized in Fig. 6.12.

Haplodiplontic life cycle: A life cycle where both the gametophytic and sporophytic generations, i.e., both haploid and diploid phases are equally dominant, the life cycle is known as haplodiplontic life cycle. In such a life cycle pattern zygote divides by mitosis and meiosis precedes spore formation during a diploid phase. The gamete formation is preceded by mitotic cell divisions. Such life cycle is exhibited by *Ulva*, *Ectocarpus* and *Laminaria*. However, in *Ectocarpus* both the haploid and diploid phases in the life cycle, i.e., both the sporophytic and the gametophytic phases in the life cycle are morphologically similar. Hence, it is referred to as homomorphic or isomorphic haplodiplontic pattern of life cycle. In *Laminaria*, however, both such generations are morphologically dissimilar. Hence, such a life cycle is called heteromorphic haplo-diplontic pattern of a life cycle.

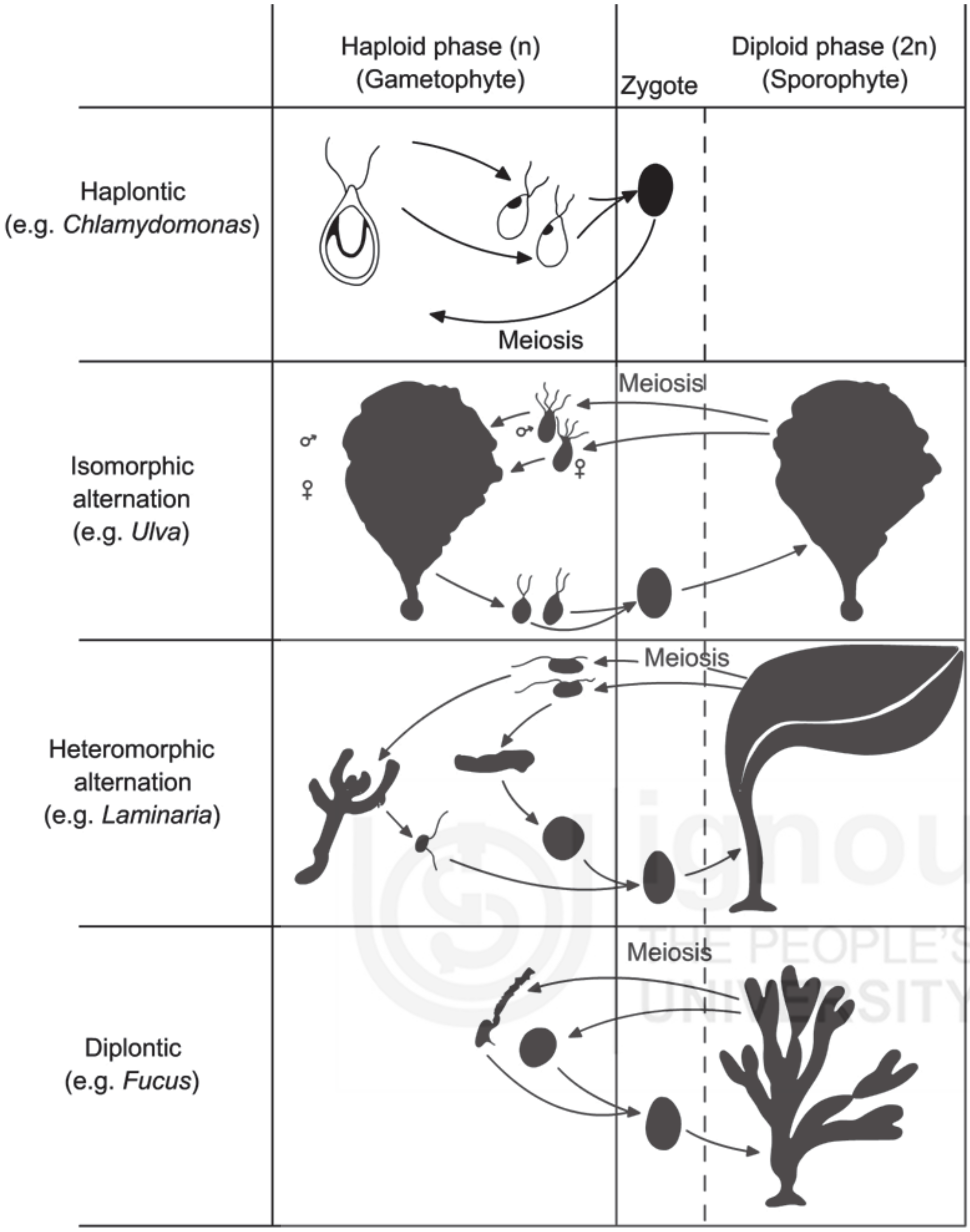


Fig. 6.12: Different types of cycles found in algae.

Diplohaplontic life cycle: In this pattern of life cycle both the gametophytic (haploid phase) as well as the sporophytic (diploid phase) generations are elaborately developed. However, the diploid phase is long drawn and a part of it is dependent on the gametophytic generation and later it gives rise to an independent diploid phase. Such life cycle is observed in a red alga *Polysiphonia*. In this alga, the gametophytes are dioecious, i.e., male and female reproductive structures are borne on independent gametophytic plants. The tetrasporophyte represents diploid sporophytic phase of life cycle while the carposporophyte, the diploid, short-lived sporophytic phase is dependent on the female gametophytic plant. Also morphologically both the male and female gametophytes and tetrasporophytic phase is isomorphic. Hence its life cycle is termed as isomorphic, triphasic, diplohaplontic type of life cycle. You will study more deails about the life cycles of *Chlamydomonas*, *Oedogonium*, *Vaucheria*, *Fucus*, *Polysiphonia* in this Unit. Some of the above life cycle patterns are diagrammatically represented in the Fig. 6.12.

SAQ 3

a) In the following statements choose the correct alternative word given in the parentheses.

   i) *Chlamydomonas* zygote undergoes (meiosis/mitosis) during germination.

   ii) Both macro- and microzoospores are formed by (*Vaucheria*/ *Ulothrix*).

   iii) In haplontic life cycle, the alga is (haploid/diploid), only the zygote is (haploid/diploid).

   iv) In (haplontic/diplontic) type of life cycle gametes represent gametophytic phase.

b) In the following statements fill in the blank spaces with appropriate word(s):

   i) The alternation of generations where gametophyte and sporophyte of a given species are morphologically independent and distinct from each other is called ……………… .

   ii) In……………… alternation of generations the thallus of gametophyte and sporophyte are morphologically alike.

   iii) *Chlamydomonas* shows ……………… type of life cycle.

6.4 CLASSIFICATION

Algae particularly seaweeds and filamentous pond alga have been considered to be a part of plant from very early times. Carl Von Linnaeus in his system of classification given in the year 1754 divided plants into 25 classes. In this system he placed Algae, Fungi, Musci and Filice into class Cryptogamia that contained all the plant forms that had concealed reproductive organs. They were often confused with bryophyta till a clear distinction was made and non-leafy plants were clubbed together as thallophyta. The term thallophyta was first definitively used by Eichler in 1886 to distinguish Algae and Fungi from Bryophyta, Pteridophyta and Spermatophyta. It had two key features that distinguish it from higher vascular plants:

(i) Sex organs/reproductive structures are unicellular or if multicellular then they are devoid of sterile covering.

(ii) Absence of multicellular embryo within the oogonium.

Eichler defined five groups in Algae namely Cyanophyceae, Diatomeae, Chlorophyceae, Phaeophyceae and Rhodophyceae. Whereas prior to this, Harney in 1836 had recognized only three groups based on their colours namely Chlorospermaeae, Melanospermeae and Rhodospermeae.

To classify algae diverse characters and / or combination of characters are often used by algologists. All these systems of classification were natural and relied primarily on morphological characters. Phycologists used several characters singly and / or in combination to come to a more scientific and widely accepted classification. Important characters used in classification are morphological – form, shape, degree of differentiation, ultrastructure, chromosome number and morphology, pigment composition, and storage products. In the last few decades, improvised molecular techniques have been used and enzymes, isoenzymes and DNA banding and homology studies are conducted to get a clear picture of algal classification.

At present, living organisms are divided into five kingdoms Monera, Protista, Fungi, Animalia and Plantae. Eukaryotic algae and Protists are placed in Kingdom Protista.

The standard botanical nomenclature is used in algae is given below:

- Phyllum – phyta
- Class – phyceae
- Order – ales
- Family – aceae
- Genus – species

Algae are primarily divided into four distinct groups:

Group I Prokaryotic algae, i.e., Cyanobacteria

Group II Eukaryotic algae with chloroplast surrounded by two membranes of chloroplast envelope.

Group III Eukaryotic algae with chloroplast surrounded by one membrane of chloroplast and other of endoplasmic reticulum.

Group IV Eukaryotic algae surrounded by two membranes of chloroplast and endoplasmic reticulum.

The different divisions of algae are clubbed into the above four types. Given below is the broad outline of classification in algae and subsequently each of the division is discussed in details.

Now we would briefly discuss the key characteristics of each division (Morphology, Ultrastructure, pigment composition and storage products) occurrence / distribution and examples.

Group I

6.4.1 Division Cyanophyta

Cyanophyta comprises of an assemblage of prokaryotic algae that are also known as blue-green algae (see Fig. 6.13). Recently it has been shown that they are more closely related to bacteria and hence the term Cyanobacteria is often used for them.

Occurrence: Cyanobacteria can thrive well in a variety of environmental conditions ranging from fresh water (*Anabaena, Oscillatoria*), oceans and seas (*Rivularia*, *Synechocystis*) and hot springs (*Mastigocladus laminosus*). They also grow luxuriantly on rocks and soils, and are often the first organisms to colonize a barren land (*Nostoc commune*). *Trichodesmium* is a marine alga that floats on sea waters. It gives an orange or grey coloured appearance to the sea. This is known as sea saw dust.

Morphology and Ultrastructure

Members of Cyanophyta occur as single cells, free living or enclosed in mucilaginous sheath. They also occur as rows of cells known as trichomes that can be branched or unbranched. The cell wall of Cyanobacteria resembles that of a gram positive (+) bacteria and has a peptidoglycan layer outside the cell wall. Some Cyanobacteria *Synechocystis* have appendages on their cell wall known as pili that help them to move. A typical Cyanophyta cell has prokaryotic organization and contains DNA fibrils, phycobilisomes, 70S ribosomes, carboxysomes and vacuoles.

The main photosynthetic pigment is chlorophyll *a* and some also show the presence of chlorophyll *b* and *d*. They also have carotenoids – Echineome and Myxoxanthophyll both of which are not found in eukaryotic algae. Members of Cyanophyta have four phycobill proteins namely C-phycocyanin, Allophycocyanin, C-phycoerythrin and Phycoerythrocyanin. Carbon and nitrogen occur as reserves in the glycogen and cyanophycean granules, respectively.

Reproduction: Akinetes

These are thick-walled cells also known as spores meant for perennation. The vegetative cells of a filament or only a few cells like those adjacent to a heterocyst may develop into spores. Akinetes have thick walls and they are generally light brown, deep brown or black in colour. The contents of the cell are highly granular with glycogen but polyphosphate is lacking. Akinetes can withstand prolonged desiccation and under suitable conditions germinate giving rise to new filaments. Reproduction occurs by simple cell division. There are no motile cells in this division. Asexual reproduction is carried out by the formation of akinetes that are thick wall cells. They also reproduce by producing hormogonia that are broken fragment of trichomes. Cyanobacteria are diazotrophs, i.e., they can fix atmospheric nitrogen (N_2) *Synechococcus* and *Trichodesmium* are nitrogen (N_2) fixing.

Examples are – *Anacystis*, *Microcystis*, *Nostoc*, *Anabaena*, *Oscillatoria*, *Spirulina*, *Gleotrichia* and *Trichodesmium*.

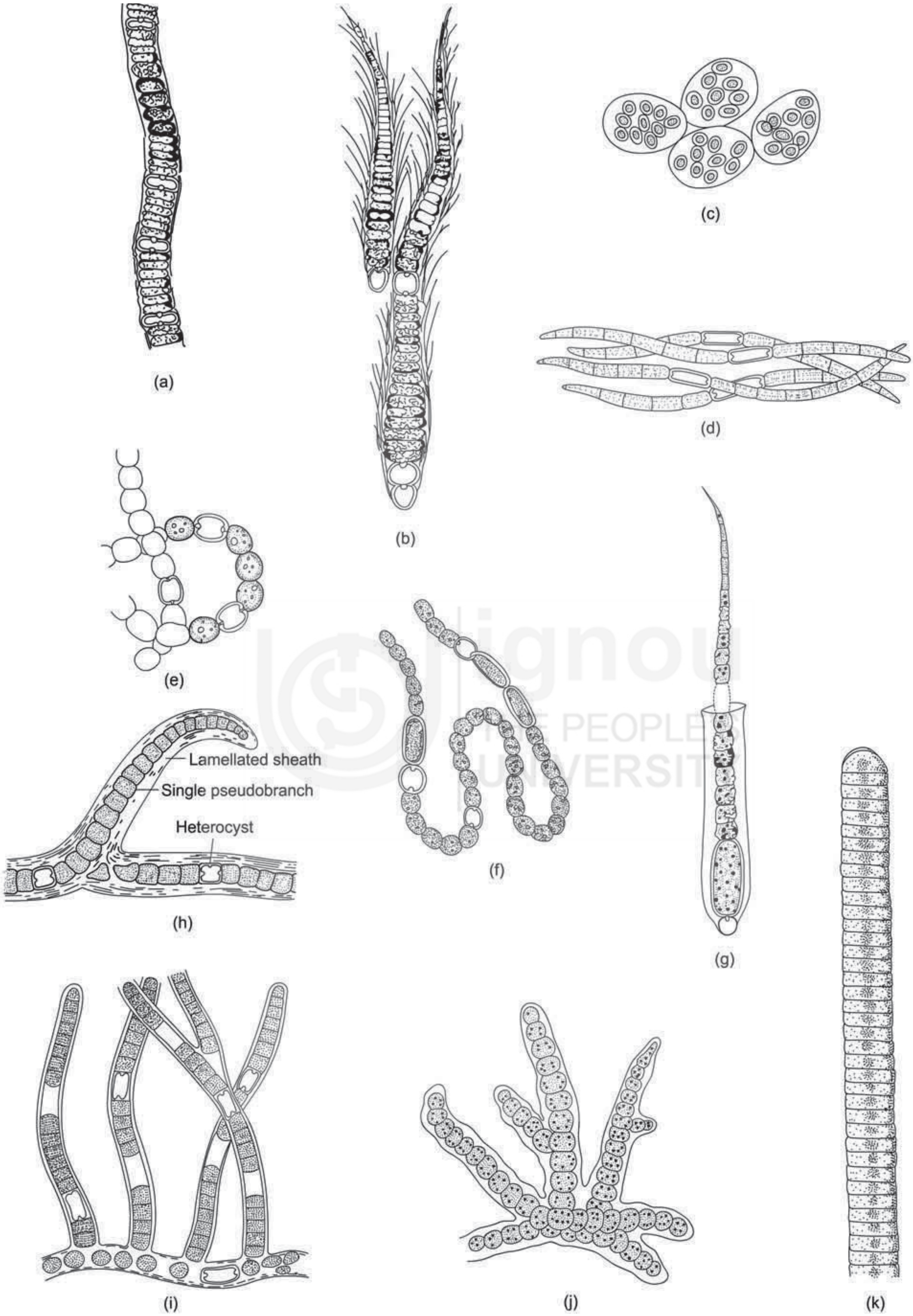


Fig. 6.13 : Some members of Cyanophyceae: (a) *Nodularia*, (b) *Calothrix*, (c) *Gloeocapsa*, (d) *Raphidiopsis,* (e) *Nostoc,* (f) *Anabaena*, (g) *Gleotrichia*, (h) *Scytonema*, (i) *Haplosiphon*, (j) *Stigonema* spp., (k) *Oscillatoria*. Source: (a-i) Kumar, 1990; (k) Singh et al., 2016.

You have learnt that eukaryotic algae has eight divisions. Each one of them is discussed in detail in the following Section.

Group II

6.4.2 Division Glaucophyta

The reason that Glaucophyta are placed just after Cyanophyta is because they have algae that have endosymbiotic Cyanobacteria in them and are devoid of chloroplasts. Hence, they are thought to represent intermediate forms depicting evolution of chloroplasts. In 1914, Pascher termed this symbiotic association of a flagellate and Cyanobacteria as 'syncyanosis'; the endosymbiotic Cyanobacteria was called as cyanelles and the flagellate host was termed as cyanome. Members of Glaucophyta lack cell wall, they possess 70S ribosomes and prokaryotic DNA. Their primary photosynthetic pigment is chlorophyll *a*, and they also possess phycobiliproteins. Evolutionary studies suggest that Glaucophyta diverged much before the red and green algae separated from each other. Glaucophyta members are found in fresh water. Some examples of Glaucophyta are *Cyanophora paradoxa* and *Glaucocystis.*

6.4.3 Division Rhodophyta

Division Rhodophyta has only one class, i.e., Rhodophyceae. It is one of the oldest group of eukaryotic algae and phylogenetic studies indicate that it has evolved from Glaucophyta and is therefore placed just after it. *Cyanidium,* an algae that thrives well in acidic waters is the oldest extant red algae.

Members of Rhodophyceae are marine in habitat and around 4000 species of sea weeds belong to Rhodophyceae. A typical cell of red algae shows the presence of chloroplasts, endoplasmic reticulum, nucleus and pit connections between adjacent cells. Besides cellulose red algae contains pectin, polysulphates and polysaccharides on their cell wall. These are source of agar and carageenans. They are non-flagellate and no motile cell is found at any stage of the life cycle. The primary photosynthetic pigment is chlorophyll *a*, chlorophyll *d* and phycobilliproteins namely phycoerythtrin and phycocyanins. The pigment phycoerythrin is responsible for the red / pink colour in Rhodophyceae. The chief storage product is floridean starch.

Some coralline red algae such as *Liagora* and *Galaxaura* deposit calcium carbonate and the calcified thallus becomes stiff. Members of Rhodophyceae exhibit sexual reproduction that is of advanced oogamous type, and there are no motile cells produced. Male (♂) gametes known as spermatia are carried to the tip of female (♀) organ – carpogonium, *i.e.,* trichogyne passively by water currents. Post fertilization the changes occurring are very specific and are not found in any other division of algae. You would read in detail about them in Unit 7. Some examples of red algae are *Porphyridium* (the only unicellular form), *Porphyra, Polysiphonia, Gelidium, Gracilaria* and *Corallina.*

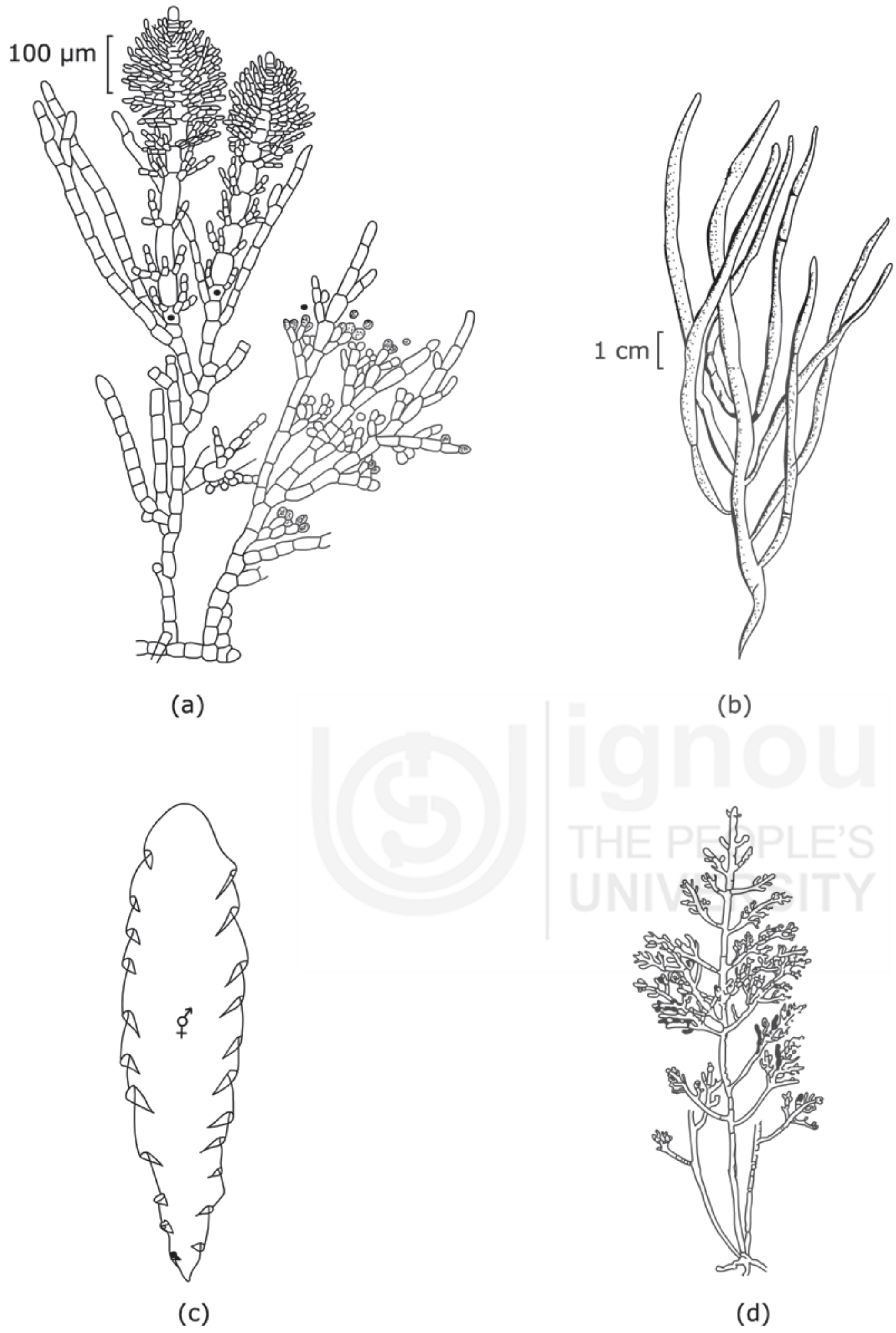


Fig. 6.14 (a-d): Some members of Rhodophyta. (a) *Batrachospermum* (diploid microthallus), (b) *Dumontia* (erect plant-macrothallus, growing from the basal crust – microthallus), (c) *Porphyra* (a full grown monoecius blade), and (*d*) *Gelidium* (whole plant). Sources: (a-c) Hoek et al., 1997, and (d) Lee, 1989.

6.4.4 Division Chlorophyta

The division Chlorophyta includes unicellular to multicellular forms and they may range from flagellate unicellular to branched or unbranched filaments, to thalloid or tubular to sheet like arrangement of cells (Fig. 6.15). Some of them also occur as colonies. Chlorophyta are primarily fresh water algae and only around ten percent (10%) are marine (order – Caulerpales, Siphonocladales). Cell structure in green algae resembles that of a typical eukaryotic cell of higher plants, and have all organelles such as chloroplasts, mitochondria, nucleus and 80S type of ribosomes. Cellulose is the main structural polysaccharide of the cell wall and xylans or mannans are also found in Caulerpales. Principle photosynthetic pigments in green algae are chlorophyll *a*, chlorophyll *b*, carotenes and xanthophylls. Members of Chlorophyta differ from the eukaryotic algae, as it forms the main storage product, i.e., starch in the chloroplast and not in the cytoplasm.

Asexual reproduction is carried by fragmentation in colonial forms; and formation of zoospores, aplanospores and autospores. Chlorophyta shows all the three types of sexual reproduction, i.e., isogamy, anisogamy and oogamy. Gametes are motile and are biflagellate, with anterior and whiplash flagella. Detailed discussion on sexual reproduction is given in Unit 7.

Examples of green algae are: *Chlorella, Chlamydomonas, Siprogyra, Cladophora, Acetabularia, Trentepohlia, Micrasterias* and *Caulerpa.*

Group – III

Division Euglenophyta, Apicomplexa and Dinophyta are a natural group of algae characterized by the presence of one membrane of chloroplast endoplasmic reticulum. We would now discuss each of them one by one.

6.4.5 Division Euglenophyta

Euglenoids are simple unicellular motile flagellates (Fig. 6.16) and occur in a variety of fresh water habitats such as ponds, streams, lakes, puddles and ditches. Some of them also inhabit marine or brackish waters. Euglenoids are also parasitic, e.g., *Khawkinsa,* and *Hegneria*. Cellular structure of euglenoids resembles that of protozoans. They have no firm cell wall and the cell surface is pellicle (thin membrane) and has helical knob-like projections. The cells have two basal bodies and have one or two emergent flagella. The flexible pellicle allows some euglenoids to undergo a flowing movement that also appears as change in cell shape. This movement is called as Euglenoid Movement. Chloroplasts of euglenoids show variety of shapes such as discoid, ribbon-like or stellate, and have chlorophyll *a*, chlorophyll *b* and carotenoids as their prime photosynthetic pigments. The main storage product is paramylon, a different type of starch that occurs as granules. Reproduction is only binary fission and in some species cysts are produced under adverse conditions. Sexual reproduction is absent.

6.4.6 Division Dinophyta

Members of Dinophyceae are found in fresh water as well as marine waters and are important members of plankton. The majority of forms are unicellular and motile. The body is divided into epicone and hypocone. The cell wall has cellulose plates inside the plasma membrane. A longitudinal flagellum emerges through the thecal plate. A typical cell consists of nucleus, chloroplast,

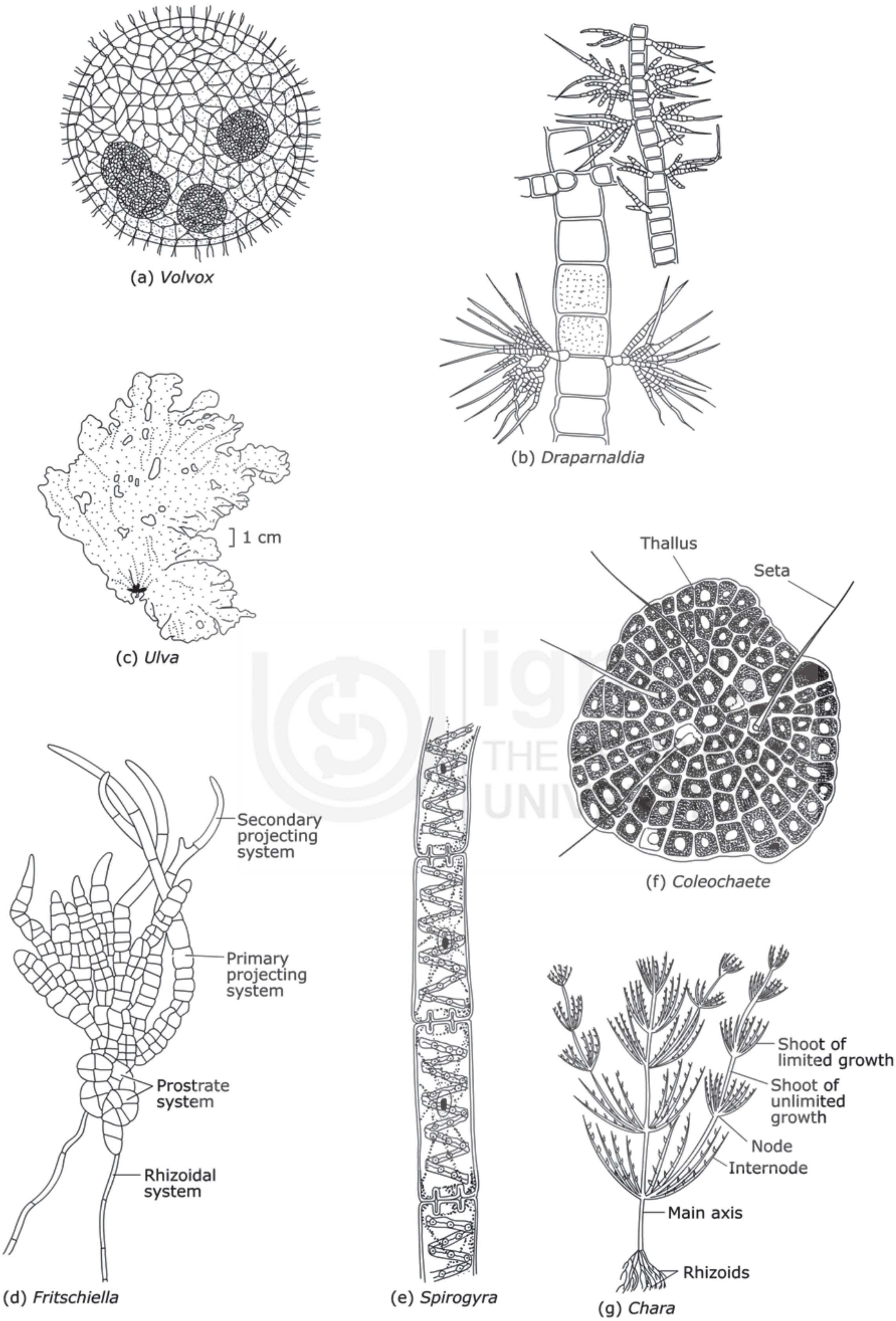


Fig. 6.15 (a-g) : Some members of Chlorophyta: a) *Volvox* (motile coenobium); b) *Draparnaldia*; c) *Ulva* (flat, blade-like gametophyte); d) *Fritschiella* (thallus); e) *Spirogyra* (a filament); f) *Coleochaete* (discoid form)*;* and g) *Chara*. Souce: (a,e) Barsanti & Gualtieri, 2006; (b,c) Hoek et al., 1997; (d,g) Singh et al., 2016; and (f) Pandey & Trivedi, 1996.

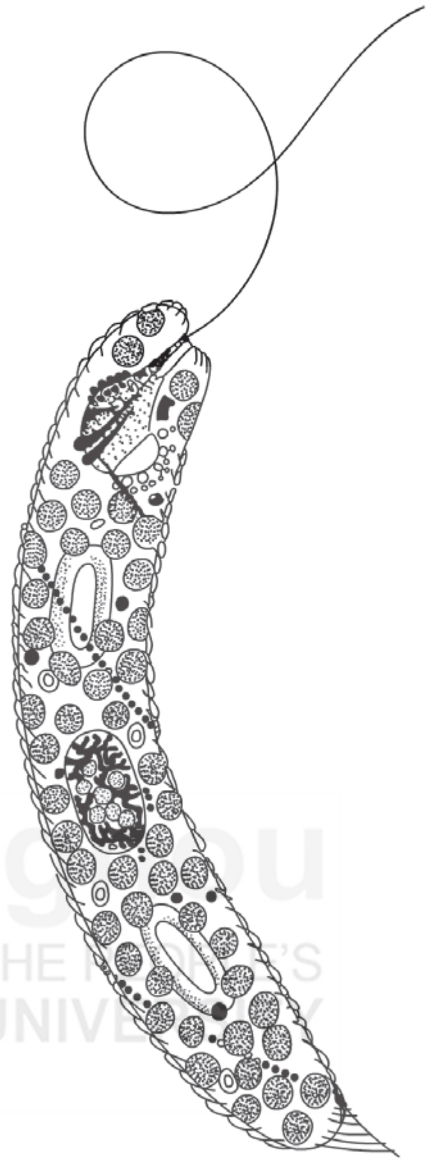


Fig. 6.16 : Diagrammatic representation of whole cell of *Euglena*. Source: Hoek et al., 1997.

endoplasmic reticulum, golgi, chlorophyll *a* and c_2 and carotenoids are chief photosynthetic pigments of dinoflagellates. Starch is the principal storage product. Marine phytoplanktons are responsible for red tide blooms.

Examples are – *Noctiluca, Gonyaulax, Peridinium* (Fig. 6.17) and *Ceratium.*

They produce asexually by simple cell division. They produce numerous aplanospores, zoospores or even non-motile cells. Isogamous type of sexual reproduction has been reported and the gametes produced are smaller than the parent cells. Some species such as *Noctiluca* are bioluminescent. Another interesting phenomenon demonstrated by members of Dinophyceae is rhythmic processes. Symbiotic dinoflagellates (zooxantellae) are formed associated with tropical and reef building corals.

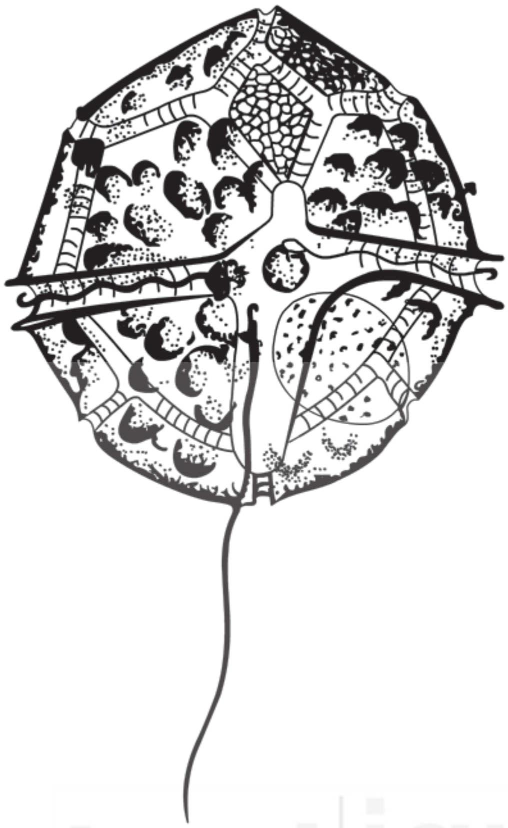


Fig. 6.17: Diagrammatic representation of *Peridinium*. Source: Hoek et al., 1997.

6.4.7 Division Apicomplexa

These algae have highly reduced plastids. These are unicellular endoparasitic with plastids called apicoplast, e.g., *Plasmodium*. They are usually grouped into algae.

Group – IV

Divisions that form a part of this group have algae that are characterized by eukaryotic algae with chloroplasts with 2 membranes of chloroplast endoplasmic reticulum.

6.4.8 Division Cryptophyta

Members of Cryptophyta (Fig. 6.18) are unicellular motile organisms that are brown in colour when alive. Many of the genera have animal like morphology and mode of nutrition. Some of them are colourless and are saprophytic in nature. Cells do not have cell wall and are dorsiventrally flattened. They have two unequal flagella that are apical in position. A cell may contain single or numerous chloroplasts. Their main photosynthetic pigments are chlorophyll *a*, chlorophyll *c*, phycocyanin, phycoerythrin and carotenoids. Starch is principal reserve food material.

Asexual reproduction is by longitudinal division of cell. Zoospores are also produced in palmelloid stage that disperse and form new thalli. Sexual reproduction has not been reported in this division.

Example – *Cryptomonas, Chroomonas.*

6.4.9 Division Heterokontophyta

Is the largest division of algae and recent (Anderson, 2004) classification system recognizes twelve classes in it namely:

- Chrysophyceae
- Synchromophyceae
- Eustigmatophyceae
- Pinguiophyceae
- Dictyochophyceae
- Pelagophyceae
- Bolidophyceae
- Bacillariophyceae
- Raphidophyceae
- Xanthophyceae
- Phaeothamniophyceae
- Phaeophyceae

Algae in this division have cells with anterior tinsel and posterior whiplash flagellum. Chlorophyll *a* and *c* are their chief photosynthetic pigments and they also contain fucoxanthin. Chrysolaminarium is their chief photosynthetic product. In the subsequent Section, we would discuss three classes in details, i.e., Bacillariophyceae, Xanthophyceae and Phaeophyceae.

Class Bacillariophyceae

Members of this class are also commonly called as diatoms, and are believed to have evolved from scaly members of Chrysophyceae.

These are unicellular and colonial forms of algae. They are widely distributed as fresh water and are found in seas and oceans as phytoplanktons. They are also found attached to wet surfaces, moist rocks and sand. Their morphology is very interesting as they have a rigid, two part, box-like cell wall that is silicified. This is called frustule and is highly ornamented on surface. Chlorophyll a, c_1 and c_2 are their principle photosynthetic pigments. Chromatophores of diatoms have high content of carotenoids particularly fucoxanthin that gives them their characteristic brown colour. Oil and chrysolaminarium are their primary storage products. Diatoms unlike other algal cells are diploid in nature. They reproduce by asexual as well sexual methods. Sexual reproduction is by fusion of two homothallic cells to form a zygote that eventually develops into an autospore, before giving rise to a new organism. The remains of the fustule form fossilized diatoms is known as diatomaceous earth and is mined and used in several industries.

Class Xanthophyceae

Members of this class are primarily fresh water and terrestrial algae with only a few marine genera. Unicellular forms are motile with one tinsel and a whiplash flagellum. There are filamentous forms also which have multinucleate cells. Chlorophyll *a*, Chlorophyll *c* and β-carotene and xanthophylls are the main photosynthetic pigments. This pigment composition gives Xanthophyceae its characteristics green yellow colour as well as its name. Cell wall has mainly

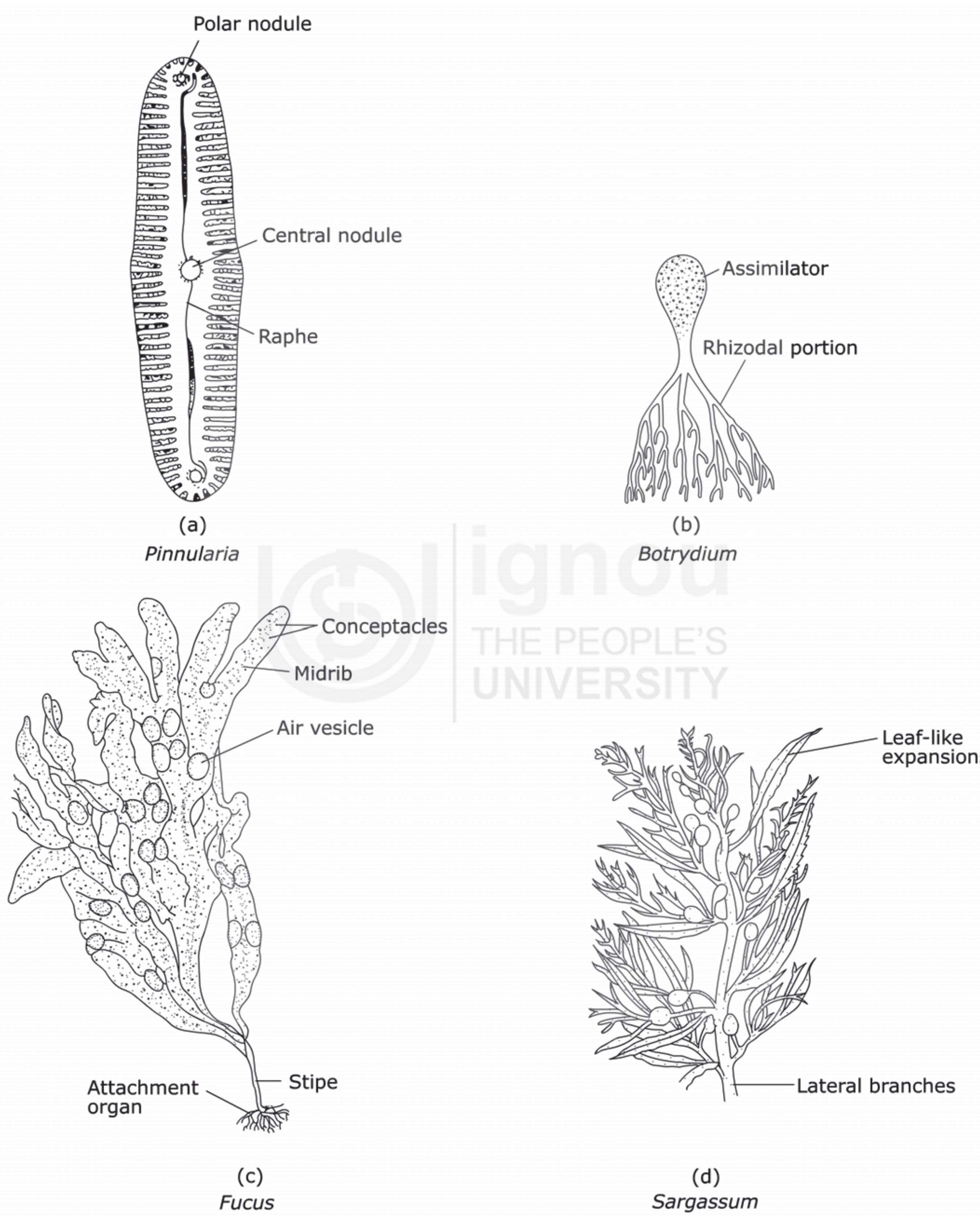


Fig 6 .18 (a-d): Some representative members of Heterokontophyta: (a) *Pinnularia* (a cell), (b) *Botrydium* (thallus), (c) *Fucus* (thallus), and (d) *Sargassum* (a branch of thallus). Source: (a) Lee, 1989; (b) Santras et al., 1993; and (c,d) Singh et al., 2016.

pectin, silica and some amount of cellulose and frequently contains two overlapping halves. Asexual reproduction is by fragmentation, biflagellate zoospores and aplanospores. Sexual reproduction has been reported in few genera. In *Vaucheria* it is oogamous type, e.g., *Vaucheria*.

Class Phaeophyceae

Members of class Phaeophyceae have the most complex morphology, and thalli may range from simple branched filamentous to massive pseudoparenchymatous bodies. However there are no unicellular or colonial forms. Majority of the genera are marine in habitat. They occur as sea weeds and are known as Kelps. They have high economic importance and are rich source of iodine, agar and related products. Cell wall of brown algae is complex and is rich in cellulose, algin and fucoidin. Principal photosynthesic pigments are cholorophyll *a*, cholorophyll *c* and carotenoids. Fucoxanthin, a carotenoid is present in very high concentration and it gives brown algae its name and characteristic colour. Sexual reproduction ranges from isogamy to oogamy. Motile swarmers have two unequal laterally inserted flagella. You would learn about *Fucus* in detail in Unit 7, e.g., *Ectocarpus, Fucus, Laminaria*

6.5 SUMMARY

- Algae are autotrophic, aquatic organisms that occur in diverse forms ranging from microscopic cellular to giant thalloid forms attached to rocks in the sea.
- Thallus or plant body show a range of morphological forms and may be distinguished as unicellular, colonial, filamentous, thalloid and polysiphonoid.
- They reproduce vegetatively, asexually as well as sexually.
- All other divisions of algae have eukaryotic cells with cell walls, chloroplasts, nucleus, mitochondria, endoplasmic reticulum, vacuoles, dictyosomes, flagella and eyespot.
- A typical flagella of algae show 9+2 arrangement of microtubules and is covered by a plasma membrane. They may have tiny hair on their surface – tinsel or may be without hair – whiplash.
- Algae show a great diversity in life cycles. All types of life cycles such as Haplontic, *Oedogonium*; Diplontic, *Fucus*; Isomorphic, *Ectocarpus*; Heteromorphic, *Laminaria;* and Triphasic, *Polysiphonia* are found in algae.
- Algae are primarily divided into four distinct groups based upon the type of cell and number of membranes surrounding chloroplasts. Previously pigment composition and principal storage product was also considered important for designing classification.
- Division Cyanophyta have an assemblage of prokaryotic algae that occur as single cells or simple filaments enclosed in mucilaginous

sheath. Their primary photosynthetic pigment is chlorophyll *a*, phycobilins, C-phycocyanin and phycoerythrin and carotenoids. Cells show a typical prokaryotic ultrastructure in which cell wall encloses photosynthetic lamella, nucleoplasm and ribosomes. Specialized cells called heterocysts occur in filamentous forms and facilitates in the process of reproduction and Nitrogen (N_2) fixation.

- Division Cyanophyta comprises of an assemblage of prokaryotic algae that are also known as blue-green algae. Recently it has been shown that they are more closely related to bacteria and hence the term Cyanobacteria is often used for them, e.g., *Aanabaena, Nostoc.*

- Division Glaucophyta comprises of algae that have endosymbiotic cyanobacteria in them instead of chloroplasts. Hence, they are thought to represent intermediate forms depicting evolution of chloroplasts, e.g., *Cyanophora paradoxa* and *Glaucocystis.*

- Division Rhodophyta is the most primitive group of eukaryotic algae. Its primary photosynthetic pigment is chlorophyll *a*, chlorophyll *d* and phycobilliproteins namely phycoeryththrin and phycocyanins and chief storage product is floridean starch, e.g., *Porphyra,* and *Polysiphonia*.

- Members of division Chlorophyta show a range of thallus. Their principle photosynthetic pigments are chlorophyll *a*, chlorophyll *b*, carotenes and xanthophylls. The main storage product, i.e., starch is stored in the chloroplasts, e.g., *Chlamydomonas, Oedogonium*.

- Euglenoids are simple unicellular motile flagellates and occur in a variety of fresh water habitats. Chloroplasts occur in variety of shapes such as discoid, ribbon like or stellate, and have chlorophyll *a*, chlorophyll *b* and carotenoids as their prime photosynthetic pigments. The main storage product is paramylon.

- Members of Dinophyceae are found in freshwater as well as marine waters and are important members of plankton. They are unicellular, motile and body is divided into epicone and hypocone. They contain chlorophyll *a*, c_2 and carotenoids as chief photosynthetic pigments, and starch as their storage product.

- Xanthophyceae members are primarily fresh water and terrestrial algae with only a few marine genera. Cholorophyll *a*, *c* and ²-carotene and xanthophylls are the main photosynthetic pigments, e.g., *Vaucheria*.

- Members of class Phaeophyceae have the most complex morphology, and thalli may range from simple branched filamentous to massive pseudoparenchymatous bodies. Majority of the genera are marine in habitat. They occur as sea weeds and are known as Kelps. They have high economic importance and are rich source of iodine, agar and related products. Cell wall of brown algae is complex and is rich in cellulose, algin and fucoidin. Principal photosynthetic pigments are cholorophyll *a*, *c* and carotenoids, e.g., *Fucus.*

6.6 TERMINAL QUESTIONS

1. Write short notes on:

   i) Colonial plant body

   ii) Tetrasporal groups

   iii) Akinetes

   iv) Zoospores

   v) Autogamy

2. Answer the following questions in 150 words.

   i) Define algae. Enumerate characteristic features of algae.

   ii) Describe the cell structure in *Nostoc*. How is it different from that of *Chlamydomonas*?

   iii) What are the different types of life cycles represented by algae? Illustrate each one of them with suitable example.

   iv) "Thallus in algae ranges from simple unicellular forms to complex thalloid forms". Elaborate the statement and give suitable examples.

   v) Give an outline of the classification system of algae.

   vi) Discuss the evolution of sex in algae. What advantages does sexual reproduction has over vegetative reproduction?

6.7 ANSWERS

Self Assessment Questions

1. a) i) True

   ii) False

   iii) False

   iv) True

   b) i) *Microcystis*

   ii) *Nostoc*

   c) i) *Chlamydomonas*

   ii) Protoplasmic threads

   iii) *Microcystis*

   d) i) Refer Sub-section 6.2.1

   ii) Refer Sub-section 6.2.1

   iii) Refer Sub-section 6.2.1

e) i) 1-b

ii) 2-a

iii) 3-d

iv) 4-c

2. a) ii) *Chlamydomonas*

b) i) akinetes

ii) aplanospores

iii) hormogonia

iv) palmella stage

v) Monoecious / homothallic

vi) Dioecious / heterothallic

vii) isogamy

viii) anisogamy

c) i) haploid

ii) zygospore

3. a) i) meiosis

ii) *Ulothrix*

iii) Haploid, diploid

iv) diplontic

b) i) heteromorphic

ii) isomorphic

iii) haplontic

Terminal Questions

1. i) Subsection 6.2.2

ii) Subsection 6.2.2

iii) Subsection 6.3.2

iv) Subsection 6.3.2

v) Subsection 6.3.3

2. i) Introduction

ii) Subsections 6.4.1 and 6.4.4

iii) Subsection 6.3.5

iv) Subsection 6.2.2

v) Section 6.4

vi) Subsection 6.3.4

6.8 GLOSSARY

Algae	:	Autotrophic, aquatic organisms that occur in diverse forms ranging from microscopic to giant thalloid forms.
Prokaryotic algae	:	The algae that have cells that are not enclosed by membrane bound organelles.
Nucleoplasm	:	The central portion of a prokaryotic cell that contains the DNA.
Heterocyst	:	Thick-walled cell that helps in fixing nitrogen in filamentous Cyanophyceae such as *Nostoc*.
Eukaryotic cell	:	Algae except Cyanophtya have cells that have membrane bound organelles such as chloroplast, nucleus, and mitochondria.
Flagella	:	Organs that confer motility to algal cells and help them to swim.
Eyespots	:	Red-coloured organelles found in Chlorophyceae and Phaeophyceae.
Zoospores	:	Motile spores that help in asexual reproduction.
Aplanospores	:	Thick-walled, non-flagellate spores that facilitate asexual reproduction.
Hypnospores	:	Thick-walled, non-motile spores formed under unfavourable conditions.
Isogamy	:	Type of sexual reproduction where male and female gametes are morphologically and physiologically identical.
Oogamy	:	Sexual reproduction in which male gamete is small and motile, and female gamete is large and immotile.

6.9 FURTHER READING

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UNIT 7

ALGAE : MORPHOLOGY AND LIFE CYCLES

Structure

7.1 INTRODUCTION

In Unit 6 you have learnt about the basic characteristic features of algae, their distribution, types of thalli, modes of reproduction and different systems of their classification. The body of an alga is called thallus as it is not differentiated into true root and shoot system. Thallus shows a lot of morphological and anatomical variations. It may range from single celled or colonial forms, to multicellular forms that may be filamentous uniseriate or branched; or complex and highly differentiated multicellular thallus. In colonial forms, a cell divides and the daughter cells remain together enclosed in a mucilaginous mass to form a colony of cells, *e.g.*, *Volvox*. Division of a cell continuously in the same plane, with daughter cells sticking together, results in a row of cells forming a filament, e.g., *Oscillatoria*. Some of the cells of a filament divide only once by a vertical plane followed by transverse divisions repeatedly and produce a branched filament. Further, when all the cells of a filament undergo divisions in cross and vertical planes it results in a sheet of one or more cells in thickness. Such multicellular thallus may show complicated differentiation as in seaweed such as *Fucus*. Thalli of algae of various morphological forms bear different types of specialised sporulating structures that help in the process of reproduction.

In this Unit, you will study in detail, various morphological types of thalli in algae, their modes of reproduction and life cycles. Each of these types is described below.

Objectives

After studying this unit, you will be able to:

- list different types of morphological forms of algae with suitable examples of each;
- differentiate between colonial and thalloid forms;
- explain the mechanism of reproduction in *Nostoc*, *Chlamydomonas*, *Fucus*, *Vaucheria, Polysiphonia*;
- assign some important genera of algae to their correct taxonomic ranks; and
- describe the life cycles of *Nostoc*, *Chlamydomonas*, *Fucus*, *Vaucheria* and *Polysiphonia*.

7.2 MORPHOLOGY AND LIFE CYCLES

7.2.1 *Nostoc*

Taxonomic position

Division : Cyanophyta

Class : Cyanophyceae

Order : Nostocales

Family : Nostocaceae

Genus : *Nostoc*

Occurrence: *Nostoc* is a filamentous algae that is found in both aquatic as well as terrestrial habitat. It occurs in colonies in which filaments called trichomes are embedded in mucilagenous matrix. These colonies vary in size and shape, and may be microscopic to a size of a pea seed. Terrestrial species such as *Nostoc commune* occur as leathery sheets on damp soil. Some species of *Nostoc* are also found in symbiotic association with fungi to form lichens. They are also found associated with *Anthoceros* and coralloid roots of *Cycas*. Some species of *Nostoc* are also grown in rice fields as they have the capability to fix atmospheric Nitrogen.

Habit: A typical colony of *Nostoc* has numerous filaments that appear like strings on beads (Fig. 7.1). These filaments called trichomes vary in length and have a sheath of mucilage around it. It is made up of numerous cells that may be round to oval and are prokaryotic and have no membrane bound organelles (Fig. 7.2). Within the trichomes there are specialised colourless, empty looking cells called heterocysts, are found in filaments at regular

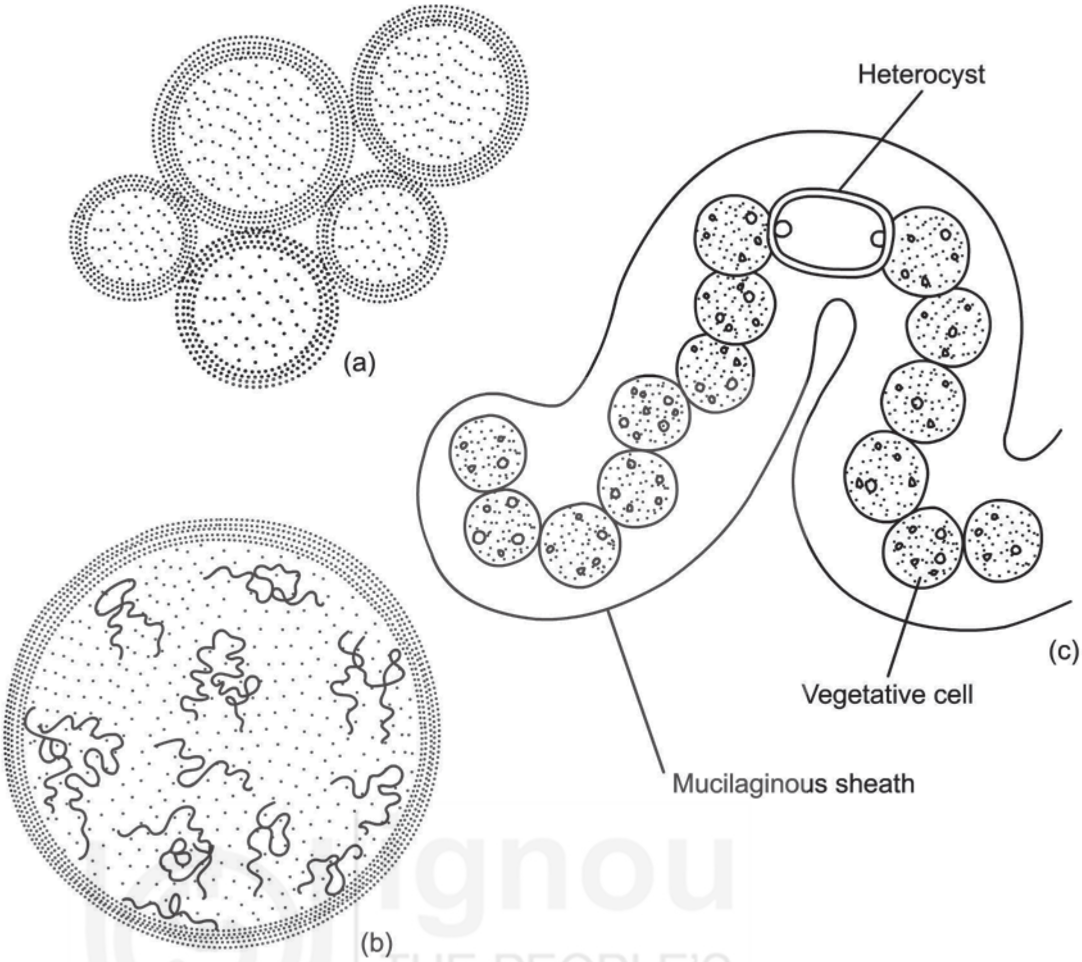


Fig. 7.1 : Habit of *Nostoc* sp.: a) External morphology of colony; b) An enlarged colony; c) A portion of filament enlarged.
***Source:* Pandey & Trivedi, 1996.**

intervals. These are larger and thick-walled cells and help in the process of reproduction.

Reproduction: *Nostoc* shows only vegetative means of reproduction which have been described below:

Hormogonium: When trichomes break at the junction of heterocyst and vegetative cell the fragment formed is called hormogonium. It slips out of the parent colony and divides to form new colonies. In the daughter filament, the terminal cell forms the heterocyst as seen in *N. commune*. It also reproduces by forming akinetes and endospores (Recall Unit: 6, Sub-section: 6.3.1)

7.2.2 *Chlamydomonas*

Division : Chlorophyta

Class : Chlorophyceae

Order : Volvocales

Family : Chlamydomonadaceae

Genus : *Chlamydomonas*

Occurrence: The family Chlamydomonadaceae comprises of unicellular, motile algae with a distinct cell wall and cup-shaped chloroplast. It is found in

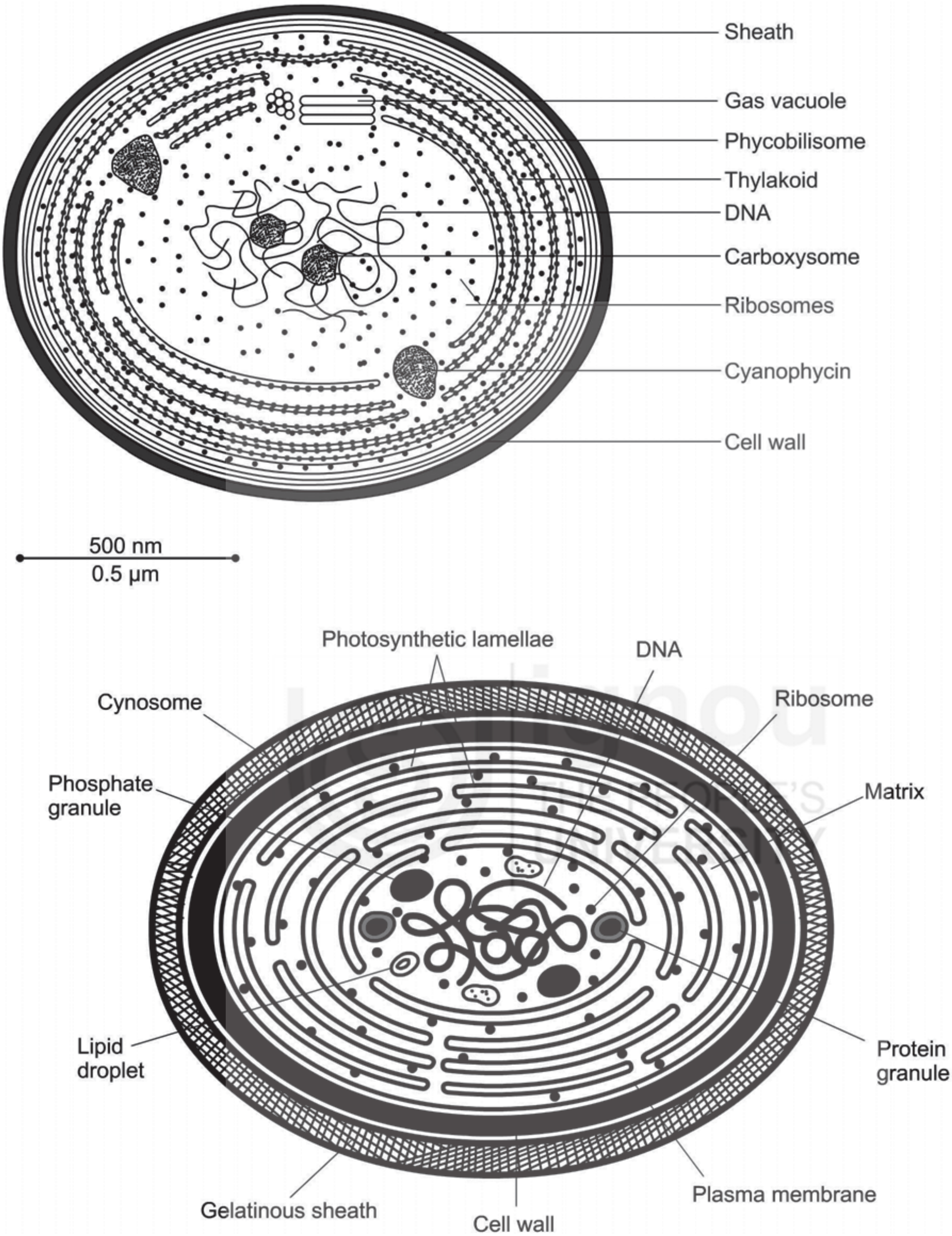


Fig. 7.2 : Ultrastructure of Cyanobacterial cells that closely resemble the *Nostoc* thallus. *Source*: https://www.google.co.in/search?q=ultrastructure+of+nostoc+cell&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj2w_H45L LVAhWKuo8KHWin AQgQ_AUICigB&biw=1366 &bih=627#imgrc=egHYvOwCkmTd2M

fresh water such as ponds, rivers and ditches. It often forms a green scum like covering on the surface of ponds. Species such as *C. halophila* grows well in marine environment. *C. yellowstonensis* grows on snow covered mountains of the Yellow Stone National park in USA giving it it’s characteristic yellowish appearance.

Habit: *Chlamydomonas* is one of the most primitive and simple free swimming eukaryotic organisms. The plant body is oval, unicellular, motile with two flagellae. The protoplast is surrounded by cell wall. A single nucleus is centrally located in the cell. A prominent basal cup-shaped chloroplast that has a pyrenoid is also present in the cell. It also contains two vacuoles at the base of the flagella that help in osmoregulation. A red eye spot or stigma acts as a photoreceptor and occurs towards the anterior end of the cell. Two anteriorly located whiplash type flagellae facilitate movement of the cell (Fig. 7.3).

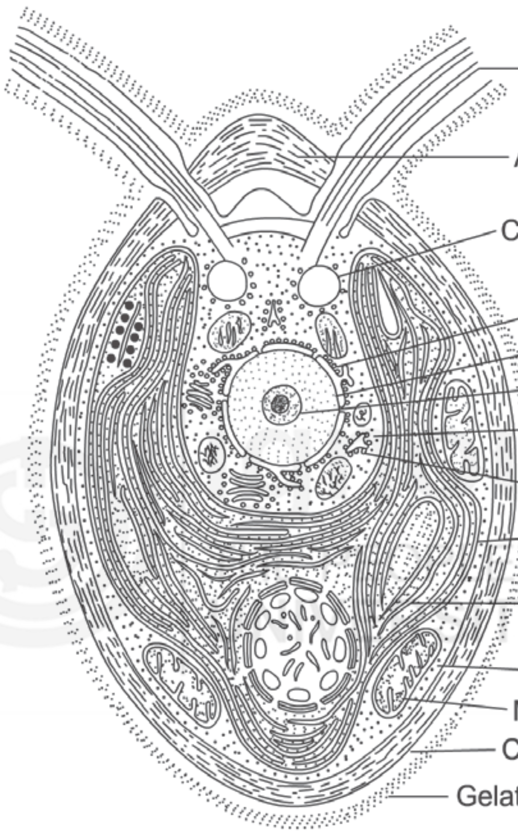


Fig. 7.3 : Diagramatic representation of a transmission electron micrograph of a single cell of *Chlamydomonas* showing two flagellae, a cup-shaped chloroplast, centrally placed nucleus. *Source :* Hoek et al, 1997.

Chlamydomonas cell is haploid. It reproduces by both asexual as well as sexual methods. **Asexual reproduction**: It takes place by formation of specialised spores such as zoospores, *i.e.,* aplanospores and hypnospores.

Zoospores: These are formed under favourable conditions from a vegetative cell that loses motility by retracting flagellae. The vacuoles disappear, protoplasm withdraws from the cell and it becomes quiescent. The protoplast divides longitudinally and after successive divisions form numerous daughter protoplasms that eventually develop flagellae of their own. These motile, bi-flagellate spores called zoospores eventually grow to form a new plant body (Fig. 7.4).

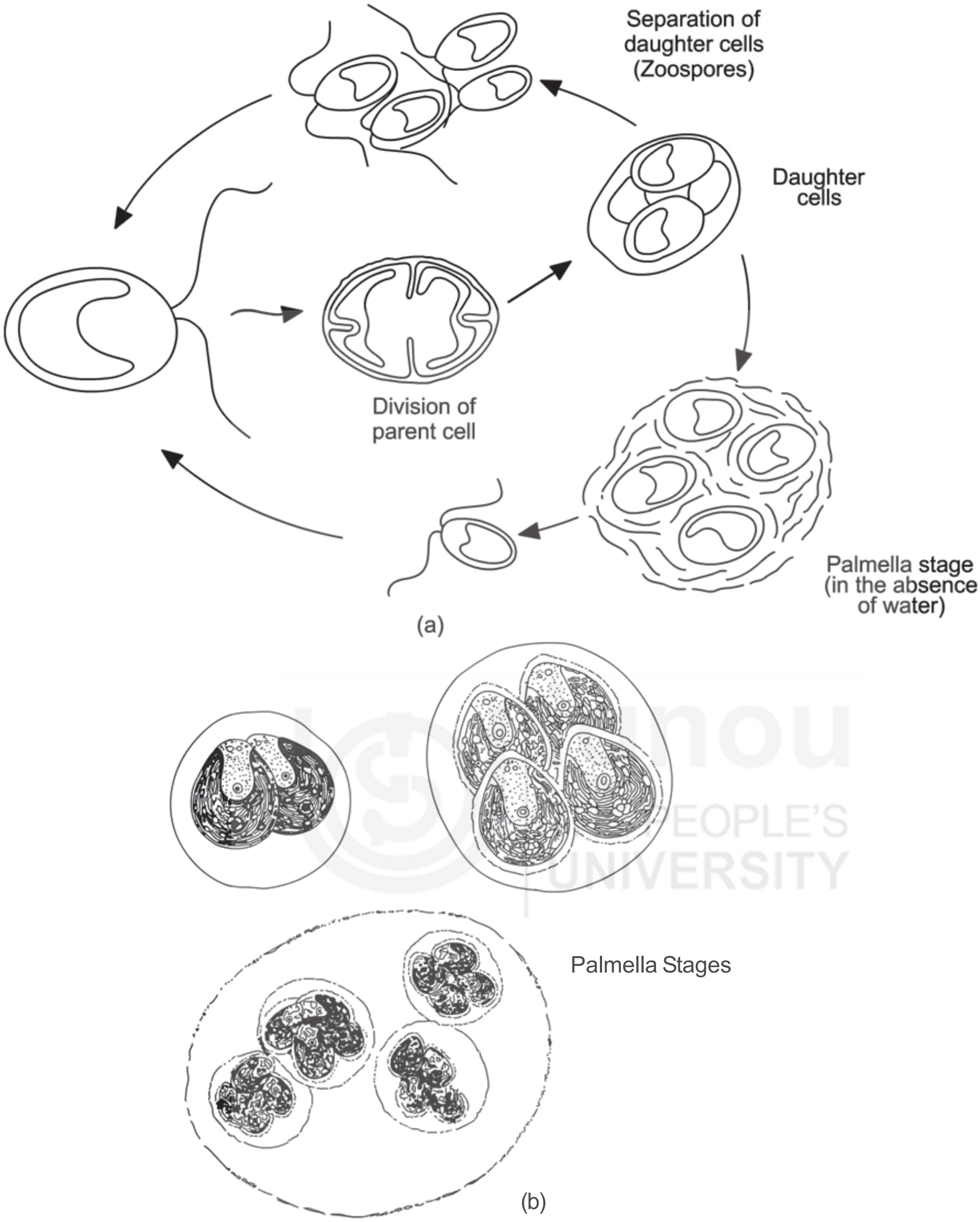


Fig. 7.4 : Diagrammatic representation of formation of zoospores and Palmella Stage in Volvocales. ***Source :*** **(a) Philip, 1986; b) Pandey & Trivedi, 1996.**

Palmella stage: Under unfavourable conditions, *Chlamydomonas* cells lose their flagellae, and their protoplasts divide repeatedly to form two to eight daughter cells. This forms a colony of immotile cells embedded into mucilaginous mass, and is known as the Palmella Stage (Fig. 7.4). When favourable conditions return, these cells regain motility and escape from the mucilaginous mass to form new motile cells. In some conditions, species such as *C. nivalis*, the immotile Palmella Stage develops a thick wall around itself that is red due to the presence of a red pigment haematochrome. This red colored, thick-walled structure is called the hypnospore.

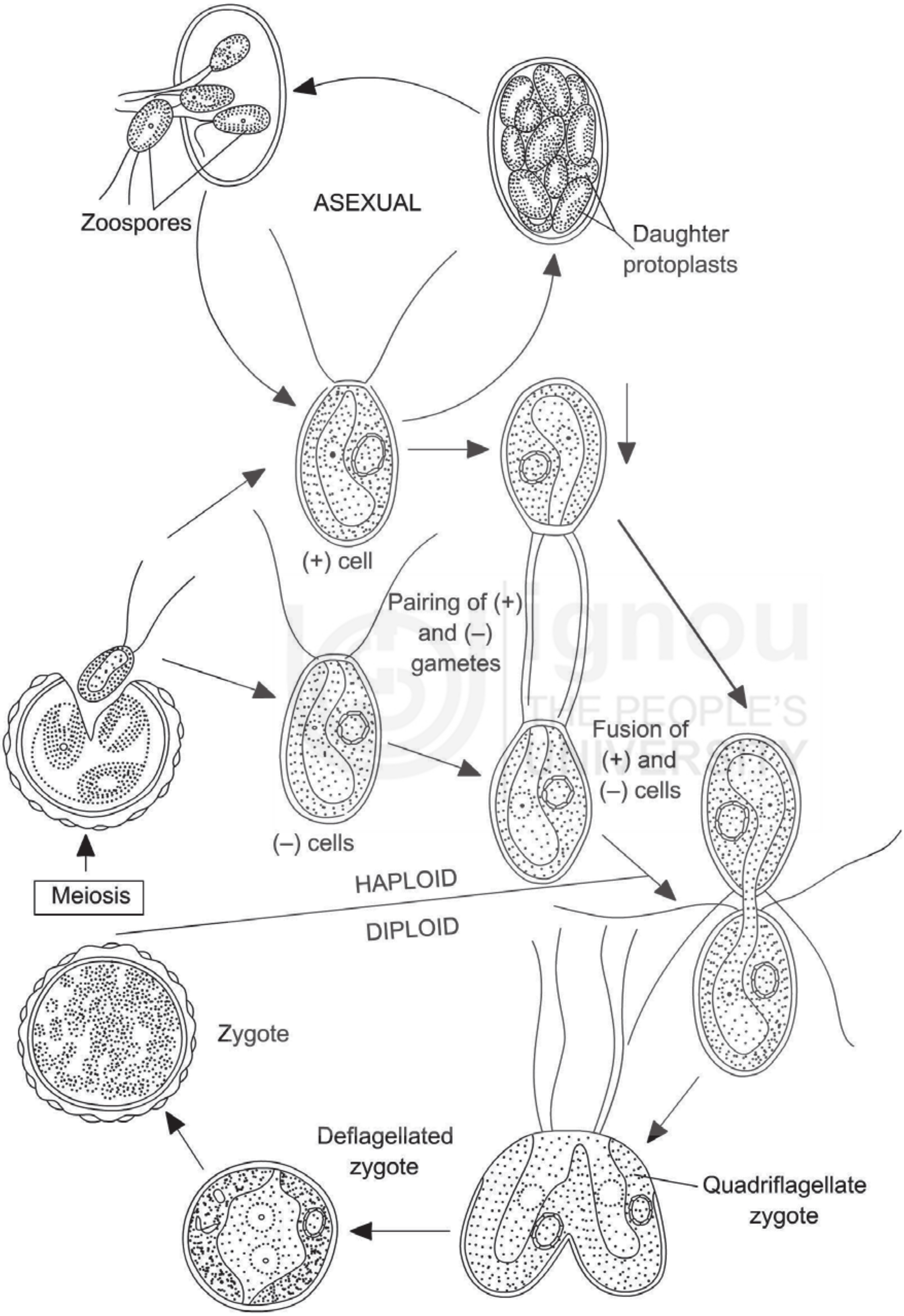
Sexual Reproduction: Sexual reproduction is seen under certain conditions such as low nitrogen, nutrient deficiency, high CO_2 concentration and presence of calcium. *Chlamydomonas* shows all the three forms of sexual reproduction, Isogamy, Anisogamy as well as Oogamy (Fig. 7.5).

Isogamy: In isogamous type of sexual reproduction mating takes place between gametes that are similar in size, shape and form and are therefore called isogametes. *Chlamydomonas* shows isogamous reproduction in homothallic species such as *C. moewusii* (with no + and – strains), as well as heterothallic species (Species with + and – strains). During mating the gametes come and lie facing each other. Gametes of opposite mating types are recognised by each other with the help of certain chemical signals such as isoglutinins. Protoplasts of the two gametes fuse to form a zygote that develops a thick wall around itself. This enters into a period of rest and is called zygospore that eventually divides and releases several motile cells (Fig. 7.5a)

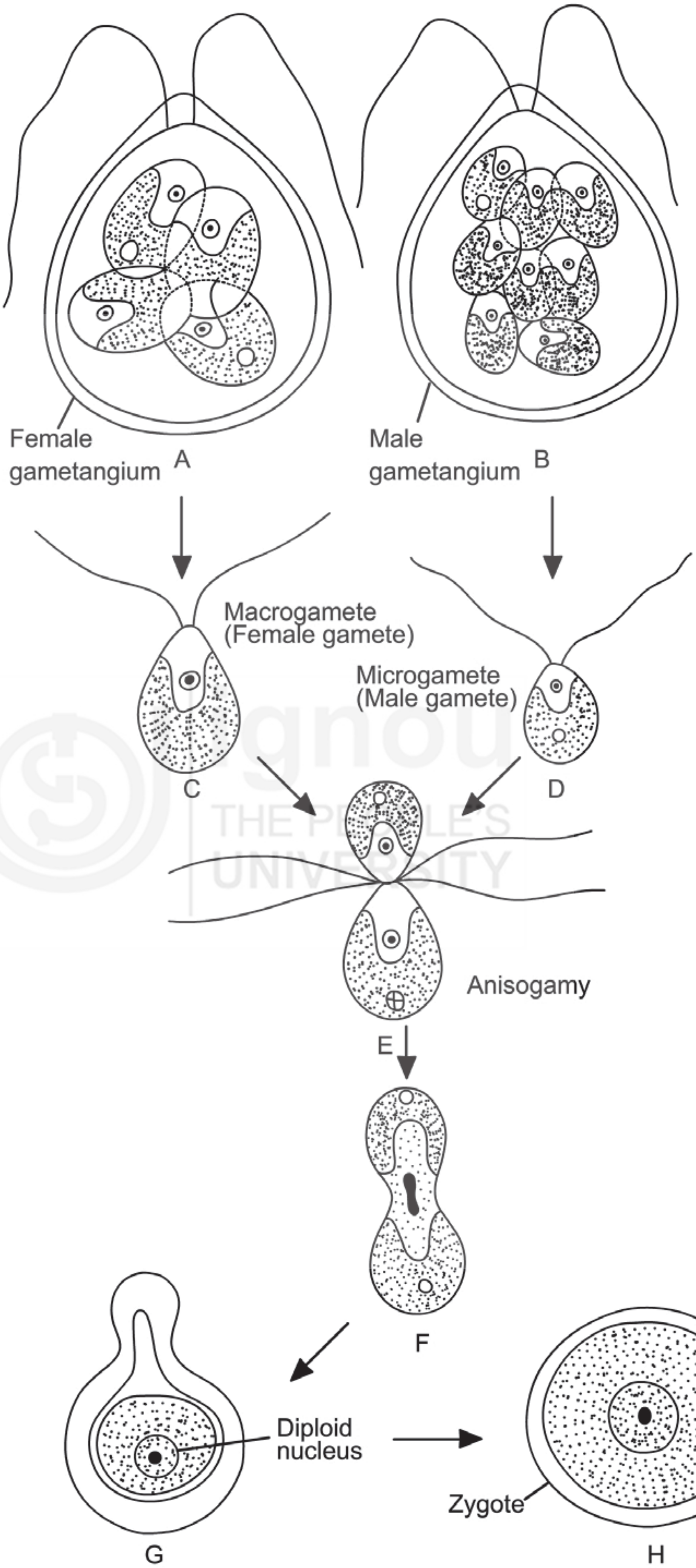
Anisogamy: *Chlamydomonas monoica* demonstrates physiological anisogamy and is considered to be an intermediate form between isogamy and anisogamy. In *C. braunii* gametes are morphologically different. The male gametes are smaller are called as microgametes, and female gametes are larger and are called as megagametes (Fig. 7.5b).

Oogamy: *C. coccifera* shows oogamous type of sexual reproduction in which the male and female gametes are distinctly different. Male cell produces sixteen biflagellate microspores, and female cell rounds off to produce a single large macrogamete. The two protoplasts fuse to form a zygote that forms an immotile resting zygospore. The diploid zygospore divides meiotically to form four haploid nuclei that eventually form motile meiospores. These develop flagella and are released from a new adult of the next generation (Fig. 7.5c).

Life cycle: Life cycle of *Chlamydomonas* has two phases, haploid and diploid (Fig. 7.6). The motile *Chlamydomonas* cell represents the haploid phase. Also the various asexual spores (zoospores, aplanospores, hypnospores, palmella stage) and gametes that it produces are haploid. Diploid stage is represented by the zygote that is formed upon fusion of two opposite mating types.


Zoospores
ASEXUAL
Daughter protoplasts
(+) cell
Pairing of (+) and (–) gametes
(–) cells
Fusion of (+) and (–) cells
Meiosis
HAPLOID
DIPLOID
Zygote
Deflagellated zygote
Quadriflagellate zygote

(a)


Female gametangium
A
Male gametangium
B
Macrogamete (Female gamete)
Microgamete (Male gamete)
C
D
Anisogamy
E
F
Diploid nucleus
Zygote
G
H

(b)

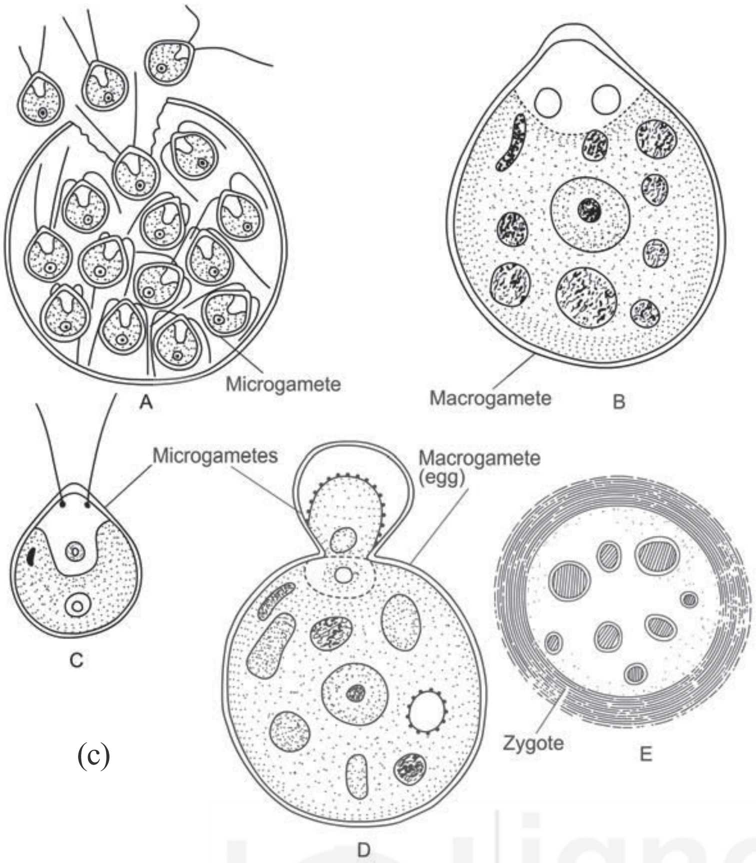


Fig. 7.5 : Sexual reproduction in *Chlamydomonas*: a) Isogamy, b) Anisogamy, c) Oogamy. *Source :* Singh et al, 2016.

SAQ 1

1. Write whether the following statements are True or False:

   a. *Nostoc* belongs to Chlorophyceae.

   b. *Nostoc* is able to fix atmospheric Nitrogen.

   c. *Chlamydomonas* is a unicellular non-motile alga.

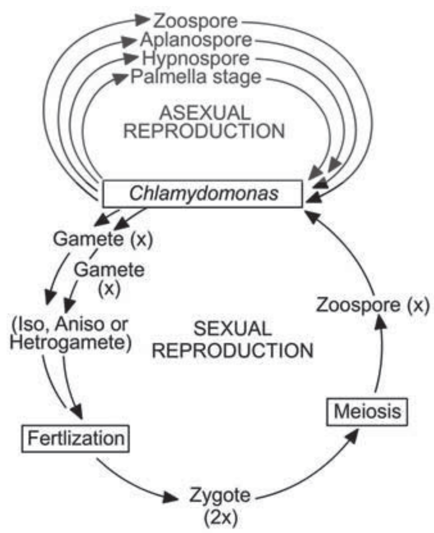


Fig. 7.6 : Diagrammatic representation of life cycle of *Chlamydomonas.* *Source :* Singh et. at. 2016

2. Fill in the blanks:

   a. .... chloroplast is present in *Chlamydomonas.*

   b. .... is the characteristic pigment of Cyanophyceae.

   c. *Nostoc* filament is covered by a ....sheath.

   d. Filaments of *Nostoc* that break from the junction of a heterocyst and a vegetative cell is known as ....

7.2.3 *Oedogonium*

Division : Chlorophyta

Class : Chlorophyceae

Order : Oedogoniales

Family : Oedogoniaceae

Genus : *Oedogonium*

Occurrence: Order Oedogoniales comprise of group of green algae that are filamentous and occur in fresh water preferably standing. Genus *Oedogonoium* is a fresh water alga occurring in ponds, streams and lakes. Plants are upright and are attached to substratum such as rocks. They also occur as epiphytes on other algae and aquatic plants.

Habit: The thallus is an unbranched filament that is attached to the substratum by a special cell known as holdfast (Fig. 7.7). Cells of the filament are cylindrical with a thin plasma membrane, cytoplasm and a single parietal nucleus. There is a large central vacuole that contains cell sap. Chloroplast is reticulate and occurs as a network that almost occupies the cell. The padded regions in chloroplasts contain the pyrenoids. The genus shows a characteristic pattern of cell division in which the parent cell wall breaks and

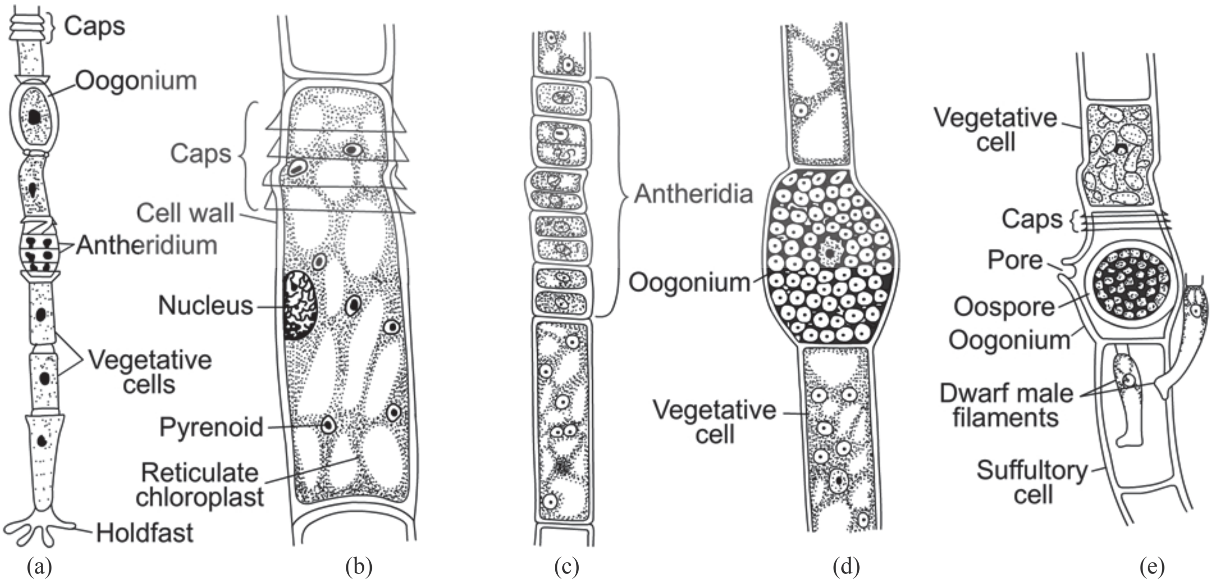


Fig. 7.7 : Diagrammatic representation of *Oedogonium* showing: a) A filament with holdfast, cap cells, oogonium and antheridium; b) A cell; c) Antheridia; d) Oogonium; and e) Dwarf male filament. *Source* : Singh et al., 2016, and b-c) Santra et al.

forms annular rings toward the apical end. These rings are called as apical caps and are made up of hemicellulose. Cells that possess these caps are known as cap cells. Cap cells also function as zoosporangia and facilitate asexual reproduction. C*ell wall is made up of chitin, pectin and cellulose. Cell division on* Oedogonium is a specialised process and leads to the formation of cells with peculiar ring-like scar called caps at their anterior ends. The following are the steps in the process of cell division in *Oedogonium*:

i) Nucleus of the cell to be divided moves to the centre of the cell from the periphery. A ring-like structure composed of wall material appears towards the upper end of the cell.

ii) The ring increases in thickness and forms a groove-like structure. Simultaneously the nucleus moves upwards and divides.

iii) Cell elongates to almost double of its original size. The distal half of the cell has membrane obtained from the stretching of the ring. After cytoplasmic division and wall formation, two daughter cells are produced. The upper daughter cell has cell wall made up in two parts; one from stretching of the ring and other from the new cell wall. This combination of two sources of cell wall leads to formation of cap-like structure that is a characteristic feature seen only in *Oedogonium*.

Reproduction: *Oedogonium* reproduces by vegetative, asexual as well as sexual methods.

Vegetative: In vegetative reproduction, simple fragmentation of the filament leads to the formation of new daughter filaments. Fragmentation may take place by accidental breakage of filaments or by dying of intermittent cells in the fragments.

Asexual reproduction: It is mediated by the formation of zoospores and akinetes. Any cap cell of the filament can function as a zoosporangium and produces a single zoospores. Zoospore is green, spherical or pear-shaped structure with a ring of flagella at the base of a beak-like protrusion. This arrangement of flagella is known as stephanokont. A typical zoospore has a chloroplast, several vacuoles and an eye spot. After liberation, the zoospore settles on a substratum and the basal cell differentiates to form a holdfast (Fig. 7.8).

Akinetes are thick-walled resting structures formed by modification of vegetative cells during a period of unfavourable growth conditions. At the onset of suitable conditions, these reddish brown akinetes germinate to form a new vegetative filament.

Sexual reproduction: *Oedogonium* shows an advanced type of oogamy wherein the gametes are morphologically distinct and are borne on specialised reproductive organs called gametangia. These gametangia are modified cells in a filament and are known as antheridium and oogonium that bear the male and female gametes, respectively. Development of sexual filaments is favoured by environmental conditions such as light, alkalinity, CO_2 concentration and nitrogen deficiency. Distribution of sex organs in *Oedogonium* is very peculiar and based upon distribution of sex organs, species may be macrandrous and nannadrous.

Macrandrous species are the ones in which the antheridia are borne on the filaments of normal size. These may further be monoecious, where the male and female gametangia are borne on the same filament e.g. *O. nodulosum*, *O. fragile* or dioecious, where the male and female gametangia are borne on separate filaments e.g. *O. crassum* and *O. aquaticum* (Fig. 7.9).

Nannandrous species *e.g. O. concatenatum* are the ones in which antheridia are borne on special reduced filaments called nannandria or dwarf males. The zoospores produced by nannandrous species are small

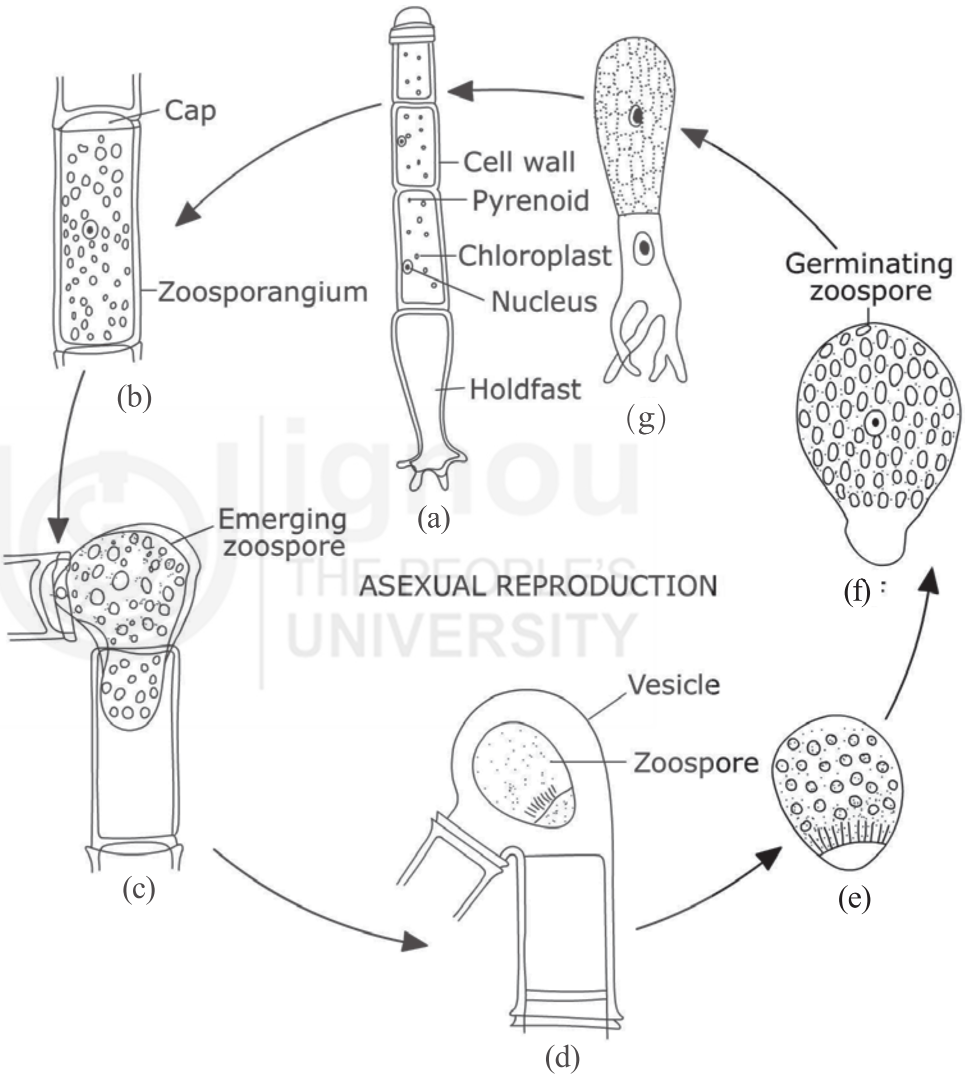


Fig. 7.8 : Stages in asexual reproduction in *Oedogonium*: a) A filament; b) zoosporangium; c-d) Liberation of zoospore; e) A zoospore; f-g) Germination of zoospore. *Source :* Singh et.al. 2016.

and are called as androspores which are borne on androsporangia. Androsporangia are produced singly, are flat, cylindrical discoid cells that resemble antheridia but are larger in size (Fig. 7.9).

Antheridia: Male reproductive organs, known as antheridia may be borne in terminal or intercalary in position and arise by multiple divisions in antheridial mother cell. They are short, flat, cylindrical and disc-like

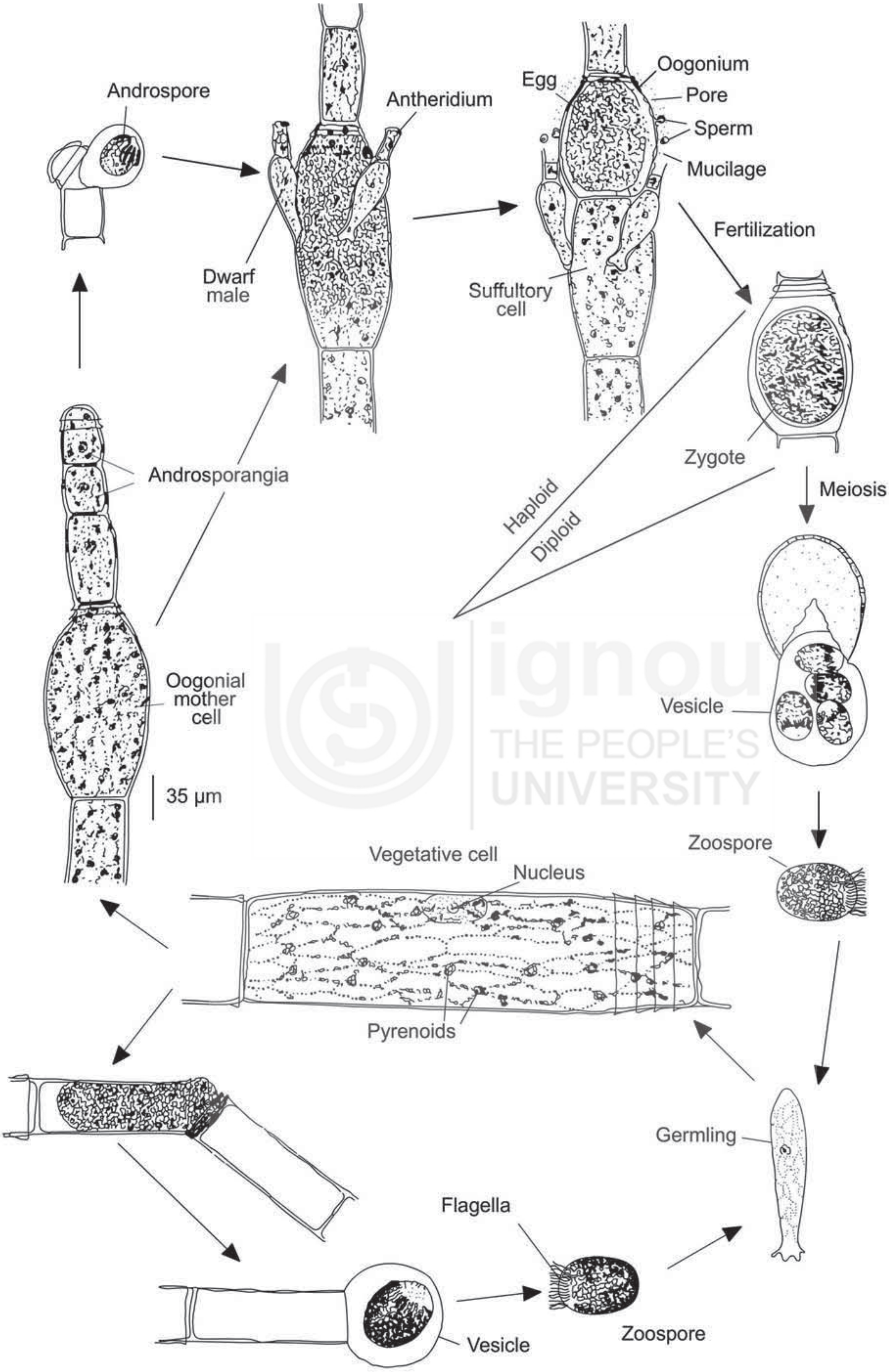


Fig. 7.9: ***Oedogonium*** **distribution of sex organs: Life cycle in Nannandrous species, Source: Smith, 1955.**

segments of a filament that occur in series. Division in protoplast leads to formation of sperms that are pale green and spherical with a beak-like protrusion. Each antheridium usually produces two sperms which have a ring of flagella at their anterior end. After being released from the antheridium, sperms swim and reach to the oogonium.

Oogonium: Any cap cell may function as an oogonial mother cell, and it divides to form an oogonium which is round or oval structure with cap cells at the apex. Cells of the filament below this are known as suffultory cells or supporting cells. The egg cell is rich in reserve food material and has a centrally placed nucleus. It is green in colour due to the presence of chlorophyll.

The process of fertilization is facilitated by water, and sperms swim into the oogonium through a slit in the oogonium wall. After fusion of two nuclei, the zygote secretes a thick wall around itself and germinates to form the new filament. In some species it does not germinate immediately, but after the resting period is over. Life cycle of *Oedogonium* is represented below in Fig. 7.10.

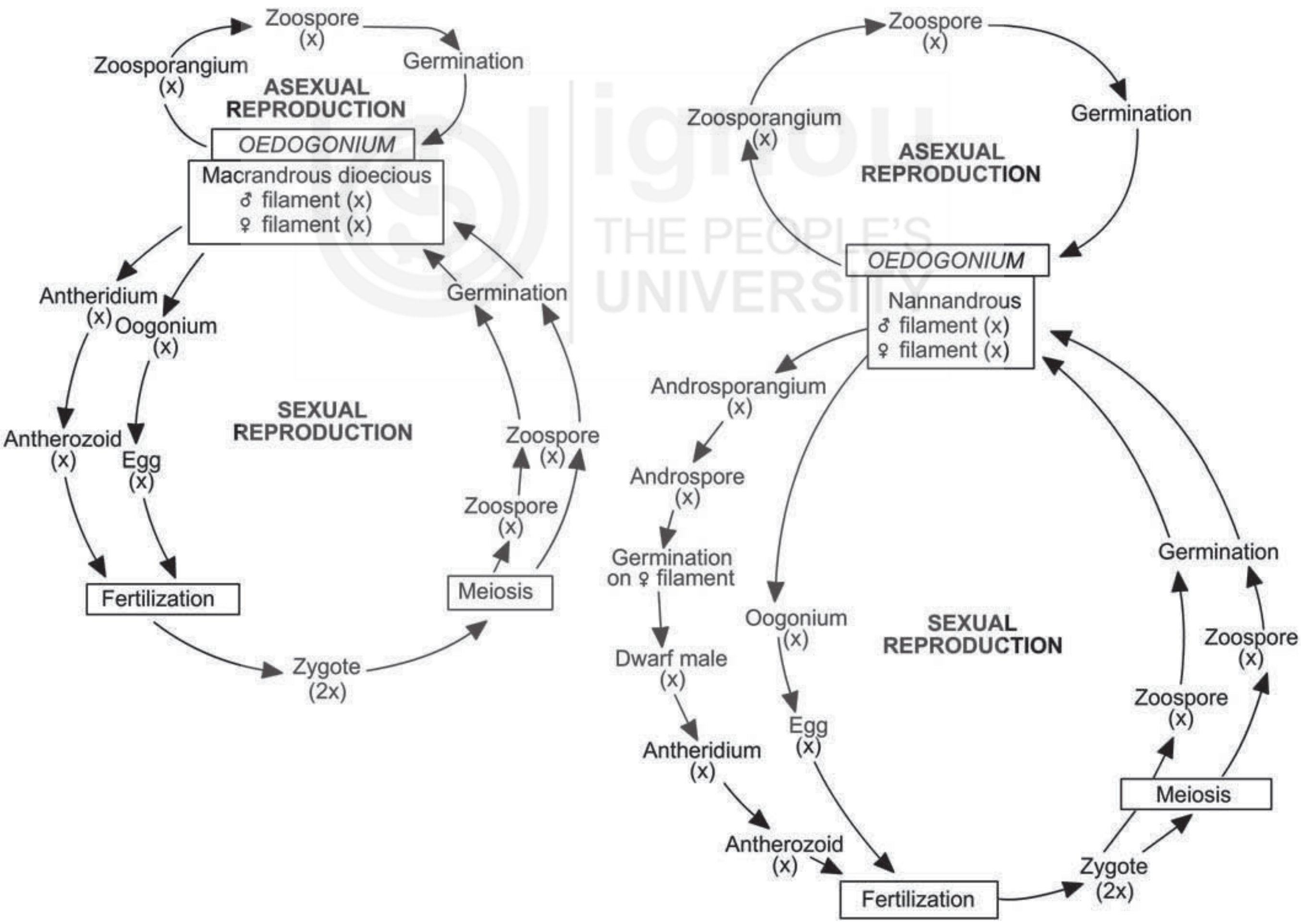


Fig. 7.10 : Life cycle of *Oedogonium*. Macrandrous species, and nannandrous species. *Source* : Singh et.al. 2016.

7.2.4 *Vaucheria*

**Division : ** Heterokontophyta

Class : Xanthophyceae

Order : Vaucheriales

Genus : *Vaucheria*

Occurrence: The genus *Vaucheria* is found abundantly in temperate regions of the world. It is found in a range of habitats – terrestrial as well as fresh water. Terrestrial species, *V. terrestris* forms a yellowish-green mat-like covering on damp surfaces. *V. amphibia* is an amphibious species, whereas *V. jonesii* is found on snow-covered peaks.

The thallus is made up of cylindrical or tubular filaments that are branched and non-septate and appear yellowish-green due to the presence of xanthophylls. These are attached to the substratum by small rhizoid like structures (Fig. 7.11). The filaments are coenocytic and the protoplasm is continuous throughout its length. Septa are produced only to demarcate reproductive structures or in case of an injury. Filament wall is made of cellulose and pectin, and is flexible and weak. Protoplasm has a central vacuole that runs continuously through the filament. It is surrounded by a continuous ring of cytoplasm that has organelles such as nuclei, chloroplasts, mitochondria and dictyosomes. Protoplasm in *Vaucheria* shows the characteristic cytoplasmic streaming, in which organelles stream or move along the longitudinal axis of the filament. Chlorophyll a, carotenoids and xanthophylls are the principle photosynthetic pigments. Interestingly, two principle pigments of Siphonales i.e. siphonein and siphonoxanthein are not present in *Vaucheria*. The main reserve food material is oil that occurs as tiny colourless droplets in the cytoplasm.

Reproduction: *Vaucheria* shows all the three types of reproduction, vegetative, asexual and sexual.

Vegetative reproduction: It is carried by simple fragmentation, in which fragments from filaments break accidentally or by mechanical shock, and eventually form a new filament.

Asexual reproduction: It is carried out by formation of zoospores that are formed in response to a change in physical conditions such as low light intensity, altered nutrient conditions *etc.* Tips of vegetative filaments form club-like structures known as zoosporangia. These are separated from the main filament by septa and produce a single zoospore that has many nuclei, each having two unequal flagella. Zoospore is a large, multinucleate structure, yellow-green in color, and is also known as synzoospore. They are motile and have many flagella. After liberation from the sporangia, zoospores swim for about 15 minutes and germinate on a substratum. *Vaucheria* also produces aplanospores and akinetes as modes of asexual reproduction during unfavourable conditions (Fig. 7.11b)

Sexual reproduction: Sexual reproduction is of oogamous type and most of the species are homothallic and monoecious *e.g.* V. *dichotoma*. Some species such as *V. litorea* are heterothallic and dioecious. Sex organs are produced on the vegetative thallus and occur close to each other, and may

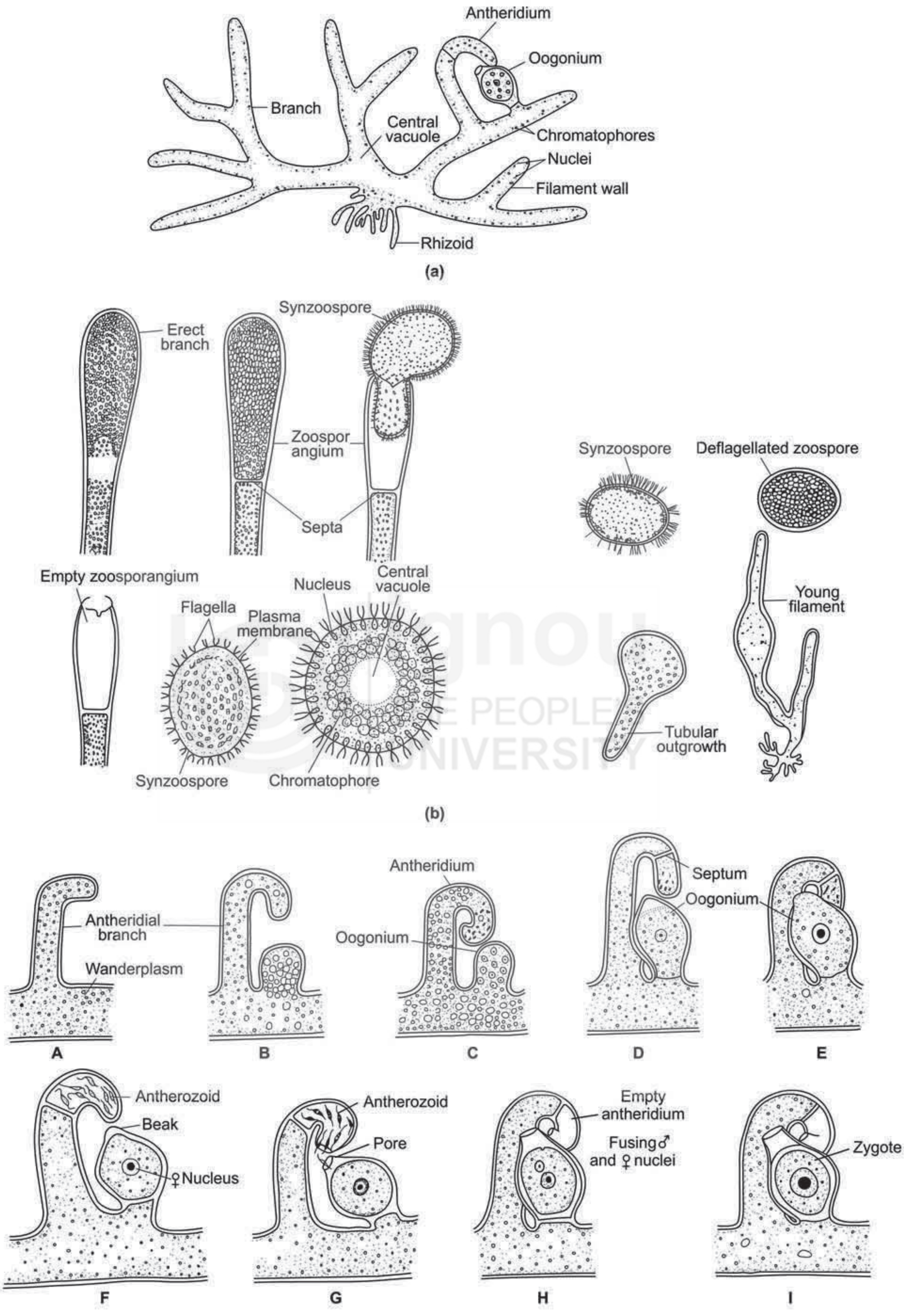
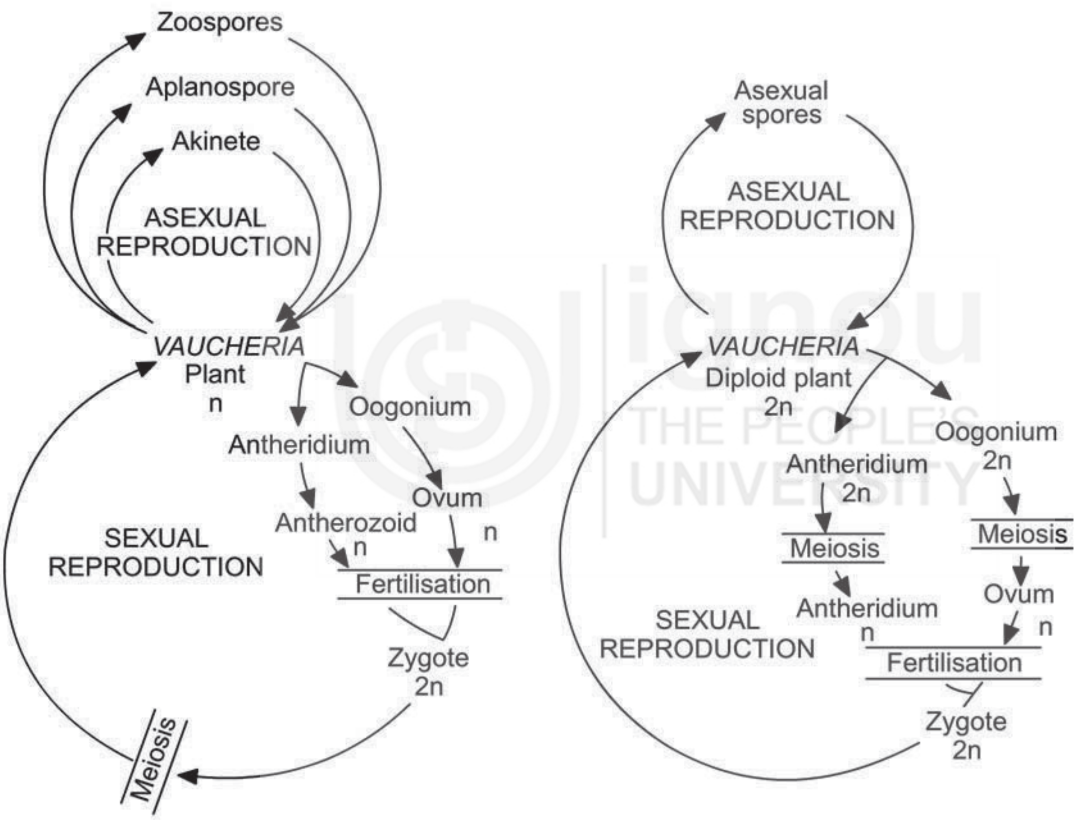


Fig. 7.11 : ***Vaucheria*****: Diagrammatic representation of: a) Vegetative thalllus; b) Development and liberation of zoospore; and c) Sexual reproduction.**
Source : **Singh el.at. 2016.**

be sessile as in *V. sessilis* or stalked (Fig. 7.11 c). They are separated from the main filament by septa. Antheridium is slender structure that may be cylindrical or tubular. It is curved like a hook and produces numerous male gametes or sperms. Sperms are small, oval or pear-shaped structures that are biflagellate, laterally inserted (one tinsel and one whiplash type flagella) and colourless. Oogonium is a spherical structure that develops as a small protuberance at the base of the antheridium. At the site of development of oogonium, cytoplasm becomes dense and multinucleate and is known as wanderplasm. At maturity, oogonium is a beaked structure having one large, round ovum which is rich in reserve food material. Antheridium and oogonium dehisce almost simultaneously followed by fertilization. The zygote rests for a small period and undergoes meiosis before germinating to form a new filament.



7.12: Diagrammatic representation of life cycle of *Vaucheria*. *Source* : Pandey & Tripathi; 1996.

7.2.5 *Fucus*

Division : Heterokontophyta

Class : Phaeophyceae

Order : Fucales

Family : Fucaceae

Genus : *Fucus*

The order Fucales is characterised by the presence of organisms that have parenchymatous diploid thallus. There is gametic meiosis and haploid generation is reduced to gametes that are in the sex organs. There is no asexual reproduction and the life cycle is diplontic.

Fucus

Fucus is an aquatic genus in which thalli are found near the sea shores attached to the rocks. They are slippery to touch as they have a lot of mucilage on their surface. The thallus is differentiated into a basal holdfast; a small stipe; and the main branch or the frond. A frond or blade, is a ribbon-like structure, thin, forked at the tip and has a prominent midrib. It is parenchymatous, highly branched and is attached to the substratum by a holdfast. The tip of the branch has apical groove that is rich in mucilage. There are several air bladders that have swollen vesicles filled with air. Fertile branches that bear reproductive structures are known as receptacles that bear sex organs in special cavities called conceptacles. Anatomically, *Fucus* thallus shows higher level of differentiation. It is divided into three zones: (i) Meristoderm or Palisade layer; (ii) Cortex, and (iii) Medulla (Fig. 7.13 a and b).

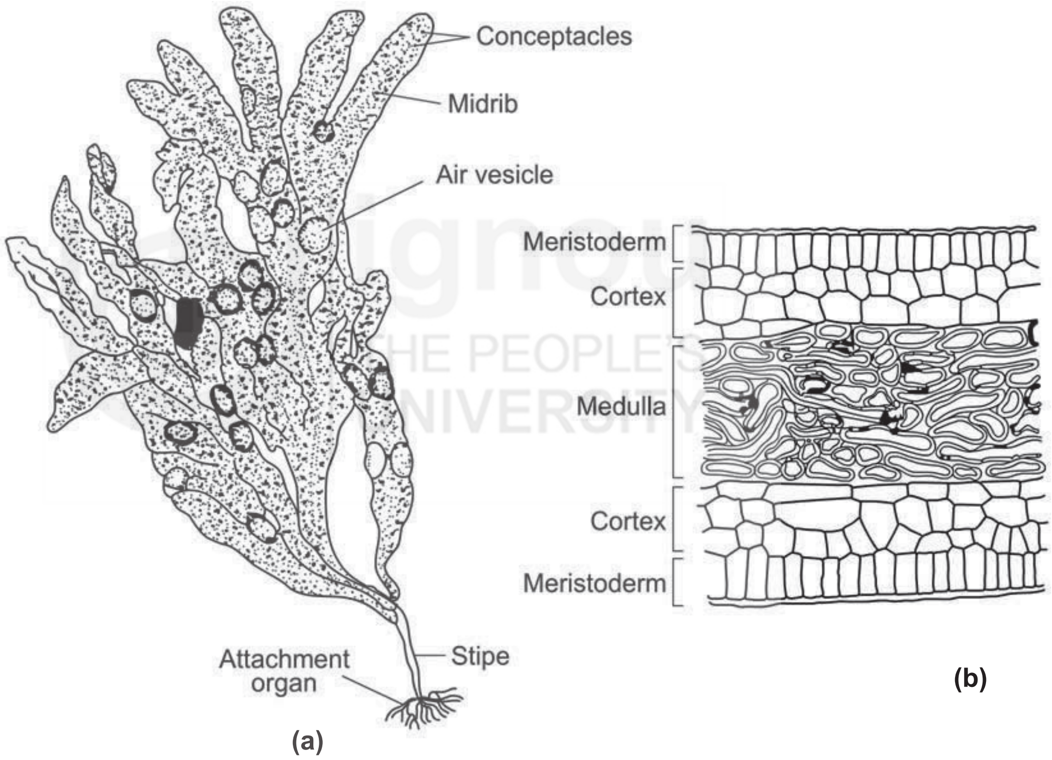


Fig. 7.13 : a) Morphology of *Fucus* thallus; b) Transverse Section through a portion of *Fucus* thallus. Source: Singh et al., 2016.

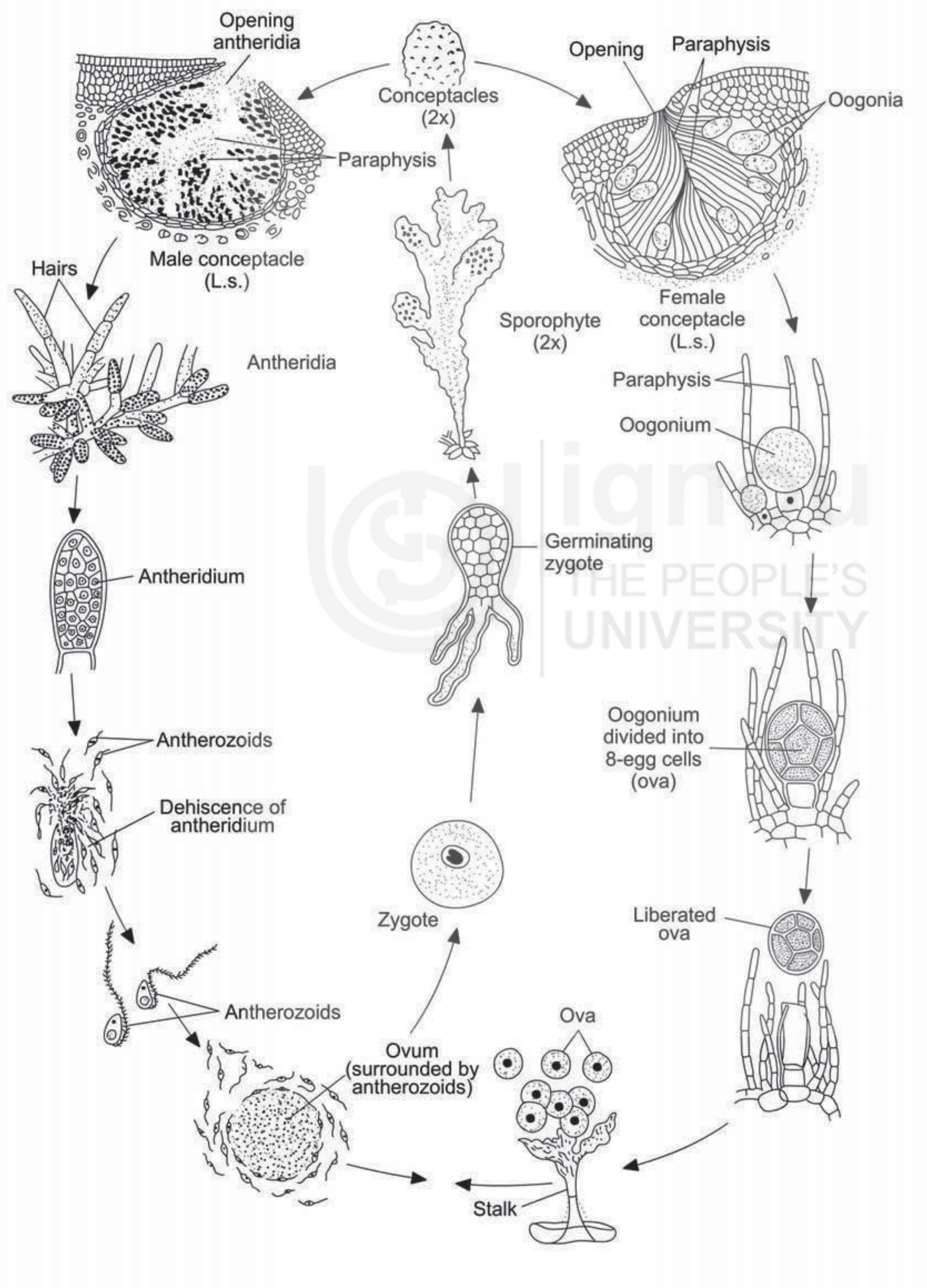
Meristoderm: is the outermost layer of the thallus. It has a layer of single cells which have chloroplasts. It is covered by mucilage that gives the thallus a slimy touch. **Cortex:** It comprises of thin-walled, parenchymatous cells and is used for storing reserve food. **Medulla:** It is the central part of the frond that in made up of narrow elongated cells. In *Fucus*, growth takes place by the apical cell at the tip of a branch which is four sided. The tip of a branch is bifurcated and gives rise to a forked type of branch.

Reproduction

Fucus reproduces by vegetative and sexual methods. Asexual reproduction by spore formation is absent in *Fucus*.

Vegetative reproduction: It takes place by fragmentation, in which broken fragments of the branches germinate to form new thallus.

Sexual reproduction: Sexual reproduction is oogamous type. Sex organs are produced on specialised branches that are called as receptacles. These have cavity like structures called conceptacles which bear sex organs antheridia and oogonia (Fig. 7.14). Conceptacles are oval structures



(a)

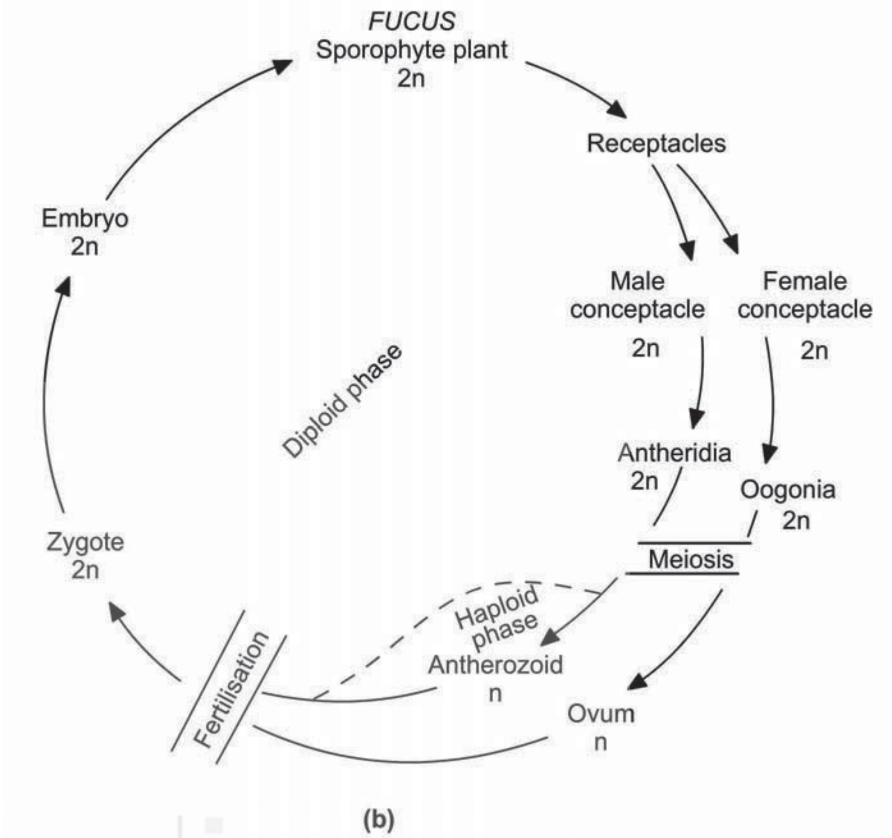


Fig. 7.14 : a) Diagrammatic representation of Life cycle of *Fucus*; b) Word diagram of life cycle of *Fucus. Source* : Pandey & Tripathi, 1996.

having a pore called ostiole. The cavity of conceptacle has a lining of sterile cells called a fertile sheet. These give rise to long, hair-like, branched or unbranched filaments called paraphyses that bear sex organs. In between them there are sterile hairs that emerge from upper part of the conceptacle called periphyses. *Fucus* thallus may be monoecious as well as dioecious. Antheridia are stalked, unicellular, oval structures, borne on paraphyses. Mature antheridium is orange in colour and its wall is differentiated into an outer exochite and inner endochite. The antheridial mother cell produces sperms by meiosis. A sperm is a tiny, pear-shaped structure, biflagellate with two lateral flagella. Oogonium is a stalked, large, one-celled, oval-shaped structure. The oogonial mother cell divides meiotically and produces eight egg cells. Sperms and egg cells are released as clumps and are called as sperm and egg bladders, respectively. Fertilization in *Fucus* takes place in open sea and hence is known as external. The attraction of sperms towards the eggs is facilitated by fucoserratin. Post fertilization, the zygote forms a thick wall around itself and eventually rests on a suitable medium and germinates to form new thallus. It has been shown that unfertilized eggs can develop into germlings parthenoginically if treated with a dilute acid. Diploid zygote germinates by producing rhizoidal outgrowth on one side. It divides by mitosis to form a lower basal and an upper apical cell which give rise to the new fronds.

7.2.6 *Polysiphonia*

Division : Rhodophyta

Class : Rhodophyceae

Sub-class : Florideae

Order : Ceramiales

Family : Rhodomelaceae

Genus : *Polysiphonia*

Habit: *Polysiphonia* is a brownish red filamentous algae. The thallus consists of a basal prostrate system and an erect filamentous system. Filaments are branched giving it a tufty or feathery appearance (Fig. 7.15). The plant body is attached to the substratum with a basal holdfast that serves as an anchor to the main plant body.

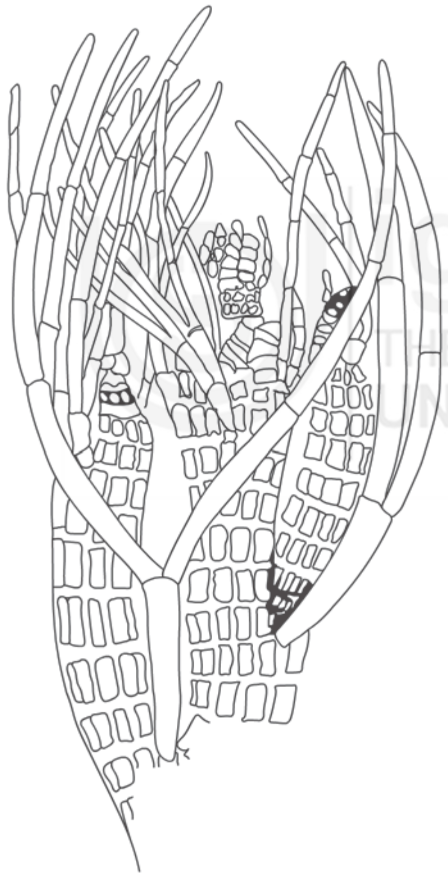


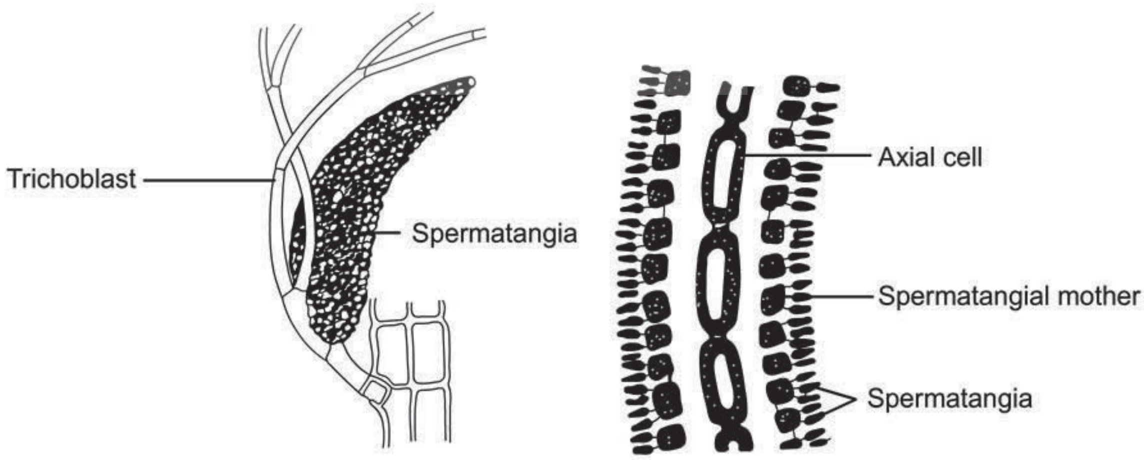
Fig. 7.15: Habit of *Polysiphonia*.

Morphology: The main filament produces two types of lateral branches: ordinary branches and trichoblasts. Ordinary branches are vegetative in nature, show unlimited growth and resemble the main axis in anatomy. The trichoblasts are specialised branches that bear the sex organs. They are monosiphonous, uniseriate and are composed of single line of colourless cells.

The aerial filaments give rise to two types of lateral branches, long and short. Short branches are colourless, arise due to limited growth and are known as trichoblasts. The genus shows typical polysiphonous growth form wherein each branch is composed of parallel systems of filaments called siphons. The central filament known as a central siphon is surrounded by a layer of peripheral siphon called as pericentral siphons. Growth of the thallus is facilitated by a dome-shaped, polyploid apical cell of a filament. Division in the apical cell produces daughter cells that give rise to lateral branches. These branches undergo longitudinal divisions to form central and pericentral cells. The central and pericentral cells are connected to each other by pit connections.

Reproduction: Sexual reproduction is oogamous. *Polysiphonia* is represented as three different morphological forms in its life cycle namely gametophyte, carposporophyte and tetrasporophyte.

Gametophyte: It is the haploid plant body that produces the male and female gametes in male and female sex organs spermatangia and carpogonia, respectively. *Polysiphonia* is dioecious and the male and female gametes are borne on different plants, however, the thalli are morphologically differentiated. Spermatangia borne on male trichobalsts are spherical or elongated in shape and bear a single male cell called spermatium. Male gametes known as spermatia are colourless, unicellular, spherical and non-motile. Female sex organ is known as carpogonium. It is a flask-shaped structure borne on carpogonial branch. Carpogonial branch has two supporting cells at its base and sterile filaments, one basal and the other lateral. Carpogonium has a basal swollen region that houses the egg cell. The upper region of the carpogonium is narrow and elongated and is called as trichogyne. Spermatia move through the trichogyne and reach the base of the trichogye where they fuse with the egg cell to form diploid zygote. Several post-fertilization changes take place in the zygote which eventually forms the carposporophyte. Mature carposporophyte also known as cystocarp is a stalked oval structure that contains gonimoblast filaments (Fig. 7.16). Terminal cell of each gonimoblast filament bears carposporangia that bears diploid carpospores. Mature cystoccarp is covered by a sheath known as pericarp. The carposporophyte is released from the cystocarp and germinates to form a tetrasporophyte which is a diploid, asexual thallus that resembles the gametophytic thallus (Fig. 7.17)



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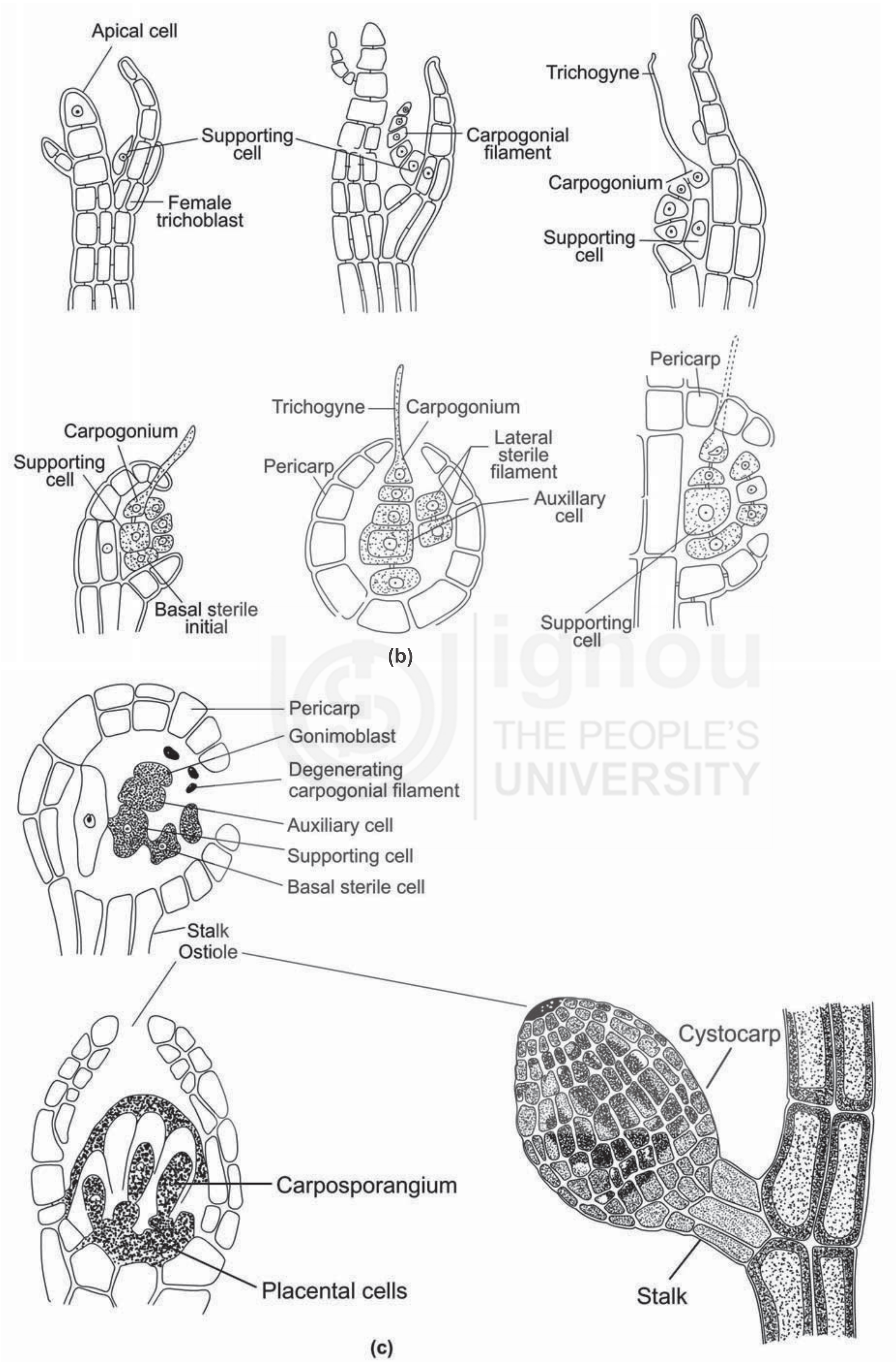

cell

Fig. 7.16 : ***Polysiphonia.*** **a) Development of Spermatangium; b-c) stages in development of Carpogonium and Cystocarp. *Source*, (a,c) Pandey & Trivedi, 1996; b) Singh et al. 2016.**

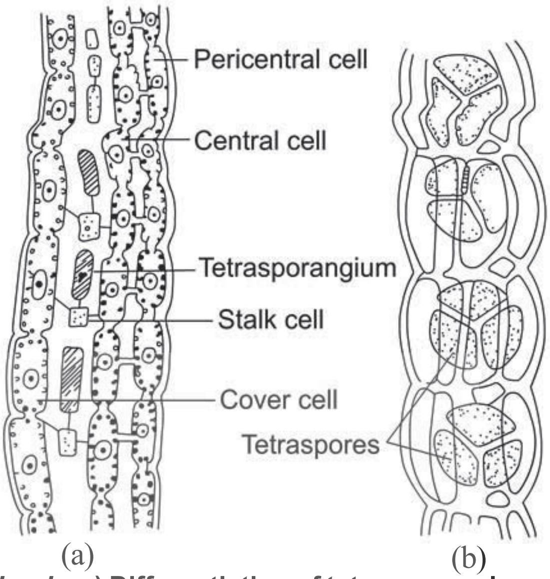

Fig. 7.17 : ***Polysiphonia*****. a) Differentiation of tetrasporangium, b) Tetraspores.**
Source **: Singh et al. 2016.**

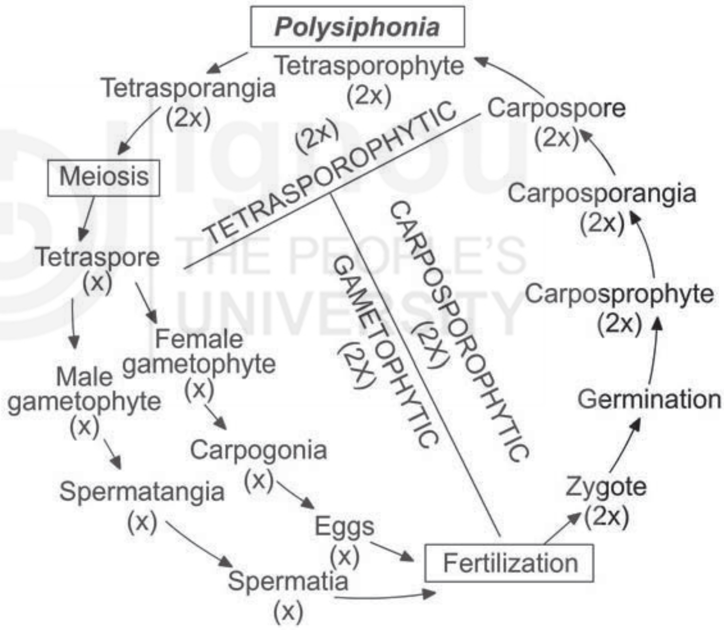

Fig. 7.18 : Diagrammatic representation of life cycle of *Polysiphonia*.
Source : Singh et al. 2016.

7.3 SUMMARY

1. Genus *Nostoc* belonging to Cyanophyta is made up of filamentous oval/ circular cells that are embedded in mucilaginous sheath. It reproduces only asexually by fragmentation and formation of hormogonia, akinetes and endospores.

2. *Chlamydomonas* is a unicellular, motile and free floating algae belonging to the division Chlorophyta. The haploid body is represented by a single oval cell that has a cup-shaped chloroplast, centrally

placed nucleus, an eye spot and two anterior whiplash flagella. It reproduces asexually by producing zoospores, aplanospores and hypnospores. Sexually reproduction is isogamous, anisogamous as well as oogamous and leads to formation of diploid zoospores that divides to form next generation.

3. *Oedogonium* is a fresh filamentous fresh water algae belonging to division Chlorophyta. It shows morphological differentiation as well as division of labour in the filament. Filament is attached to substratum by a basal holdfast; some cells have ring on them and are known as cap cells that lead to formation of zoosporangia. Sexual reproduction takes place by antheridia and oogonia borne on filaments that may be monoceious or dioceous.

4. *Vaucheria* is a filamentous, non-septate yellow algae belonging to class Xanthophyceae. The thallus is made up of coenocytic filaments in which the protoplasm runs continuously. It appears yellowish due to the presence of Xanthophyll. Asexual reproduction is done by producing Zoospore, Aplanospores and Akinetes. Sexual Reproduction is oogamous and species can be homothallic and heterothallic.

5. *Fucus* is an aquatic algae belonging to class Phaeophyceae. The thallus is parenchymatous shows higher degree of differentiation. Vegetative reproduction takes place by fragmentation. Sexual reproduction is oogamous and the process of fertilization is external and mediated by chemical signals such as fucoserratin.

7.4 TERMINAL QUESTIONS

1. Differentiate between the following:
   a) Hormogonia and akinetes
   b) Palmella and Heterocyst
   c) Homothallic and heterothallic
   d) Xanthophyceae and Chlorophyceae
2. List characteristic features of *Nostoc*.
3. Give diagrammatic representation of diploid life cycle of *Chlamydomonas*.
4. Is *Vaucheria* a unicellular or multicellular alga? Justify your answer by elaborating upon its structure.
5. Describe briefly the habit, structure of thallus and mode of reproduction in *Fucus*.
6. Elaborate upon the post-fertilization changes in *Fucus*.
7. Briefly describe the major phases in life cycle of *Polysiphonia*. How is it different from that of *Fucus*?

7.5 ANSWERS

Self-Assessment Questions

1. a) False
   b) True
   c) False
2. a) Parietal
   b) Phycocyanin and/or phycoerythrin
   c) Gelatinous
   d) Hormogonia

Terminal Questions

1. a) Sub-section: 7.2.1
   b) Sub-section 7.2.2
   c) Sub-section 7.2.2
   d) Sub-section 7.2.4
2. Sub-section 7.2.1
3. Sub-section 7.2.2
4. Sub-section 7.2.4
5. Sub-section 7.2.5
6. Sub-section 7.2.5
7. Sub-section 7.2.6

7.6 GLOSSARY

Heterocyst : Specialised, colourless, empty looking cells found in the trichome of *Nostoc* in between normal vegetative cells.

Eye spot : A photoreceptor organelle found in *Chlamydomonas* cell occurring at the anterior end of the cell.

Palmella stage : A colony of immobile daughter cells formed in *Chlamydomonas* under unfavourable conditions. At the onset of favourable conditions, the daughter cells are released and they germinate to form new colonies. This is a means of asexual reproduction in *Chlamydomonas*.

Cap cells : Vegetative cells in filament of *Oedogonium* having cap-like structures at their upper ends.

Macrandous : Species of *Oedogonium* in which antheridia are borne on filaments of normal size.

Nannandrous : Species of *Oedogonium* in which antheridia are borne on filaments that are smaller in size than that of the normal filaments.

Coenocytic thallus : Thallus in which filament is not divided by septa. The organelles lie in the cytoplasm in the filament as seen in *Vaucheria*.

Frond : The main branch of *Fucus* thallus is known as a frond. It is a ribbon-like structure, thin, forked at the tip and has a prominent midrib.

Conceptacles : Cavity-like oval structures in *Fucus* that bear antheridia and oogonia. These are borne on receptacles.

Receptacles : Specialised branches in *Fucus* that bear sex organs.

Paraphyses : Long hair-like branched or unbranched filaments borne in the cavity of conceptacle in *Fucus*. These bear antheridia and oogonia.

Periphyses : Sterile hair-like filaments that are present at the tip of the conceptacles.

Polysiphonous : A type of growth form where the main branch is made up of a parallel system of filaments called as siphons. Found in genus *Polysiphonia*.

Trichoblasts : Specialised branches in *Polysiphonia* that bear sex organs.

7.7 FURTHER READING

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UNIT 8

ALGAE: ECONOMIC IMPORTANCE

Structure

8.1 INTRODUCTION

Algae are important both for environment and human beings. In Japan, Taiwan, China and Hong Kong some species of algae are part of daily meal. There are large industries in these countries for farming algae on commercial scale. These countries also export various algal products. In this unit, you would study about the vast potential of algae as a source of human food, animal feed, biofertilizers, energy, pharmaceutical and other products. The economic value of algae is being realised in our country and various useful products of algae both for our country and for export purposes are being produced at commercial scale.

Objectives

After studying this unit, you will be able to:

- give examples of economically important algae;
- list algal species that are edible and mention their nutritional value;
- describe different algal products and their uses;
- explain the use of algae in wastewater treatment, as biofertilizer, as source of energy, in industry and as medicines; and
- Describe various effects of algae on humans and the ecosystem.

8.2 SOURCE OF NUTRITION

In order to fulfill the demand of growing global population there is constant search for new food sources. About 90% of the food is obtained from land. Though aquaculture or farming in fresh water, brackish water and sea water is almost as ancient as agriculture, its potential has not been fully explored. Among marine organisms – algae appear to be one of the promising food resources. Many of the edible algal forms are rich in proteins, vitamins and minerals including iodine. Kelps, brown algae, e.g., species of *Laminaria* (Fig. 8.1) are rich sources of iodine. These algae can accumulate iodine in concentrations 10,000 times greater than those found in sea water.

Algae synthesise some essential polyunsaturated fatty acids which are rarely synthsised by higher plants or animals. Algae grow rapidly and their farming can be carried out in fresh water, brackish water, shallow coastal areas and also in open seas. It is worthwhile to explore algae and algal products that have potential for food.

The idea of including algae in human diet is relatively new in India but in maritime countries algae and algal products are daily consumed along with other food items. The consumption of seaweeds by coastal Japanese people dates back to 600 B.C. and by Chinese to Sixth Century A.D. About 160 species of algae are used as commercially important food sources.

Table 8.1 Lists some edible algae consumed in different parts of the world.

Table 8.1: Edible algae in various countries.

Names of Algae	Countries where these are Consumed
Seaweeds	
Porphyra	Japan – as nori, China – as tsatsai and zicai, Korea – as kim and laver, Phillipines, U.K.
Laminaria	Japan – as kombu, China – as taidaine, Korea, Phillipines
Undaria	China, Phillipines. Japan – as wakame,
Lemanea	India, Manipur – as nughee
Enteromorpha	Phillipines
Palmaria	Canada, U.K.
Chondrus crispus	Canada, U.K.
Ulva lactuca	Scotland – as salad
Microalgae	
Spirulina	Central America, Mexico, W. Africa – as duhee, USA, Israel, Taiwan, Thailand
Phormidium	Mexico
Chroococcus	Mexico
Nostoc commune	Mexico, Mongolia, China, Fiji, Equador
Nostoc edule	Mongolia, China, Peruvian Andes
Nostoc verrucosum	Thailand
Chlorella	Japan, Mexico, U.S.A., Taiwan, Germany
Prasiola	China, Japan
Spirogyra	Burma, Thailand, India
Oedogonium	Burma, Thailand, India

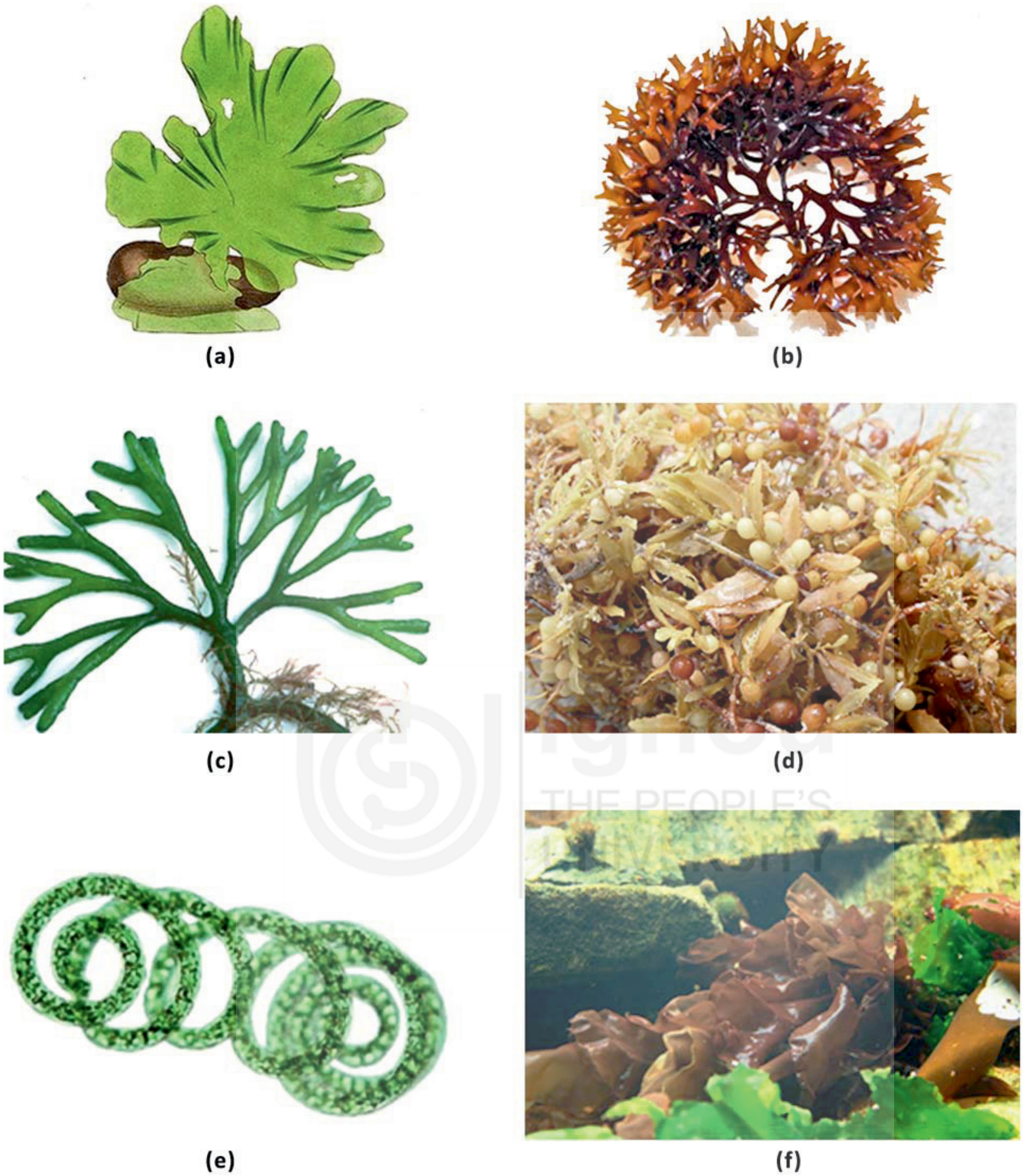


Fig. 8.1: Some edible algae: a) *Ulva lactuca;* b) *Chondrus crispus*; c) *Codium compendium*; d) *Sargassum*; e) *Spirulina*; f) *Porphyra*. It may be noted that all the pictures are not of the same scale.

***Sources*: (a) https://en.wikipedia.org/wiki/Ulva_lactuca. (b) http://www.docaitta. com/2012/05/ foraging-irish-moss-chondrus-crispus.html (c) https://www.google.co.in search?q=codium&source=lnms&tbm=isch&sa =X& sqi=2&ved=0ahUKEwipkvXm6YfUAhWCHpQKHRluC7sQ_AUIBigB&biw=1366&bih= 625#imgrc= fklaFmd Pc1FxSM: (d) https://en.wikipedia.org/wiki/Sargassum#/media/ File:Sargassum_on_the_ beach,_ Cuba.JPG (e) https://www.google.co.in/ search?q=spirulina&source=lnms&tbm=isch&sa= X&sqi=2&ved= 0ahUK EwiDp 8K26ofUAhUDEpQKHSklBO0Q_AUIBigB&b iw=1366&bih=625#imgrc= edYrMeP0zLt8qM: (f) https://www. google.co.in/search?q=porphyra&noj= 1&source=lnms& tbm=isch&sa=X&ved= 0ahUKE wi5ysDgnl_ UAhUm TY8KHVRUA2EQ_ AUICigB&biw=1366&bih=625#imgdii= okszvAnhbkr3XM: &imgrc=TIUe_YG-BOrU_M:**

Spirulina (Fig. 8.1) contains about 65% proteins and is also rich in carotenes. It can be grown in wastewater. It is mass cultured in Mexico, Taiwan and India. Because of its high nutritive value it has been identified as a source of single cell protein (SCP). It is used as a supplement to vegetarian meal. It can be supplemented in the diet of children to curb malnutrition prevalent in developing countries. The natives of Mexico and Africa have been using it since long. It is also been popularised in India. It has great potential for culture and export as health food by our country. Presently, a few private and government agencies are engaged in its commercial farming. The Central Food Technological Research Institute (CFTRI), Mysore has developed technology to grow *Spirulina* on large scale.

Chlorella is another single cell alga that grows very rapidly. It is rich in proteins, lipids and contains many vitamins in high concentration. Its nutritive value is almost equivalent to soybean and spinach. In Japan, Taiwan and other South East Asian countries it is grown as health food having 'cure all properties'. Taiwan alone produces 1500 tons dry weight *Chlorella* annually. After harvesting the cells are washed and the pigments are extracted. The dried algal mass is ground and stored in powdered form. Processed *Chlorella vulgaris* E-25 is sold as Momotaro E-25 in Japan in packets of 5 grams.

Marine algal foods are both conventional and delicacy in Japan, Korea, China, Phillipines and Thailand. Many species of algae such as *Enteromorpha*, *Caulerpa*, *Ulva lactuca*, *Gelidiella*, *Laurencia* and *Gracilaria* are eaten raw as salad. *Gracilaria* is used in preparing a tasty dessert. *Ulva lactuca* and *Gelidiella acerosa* are cooked with other vegetables like spinach is cooked in India.

Among seaweeds, *Porphyra* is important. It contains 30-35% proteins, 40-45% carbohydrates and is rich in vitamins. The mature *Porphyra* is harvested, dried and pressed into sheets. The sheets are toasted and cut into pieces and are eaten with rice, raw fish or some vegetables. They are also used for flavouring soups and in 'sushi'. In Japan *Porphyra* called as nori, farming is carried out over 60,000 hectare area in sea by either placing concrete blocks on the sea floor to enhance seaweed growth or on bamboo-cum-rope network or raft like network of bamboos. In North Atlantic Coast *Palmaria* called dulse and *Porphyra* are the most widely used seaweeds. In the Pacific countries and Asia a great variety of seaweeds are harvested from the shore and are consumed as food. *Undaria* a brown alga, is used in Japan for extracting an edible product called wakame. A list of edible seaweeds of Indian Coasts is given below (Table 8.2).

Table 8.2: Edible seaweeds from Indian Coasts.

Name of the Algae
Green algae: *Chaetomorpha*, *Caulerpa*, *Codium*, *Enteromorpha*, *Ulva*.
Red algae: *Rhodymenia*, *Laurencia*, *Acanthophora*.
Brown algae: *Padina*, *Turbinaria*, *Chnoospora*, *Hydroclanthrus*, *Sargassum*.

SAQ 1

a) Fill in the blank spaces with appropriate words.

   i) Edible algae are important nutritional sources because they are rich in ...., ..., ... and ....

   ii) *Spirulina* contains .... % of proteins.

   iii) Algal farming can be done in fresh water, ... water, shallow and .... sea waters.

   iv) Single cell alga .... is sold as health food in Japan as it has .... properties.

   v) *Spirulina* can be grown in .... water.

   vi) The dried pressed sheets of .... are toasted and eaten with rice, raw fish or vegetables.

   vii) Algae synthesise .... polyunsaturated fatty acids.

b) Name three nutritionally important algae that are cultured for commercial purposes.

8.3 SOURCE OF ANIMAL FEED

Spirulina, *Chlorella* and many types of seaweeds are cultured on commercial scale for human consumption because of their high nutritive value. These can also be used as fodder for livestock or can be used as a supplement to their regular feed. During World War I when fodder was in short supply, seaweeds were tried as cattle feed and the quality of milk was found to be unaffected. Thereafter, seaweed based stock feed factories were set up in France, Norway, Denmark, Germany and USA. The seaweeds used as fodder are *Rhodymenia*, *Laminaria*, *Alaria*, *Fucus*, *Ascophyllum*, *Macrocystis*, and *Sargassum* (see Fig. 8.2). According to some reports the milk of cows fed with seaweeds had high fat contents than those fed on conventional fodder.

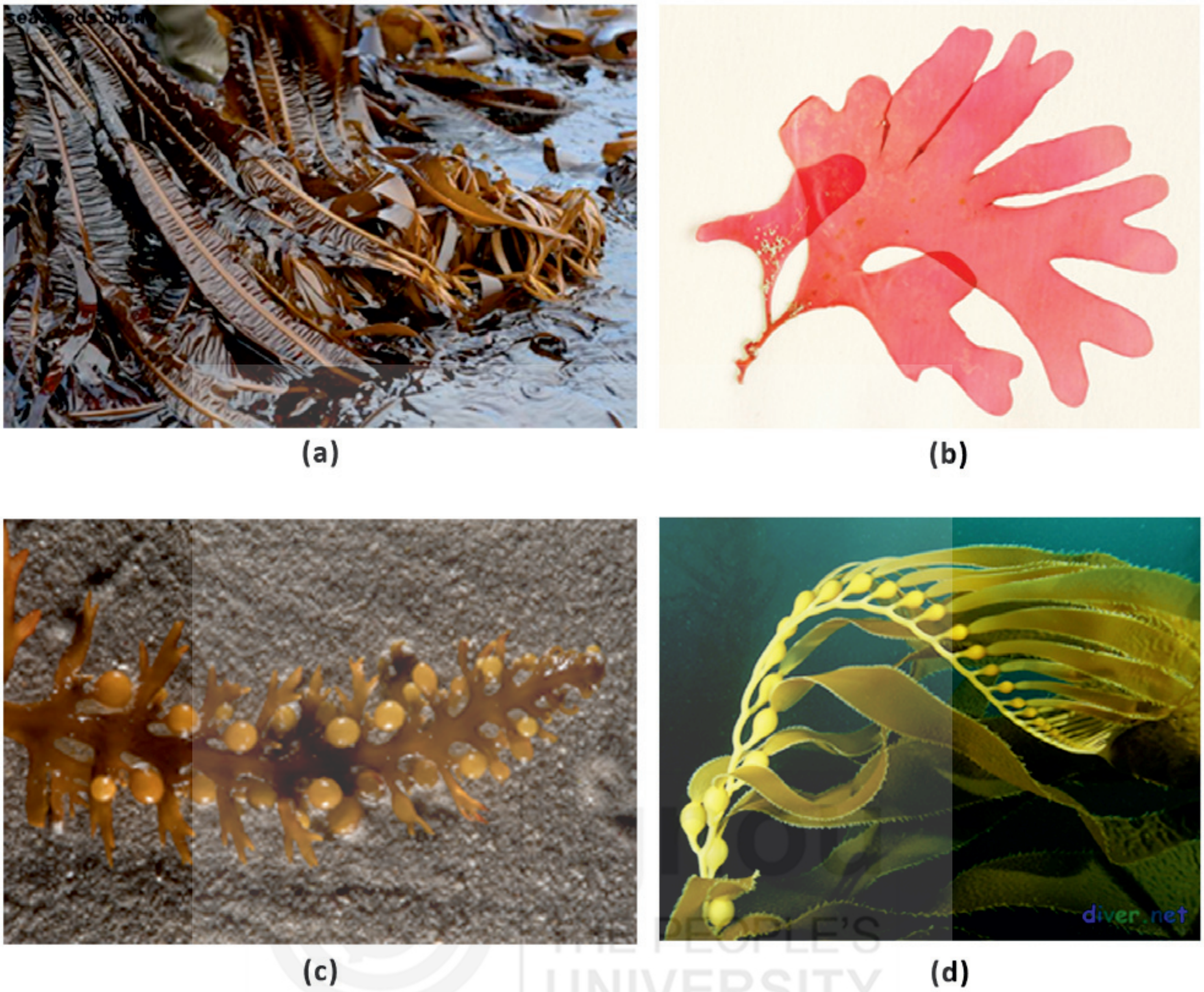


Fig. 8.2 : Algae used as fodder: a) *Alaria esculenta*; b) *Rhodymenia pseudopalmata*; c) *Sargassum*; d) Macrocystis. The pictures are not of the same scale.

Sources: (a) https://www.google.co.in/search?q=alaria&noj=1&source=lnms&tbm=isch&sa= X&ved=0ah UKEwiXuJvy74fUAhVBGZQKHbJxCiEQ_AUICigB&biw=1366&bih= 625#imgrc=2zs8FjE-4xI0AM: (b) https://www.google.co.in/search?q=Rhodymenia&noj=1&source =lnms&tbm=isch&sa= X&ved=0a hUKEwj8vfL28YfUAhU Do5QKHbzwD1wQ_AUICigB&biw=1366&bih=625#imgrc= PeS5CKqQ7znARM: (c) https://www.google.co.in/search?q=&tbm=isch&tbs=rimg:CXkaLAtfehs7 IjiW UEuUBkq_13VIq1pEUklKYY0UvMgMMVKHFMUNY9yeeNrSus24E1A96pXX_1 NE54oCTvEhfc GH08rCoSCZZQS5QGSr_1 dEdt1mxOos4SEKhIJWWrWkRSQgpgRumMKWQdfSpcq EgljRS8yAwx UoRGtodiNrKz8JSoSCcUxQ1j3J542EcuOHvBkks _13KhIJtK6zbgTUD3oRDskOVrUN984q EgmIdf80Tnig JBHBoDL5KLTJjyoSC e8SF9wYfTysETvuZPX67cKH&tbo=u&sa=X&ved=0ahUKEwjM-Lzy9lfUAhXKjJQKHZw_BR8Q9C8IHA&biw=1366&bih=625&dpr=1#imgrc=UgjAhUCSfietOM: (d) https://www.google.co.in/search?q=macrocystis&noj=1&source=lnms &tbm=isch&sa= X&ved=0ah UKEwj5kb7r9ofUAhUEkpQKHU_s AR0Q_AUICigB&biw=1366&bih=625#imgrc=nDyJ1tXu-0o6TM:

In addition to the use of seaweeds as fodder for livestock they are also added in powdered form to the regular feed of cattle, pigs, sheep, fish and poultry. In India *Sprulina* is grown in wastewaters in Lucknow, Nagpur and Varanasi. It is fed to fish, poultry and cattle with the aim to improve the health and productivity of the animals. Besides seaweeds microalgae *Chlorella*, *Scenedesmus*, and *Spirulina* are used in poultry, fish, oyster, prawn and mollusk raising industries.

SAQ 2

Identify the True statements from the following:

a) Seaweeds cannot be used for animal feed.

b) Microalgae are used to feed fish and poultry.

c) Milk of cows fed with seaweeds have high fat contents.

d) *Spirulina* is grown in wastewaters in India.

8.4 TREATMENT OF WASTEWATERS

Wastewater from lavatories, bathrooms and kitchens of the houses contains large amount of organic material and is generally known as sewage. It is foul smelling but is rich in nutrients. If it is discharged into ponds, lakes or rivers the growth of various types of bacteria and viruses takes place that results in epidemics of diseases like cholera, gastroenteritis, typhoid, viral, jaundice and many other diseases. In cities a vast amount of sewage is produced. It needs to be treated in order to remove the organic matter and nutrients so that the water could be reused or disposed off into a river or lake.

Sewage treatment (Fig. 8.3) involves broadly the following two stages:

In the first stage, diluted sewage is allowed to decompose in the absence of air (anaerobic digestion) by anaerobic microorganisms. When it gets partially digested the methane gas (biogas) is produced.

In the second stage the sludge is vigorously aerated with air or oxygen so that complete oxidation may take place. This process can best be done economically and profitably by using algae. Some of the algae used are *Chlorella*, *Scenedesmus*, *Spirulina*, *Chlamydomonas*, and *Oscillatoria*. In shallow ponds exposed to bright sunlight algae grow profusely. During photosynthesis they produce oxygen that helps aerobic microorganisms to breakdown organic matter completely. The water of oxidation ponds can be safely used for horticultural purposes. The algal biomass produced can be profitably used for other purposes like feed for cattle or poultry.

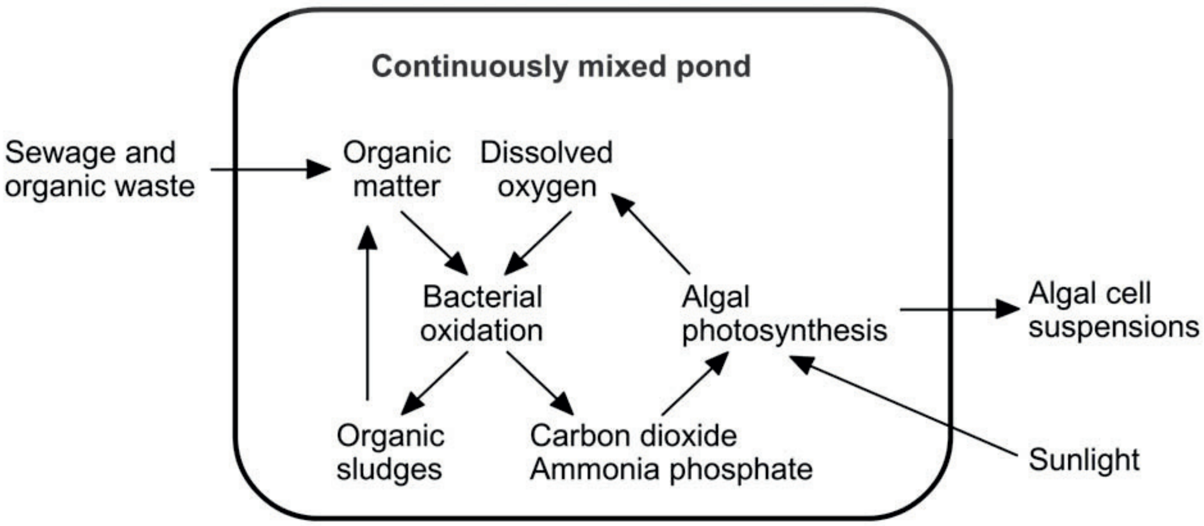


Fig. 8.3: The cycle for photosynthetic oxygenation of wastewaters.

Algae as Bioaccumulator of Toxic Pollutants

It has been observed that algae can accumulate several thousand folds of pesticides and toxic metals such as Zn, Hg, Cd, Cu, Pb prevalent in industrial effluents. Hence algae can be used for treatment of industrial effluents to remove toxic pollutants. The algal biomass can also be used for biogas production.

SAQ 3

Complete the following statements.

a) The main requirement of sewage digestion is a good supply of ....

b) Algae can be used for wastewater treatment to replenish .... used by the aerobic decomposers.

c) Contamination of drinking water by sewage can cause ...., ..., ...

d) The algal biomass recovered after the treatment of wastewater can be fed to ....

e) The algal biomass produced after the treatment of industrial effluents can be used for the production of ....

8.5 BIOFERTILIZER

With the increase in population it has become necessary to increase the yield of crop plants and this has resulted in large scale use of chemical fertilizers. It is only recently that people have realised the harmful effects of such fertilizers on environment particularly the soil. Being soluble in water much of the fertilizers added to crops are washed away by irrigation water or rain to reach water resources like ponds, lakes, and rivers. This brings about the growth of algae and bacteria leading to severe water pollution. Besides such undesirable side effects, chemical fertilizers affect the chemical and physical properties of soil and it becomes unfit for growing crops. Traditionally farmers use farmyard manure (FYM) produced from agricultural wastes. Although they are good as soil conditioners but are poor in nutrients. In recent years a number of organic, nutrient-rich fertilizers of biological origin termed as biofertilizers have become popular. Some of the algal biofertilizers that are being developed and used successfully in India and abroad are discussed below.

8.5.1 Seaweed

In coastal areas seaweeds are washed ashore. These are collected and composted like farmyard manure. Seaweed compost is rich in minerals like potassium, phosphate, sulphate and trace elements. Several vegetable crops like bhindi, brinjal, tapioca, cucurbits; fruits like lemon; trees such as palm and papaya are found to be benefitted by this manure.

Extracts of seaweeds, seaweeds boiled in water are found to be stimulatory for the germination and seedling growth of red gram, tomato and other plants. Such extracts are commercially available in Norway as Algifert and SM3 in England. Similar water extracts of common cyanobacteria like *Cylindrospermum*, *Calothrix*, *Anabaena*, and *Aulosira* are also found beneficial for the growth and yield of crop and vegetable plants. In India, *Turbinaria* is used as a fertilizer for palm trees.

8.5.2 Blue Green Algae

Nitrogen-fixing cyanobacteria can be grown in shallow puddles or metal pans in summers wherever sunlight and water are available in plenty. The thick mats that develop within a week or so are dried and kept in bags. This is how the farmers grow their own fertilizer during the summer season when the field is without the crops. Such dry algal material is a rich source of nitrogen and phosphorous besides several important elements. Agricultural departments supply kits to the farmers to grow their fertilizer. This method is very popular in the paddy (rice) growing areas of South India. Cyanobacteria are also added to the paddy fields immediately after the transplantation of seedlings. They multiply rapidly and supply nitrogen and other nutrients to the plants directly or by their decay.

Indian Agricultural Research Institute, New Delhi has developed simple method for Indian farmers to grow their own biofertilizers. Some of the important nitrogen fixing cyanobacteria are: *Anabaena oryzae*, *Nostoc commune* (Fig. 8.4), *Tolypothrix tenuis* (Fig. 8.4), *Aulosira fertilissima*, *Anabaenopsis arnoldii*, *Calothrix confervicola*, *Haplosiphon*, *Fritschiella*, *Mastigocladus*, *Westiella*, *Westiellopsis.*

Water fern, *Azolla* (Fig. 8.5) is very common in the ponds all over India. It harbours a symbiotic nitrogen fixing cyanobacteria – *Anabena* in its leaf pockets is very common in the ponds all over India. In China, Vietnam and other South East countries it is grown and is used as a fertilizer in the rice fields as well as feed for cattle and poultry. It grows very rapidly when inoculated in the rice fields. It can also be grown separately and composted, stored and added to crops when needed.

The length of time required for the development of *Azolla* depends upon various factors such as soil chemistry, ploughing, temperature, irradiance, water availability, nature of inoculant environmental and climatic conditions. After the decay of *Azolla* the fixed nitrogen becomes available to the crop. Successive *Azolla* farming in the same field results in an increased soil conditioning. In India *Azolla* technology suitable for small scale farmers has been perfected by Indian Rice Research Institute, Cuttack, Odisha.

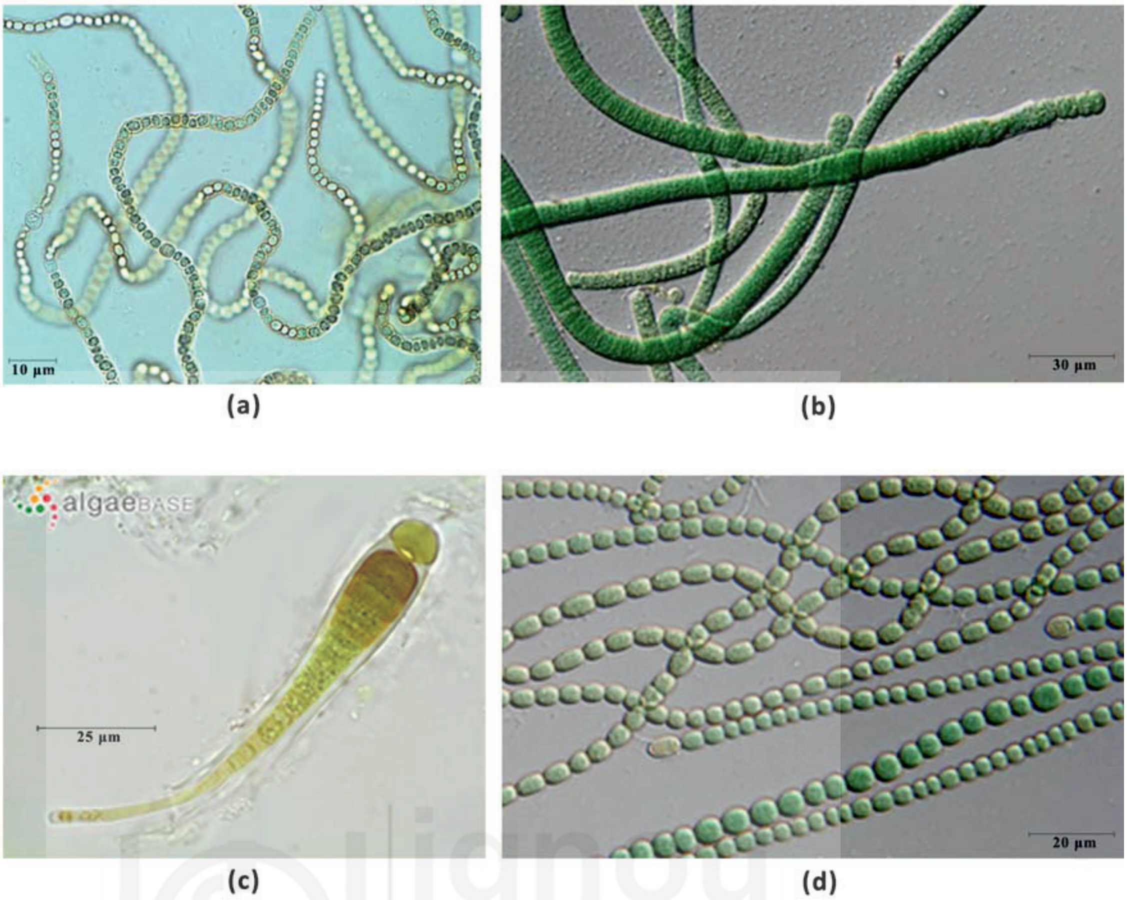


Fig. 8.4 : Blue green algal biofertilizers. a) *Nostoc*; b) *Tolypothrix tenuis;* c) *Anabaena*; d) *Calothrix*.

a) https://www.google.co.in/search?q=Nostoc+muscorum&noj=1&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiwicfa-IfUAhWBt5QKHdOvADIQ_AUICigB&biw=1366&bih=625#imgrc=7IERFZlf4jOH-M:

b) https://www.google.co.in/search?q=tolypothrix+tenuis&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiw6omPqI_UAhWJ s48KHYsmAWYQ_AUIBigB&biw=1366&bih=625#imgdii=E6aA2paFDM8INM:&img rc=_Rt5VwWvlwEX4M:

c) https://www.google.co.in/search?q=Anabaena&noj=1&source=lnms&tbm=isch&sa=X&ved=0ahUKEwig6Nff_IfUAhUFKJQKHYueD04 Q_AUICig B&biw=1366&bih=625#imgrc=IJWx2TD3q7kLAM:

d) https://www.google.co.in/ search?q=calothrix&noj=1&source=lnms&tbm=isch&sa=X&ved=0ah UKEwjc5MC3_YfUAhUHGJQKHS_DD L8Q_AUICigB&biw=1366&bih=625#imgrc=xE8RT5ILhxLBGM:

Blue green algae are also used in the reclamation of usar lands. In our country large tracts of land are not fit for cultivation because of their high alkaline conditions. The soils in such tracts are known as usar soils. The only organism that can grow there profusely are blue green algae. During the rainy season bunds are constructed to retain the rain water and it is then inoculated with blue green algae. The algae rapidly grow and forms thick mats adding a lot of organic matter to the field and lowering the alklanity of the soil. By repeating this process for two or three seasons the quality of the soil improves markedly and one can grow crops like rice, wheat and sugarcane in such lands.

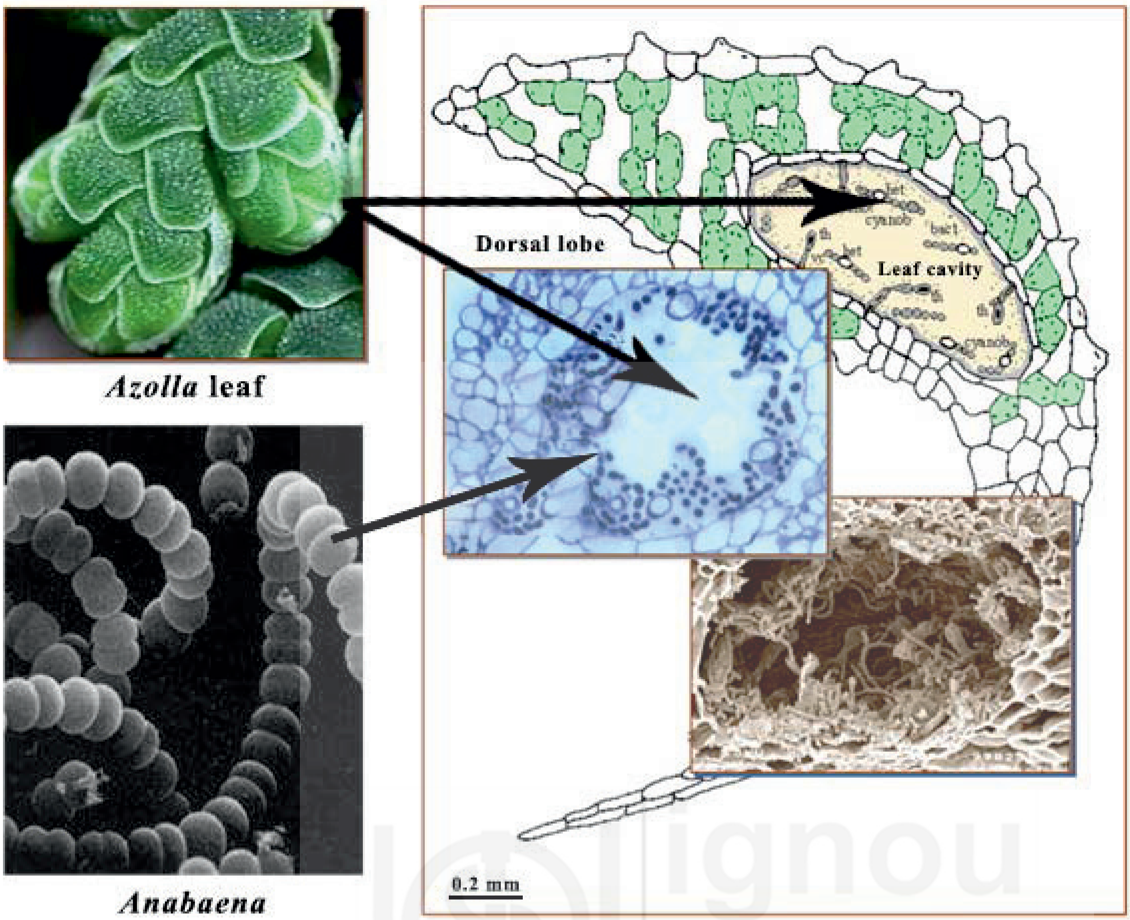


Fig. 8.5: *Azolla* plant harbouring the blue green alga *Anabaena*.

***Source*: https://www.google.co.in/search?q=anabaena+in+azolla&noj=1&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiVitOt-ofUAhUIv5QKHRGjDGkQsAQINw&biw=1366&bih=625#imgrc=LGyngTn4wpJxhM:**

SAQ 4

Write the names of the algae involved in the following:

a) The algal-fern association used to enrich rice fields with nitrogen.

b) A blue green alga used as a fertilizer.

c) A seaweed used to fulfill the fertilizer needs of palm trees in India.

d) A type of alga used for enriching the soil with minerals.

e) The algae grown to reduce the alklanity of usar soils.

8.6 SOURCE OF ENERGY

The fossil fuel reserves like coal, peat, crude oil products (hydrocarbons) and natural gas on the Earth are limited. At present, they are being consumed at much faster rate than before due to rapid industrialisation. Unfortunately, they are non-renewable and it is estimated that they will soon be depleted.

Therefore, serious efforts are being made to find out alternate renewable sources of energy. Algae are identified as one such potential source.

Algal biomass is found quite suitable for use in biogas plants for producing methane gas. It can be fermented in anaerobic digesters as sole substrate or along with sewage sludge. It has been shown that *Spirulina* when added to sewage sludge doubles the production of methane. In Bhavnagar *Sargassum tenerrimum* has been successfully used in biogas plants.

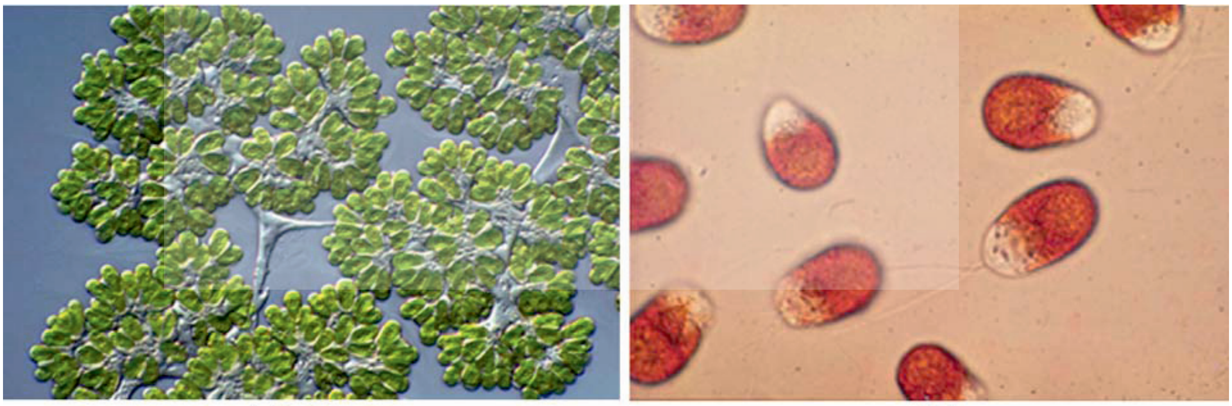
Algae having potential for energy production are: *Spirulina*, *Botryococcus braunii*, *Sargassum tenerrimum*, *Alteromonas gracilis*, *Chlamydomonas*, *Dunaliella*, *Anabaena* (for hydrogen).

Algae synthesise energy rich molecules like long chain hydrocarbons, glycerol and lipids. When some algae are grown without nitrogen and silicon, there is an increase in the synthesis of lipids. These energy rich chemicals can be converted into petrol and diesel. Glycerol required in pharmaceutical industry is produced by *Alteromonas gracilis*, *Chlamydomonas* and *Dunaliella* (Fig. 8.6).

Glycerol is the major photosynthate in *Dunaliella*. This unicellular wall-less halophytic alga is an ideal organism for the production of glycerol. It can be grown in the arid zones of Rajasthan and elsewhere where highly saline water is readily available. Its biomass is rich in protein and β-carotene and can be used as animal feed. In Australia and Israel glycerol is commercially produced from *Dunaliella*.

Although glycerol is not a good liquid fuel as it is highly oxygenated, but it can be converted to other liquid fuels like ethanol, butanol and propane-diol that can be used as a substitute for petrol. In Brazil ethanol is used in place of petrol and in USA it is added to gasoline and sold as gasahol.

Another alga with potential is *Botryococcus braunii* (see Fig. 8.6) which under saline conditions produces long chain hydrocarbons including fatty acids. In Sumatra oil is extracted from this alga.



(a) (b)

Fig. 8.6: (a) *Dunaliella salina*, and (b) *Botryococcus braunii*.

Source: **a) https://www.google.co.in/ earch?q=Dunaliella+ salina&noj=1&source= lnms&tbm=isch&sa=X&ved=0ahUKEwjCsvvt ofUAhUEIJQKHd97Bhk Q_AUICigB&biw= 1366&bih=625#imgrc= UJbX oNFp AUdWGM: b) https://www.google.co.in/ search?q= botryococcus &noj=1&source=lnms& tbm=isch&sa=X&ved= 0ahUKEwjkIle __4fUAhWGipQKHXo 6CkgQ_AUI CigB&biw= 1366&bih=625#imgrc=EUI6XAhv0V-zJM:**

The possibility of hydrogen production by cyanobacteria has drawn much attention, because they can produce hydrogen in the presence of light in a nitrogen free atmosphere. Hydrogen along with air is used in fuel cells to produce electricity without polluting the atmosphere.

The strains of algae having potential for hydrogen production are: *Chlorella*, *Scenedesmus*, *Synechococcus*, *Macrocystis*, and *Oscillatoria*.

Another area that has been successfully explored is the sustained photo-production of ammonia from nitrate by cyanobacteria. This requires inhibition of enzyme glutamate synthetase. Consequently, the alga produces ammonia at high rates with fairly high efficiency.

SAQ 5

Which of the following statements are true?

a) Long chain hydrocarbons and fatty acids are energy rich molecules.

b) Certain algae synthesise glycerol molecules.

c) Algal mass cannot be used in biogas plants.

d) Blue-green algae are being explored for the production of hydrogen

8.7 INDUSTRIAL APPLICATIONS

A large number of algal products have proved to be of great commercial use. A variety of compounds are obtained from seaweeds and these are discussed below under the headings Phycocolloids, Diatomite, and Pigments. The economically important seaweeds in India include species of red algae such as – *Gelidiella acerosa*, *Gracilaria edulis*, *Gracilaria corticata*, *Gracilaria foliifera*, *Gracilaria crassa*, *Hypnea musciformis*, *Hypnea valentiae*, *Hypnea pannosa*, *Sargassum wightii*.

In our country, seaweed utilization has got a boost since the establishment of Marine Algal Research Station at Mandapam near Rameshwaram and also due to the keen interest taken by some Universities in the coastal areas. Most of the natural seaweed growing areas are located in Tamil Nadu coast, Ramnad district where villagers found it profitable to collect and sell seaweeds to the local industries. In the Gulf of Mannar there are a number of Islands having rich growth of seaweeds and today these places are used for large scale cultivation of seaweeds for producing various algal products.

8.7.1 Phycocolloids

The colloids obtained from algae are called as Phycocolloids. In cells polysaccharides are of three types: structural (cell wall); exocellular mucilages and interacellular reserves (starch). The exocellular mucilages are made of monosaccharide units which may be sulphated. They are rich in ribose and arabinose. Animals also contain sulphated polysaccharides. The presence of sulphate makes these polysaccharides good thickening or gelling agents.

Alginic acid, agar and carrageenans are high molecular weight polysaccharides and possess colloidal properties. They are constituents of cell wall of mostly red and brown seaweeds. They are used as viscofers, emulsifiers and lubricants in food, paper, textile, drug and caustic industries. Since there are no synthetic substitutes or non-algal sources for obtaining them, seaweeds are of great value.

Alginic Acid

In the cell wall of algae, alginic acid is present in the form of alginates – Na, K, Ca, NH_4 salts of alginic acid. Since the sodium salt is soluble in water, the extraction is done with sodium hydroxide. Alginates are used for wide variety of purposes (Table 8.3). They are also used for making flame-proof fabrics and plastic articles. This polymer can absorb large quantities of water, therefore, it is used as highly absorbent gauze in internal operations to stop bleeding effectively. Owing to its non-toxic and colloidal property it is used for making antibiotic capsules.

Table 8.3: Uses of Alginates

Purpose	Items
Thickening agents	Jams, jellies and sauces, cosmetics, textiles and pharmaceutical industries.
Stabilisers	Ice creams, milk shakes and squashes.
Emulsifiers	For the preparation of paints and polishes.
Surface coating agents	For flame proof fabrics, plastics.
Absorbents	In surgical operations.

Coasts of North and South America, Australia, New Zealand are rich in *Macrocystis* which is commercially harvested for alginic acid and in North Atlantic, *Ascophyllum* is a source of alginates. In our country alginates are produced from *Sargassum* and *Turbinaria*. Algae commonly used for the extraction of alginic acid are: *Macrocystis*, *Laminaria*, *Ascophyllum*, *Sargassum*, and *Turbinaria*. These are abundant in coastal Japan, Chile, Mexico and U.S. *Gracilaria* and *Gelidium* are abundant in coastal Japan, Chile, Mexico and US. *Gelidiella acerosa* is the principal agar yielding alga in India.

Due to indiscriminate harvesting year after year, there is tremendous depletion of naturally growing seaweeds and so now it is necessary to resort to cultivation to provide constant supply of seaweeds in quantity and quality. Methods are now available for marine cultivation of *Gracilaria and Gelidiella* and village women are being trained to undertake this work for extra income.

Agar

The gelatinous substance agar is well known for the solidification of culture media in microbiology and tissue culture. It is a mixture of agarose and agaropectin and is extracted from about 80 algal species of seaweed. The commonly used algae are *Gracilaria edulis*, *Gelidella acerosa* and *Gelidium*.

Like alginic acid it is also used in the manufacture of puddings, ice creams, jellys and soups. As stabiliser or emulsifier it is used in cosmetics, leather and pharmaceutical industries. Because of its laxative property it is used for the treatment of constipation.

Alginic acid, also called algin or alginate, is an anionic polysaccharide distributed widely in the cell walls of brown algae, where through binding with water it forms a viscous gum.

Carrageenan

The main sources of carrageenan are *Chondrus crispus* commonly known as 'Irish Moss' and *Eucheuma* spp. The polysaccharide in carrageenan are sulphated. Like alginic acid and agar, it is used in dairy industry and in cosmetics, textile, pharmaceutical, leather and brewing industries.

8.7.2 Diatomite

Diatoms have rigid silicified cell walls. The entire cell wall of a diatom is known as frustules. The fossilised frustules of diatoms are commonly known as diatomite or diatomaceous earth. They form sedimentary rocks and serve as biogenic silica sources. Due to low density, high porosity, large surface area, low abrasion capacity and chemically inert nature, diatomite is used in industry. The uses of diatomite are listed in Table 8.4.

Table 8.4: Uses of Diatomite

Purpose	Uses
Filter	For clearing lubricating oils and aviation fuels, for refining sugar.
Insulator	In boilers, furnaces, refrigerators, for making soundproof rooms.
Abrasive	In scouring and polishing powders like tooth powder, bleaching powder, glass cleaners, paints and varnishes.
Filter	In battery boxes.
Inert substances	Controller of burn and friction in match heads and cigars, for packing explosive materials.
Absorptive	In handling and packing hazardous materials.
Anticake	In fertilizers.

8.7.3 Pigments

One of the criteria for classifying algae is the presence of photosynthetic pigments – chlorophylls, carotenes, xanthophylls and fucoxanthin that impart distinct colours such as red, blue, green, yellow, golden and brown to them. These pigments are extracted on commercial scale and are used for various purposes. *Dunaliella* and *Spirulina* are rich sources of β-carotene, the precursor of vitamin A. In comparison to other sources of β-carotene microalgae offer several advantages. They require a short generation time for growth and can be grown in sewage water. The amount of β-carotene in them is in high concentration. It may be noted that β-carotene has been identified as an anticancer drug.

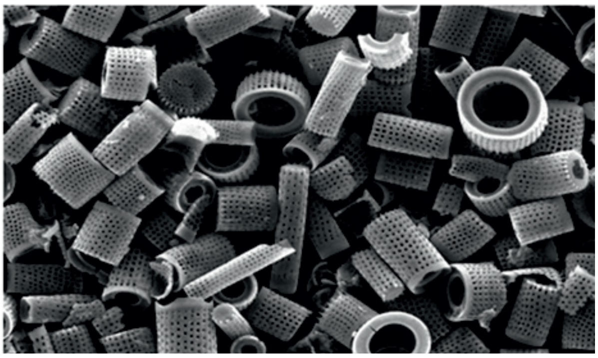


Fig. 8.7: **Scanning electron micrograph of a fragment of diatomaceous earth showing the remnants of silicified cell walls of fossil diatoms (arrows).**

Source: **http://www.mtsylviadiatomite.com.au/news/2009-nothing-pure-whole-diatoms-first-results**

β-carotene and other pigments like xanthophylls, cantaxanthin and zeaxanthin are used as food colourants. For example β-carotene is used for colouring soft drinks and margarine and cantaxanthin is used for colouring chicken skin, gold fish skin and egg yolk.

8.8 MEDICINAL USES

Some algae have antibacterial, antiviral and antipyretic properties. They are used for wound healing, treatment of heart diseases, gout, goiter, hypertension, gall stone, bowel movement, skin diseases and as vermifuge. The beneficial uses of algae in medicine are summarised in the Table 8.5.

Table 8.5: Medicinal uses of algae

Used as	Active Compound
Antibiotic	Chlorellin (*Chlorella*)
Vermifuge	Kainic Acid (*Digenea*)
Cough syrup	Carrageenan
Anticoagulant	Agar
Diagnostic tool for understanding the nature of seizure in epilepsy	Kainic Acid
Anticancer agent	Decoction of *Laminaria, Sargassum*
Binding agent for medicinal tablets	Fucoidin and agar

8.9 ALGAL COMPANIES

Several companies have set up large scale industries to utilise algal potential for a range of products. Of these Dupont and Sohio (USA), Kirin Brewery and Dainipa (Japan), Thapar Corporation (India), Wester Biotechnology Limited (Austraia), Siam Algae Company (Bangkok). The market value of algae given in Table 8.6 would give you an idea of the algal products and the market size.

Table 8.6: Variety of products obtained from algae, their approximate value and market size.

Algal products	Uses and Examples	Approximate Value $/Kg	Approximate Market*
Radioactive isotopic labelled compounds	Biochemical and medical research	>1,000	Small
Phycobiliproteins	Diagnostic food colours	>10,000 >100	Small Medium
Pharmaceuticals	Anticancer Antibiotics	Unknown Very high	Large Large
β-carotene	Food supplement Food colour	500 300	Small Medium
Xanthophylls	Chicken feeds Fish feeds	200-500,1000	Medium Medium
Vitamins C and E	Natural vitamins	10-50	Medium
Health foods Polysaccharides	Supplements Viscofers, gums Ion exchangers	10-20 5-10	Medium to large Medium to large
Bivalve feeds	Aquaculture	20-100 1-10	Small Large
Soil inocula	Conditioner, Fertilisers	>100	Unknown Unknown
Amino acids	Proline Arginine Aspartate	5-50 5-50	Small Small
Single cell protein	Animal feeds	0.3-0.5	Large
Vegetable oils	Foods Feeds	0.3-0.6	Large
Marine oils	Supplements	1-30	Small
Waste treatment	Municipal industrial	1	Per kg algael arge
Methane, H_2, Liquid fuels	General uses	0.1-0.2	Large

* Market sizes ($ million): Small <$10; Medium $10-100; Large >$100.

8.10 OTHER EFFECTS

In the previous sections you have studied some uses of algae for human beings. There are some effects of algae that are not considered useful and welcome by humans. This aspect is discussed in this section.

8.10.1 Eutrophication

Algal blooms, technically known as Eutrophication refers to rapid and excessive growth of algae covering stationary water bodies such as reservoirs. The water in such instances is not suitable for recreational purposes that are for swimming, boating or fishing activities. Due to algal growth particularly during cloudy weathers, oxygen in the water gets depleted, as a result the fish and other aquatic animals get suffocated. Fish also die because they get choked in mouth and gills when entangled in large masses of algal filaments.

Sometimes, you may have experienced strange odour and taste in your drinking water supply. This could be due to certain algae which impart grassy, fishy, musty or some other odour and sweet or bitter taste to the water. The odour and taste are because of the metabolic and /or decomposition products of algae. Only a few cells of algae of Division Chrysophyta are sufficient to give bad taste and foul smell to water. Similarly, if *Synura*, diatoms or blue-green algae get into the filters of water supply, the filters get clogged and serious economic losses occur. Some algae that impart odour and taste to water include: *Macrocystis*, *Anacystis*, *Chlamydomonas*, *Ceratium*, *Synedra*, and *Synura*.

Some algae produce toxins which enter humans and animals directly or through food chains. For example, a person can get poisoned on consumption of oysters or fish that feed on toxic dinoflagellates. This algal toxin inhibits nerve transmission and thus results in paralysis and even may cause death.

Ingestion of toxic algae with drinking water or during swimming may cause gastric problems, skin infections or respiratory disorders. The alga *Prototheca* causes disease, protothecosis which manifests in the form of skin lesions, inflammation around joints and defective leucocytes in humans. Persons working with diatomaceous earth suffer from algal silicosis. Arsenic poisoning is caused by the excessive consumption of seaweeds. Affected persons suffer from skin rashes, blistering and inflammation. Fresh water blue-green algae produce alkaloids which are neurotoxins. In Table 8.6 some medical problems and the causative algae have been listed.

Table 8.6: Some medical problems and causative algae

Medical Problem	Causative Agent
Dermatitis (skin inflammation)	*Lyngbya majuscula*, *Chlorella*
Gastric problem	*Anabaena*, *Oscillatoria*
Respiratory disorders	*Chlorella*, *Oscillatoria*, *Anabaena*, *Gymnodinium*
Neurological disorders	*Pyrodinium*, *Protogonyaulax*
Algal silicosis	Diatomaceous earth
Arsenic poisoning	Excessive consumption of seaweeds
Allergens	*Lyngbya major*, *Chlorella*, *Oscillatoria*, *Anabaena*

Some algae such as *Chlorella* and *Zoochlorella* and some others are parasitic on aquatic invertebrates such as *Hydra*, snails, sponges and mussels.

Algae are responsible for some plant diseases also. For example, the green alga *Cephaleuros* caused red rust of tea resulting in reduced yields.

Control of Algal Growth

Chemical and biological methods can be used to control undesirable growth of algae. Several algicides are known such as copper sulphate, quinines, phenols and others that selectively target algae. Algal growth can also be controlled by introducing suitable crustaceans or fish fingerlings in the affected reservoir. Certain viruses which kill blue-green and green algae are also useful for control.

SAQ 6

a) Complete the following statements.

i) Alginates are present in the .... of seaweeds. They are extracted by using .... because sodium alginate is soluble in water.

ii) The colloids present in seaweeds are called ....

iii) Alginates are used for making .... proof fabric and .... articles.

iv) Alginic acid is highly .... therefore it is used in surgical operations to stop .... effectively.

v) Agar is used as .... medium for micro-organisms.

vi) The cell wall of diatoms is rigid because it is ....

vii) Diatomite is used as abrasive in .... polishing powders.

viii) β-carotene is identified for having .... properties.

ix) Gelidiella acerosa is the principle .... yielding alga in India.

x) Irish moss is the main source of ....

b) List medicinal uses of algae.

c) List the harmful effects of algae.

8.11 SUMMARY

In this unit you have studied that:

- Algae are important and potential source of food and fodder, biofertilizers, energy and various medicinal and industrial products.
- Microalgae and seaweeds are nutritionally rich. The commonly edible species are *Porphyra*, *Ulva*, *Chondrus*, *Palmaria*, *Gracilaria*, *Gelidiella*, *Caulerpa*, *Laminaria*, *Spirulina* and *Chlorella*. Some of these are cultured commercially on mass scale.
- Algae are used as fodder for cattle and as feed for poultry, fish, oyster, mollusks and caterpillars of silkworms.

- Microalgae *Spirulina*, *Chlorella*, *Scenedesmus*, *Oscillatoria* are used for treatment of waste water.
- Blue green algae enrich the soil with nitrogen, and seaweeds with potassium and soil binding polysaccharides.
- The possibility of the production of H_2O, NH_3 and hydrocarbons by algae is being explored. The algal biomass is used for the production of biogas.
- Several compounds such as alginic acid, carrageenan, agar, diatomite and pigments are extracted from algae. They have various applications.
- Algae are also used for medicinal purposes.
- Excessive growth of algae in certain conditions becomes a nuisance, and it dominates the water resources and often affects the aquatic animals adversely. The water supplies get fouled by them that may lead to epidemics.

8.12 TERMINAL QUESTIONS

1. List various uses of algae.
2. List three major edible algae popular in maritime countries. How are they consumed?
3. What are the advantages of using algae as biofertilizers?
4. List four uses of alginic acid.

8.13 ANSWERS

Self-Assessment Questions

1. a) i) proteins, vitamins, minerals, iodine
      ii) 65
      iii) brackish, open
      iv) *Chlorella*, cure-all
      v) waste
      vi) *Porphyra*
      vii) essential

   b) *Spirulina*, *Chlorella*, *Porphyra*

2. b), c), d)

3. a) oxygen, b) oxygen, c) water borne diseases, d) cattle, e) biogas

4. a) *Anabaena-Azolla*,

   b) Any one of the following: *Anabaena oryzae*, *Nostoc commune*, *Tolypothrix tenuis*, *Aulosira fertilissima*, *Anabaenopsis arnoldii*, *Calothrix confervicola*, *Haplosiphon*, *Fritschiella*, *Mastigocladus*, *Westiella*, *Westiellopsis*,

c) *Turbinaria*,

d) seaweed,

e) Blue green algae.

5. a), b), d).

6. a) i) cell wall, NaOH

ii) phycocolloids

iii) flame, plastic

iv) absorbant, bleeding

v) culture

vi) silicified

vii) scouring

viii) anticancer

ix) Agar

x) Carrageenan

b) Algae have antibacterial, antiviral and antipyretic properties. They are used for wound healing, treatment of heart diseases, gout, goiter, hypertension, gall stone, bowel movement, skin diseases, as vermifuge, in cough syrup, as anticoagulant, as anticancer agent, as binding agent for tablets and as diagnostic tool for understanding the nature of seizure in epilepsy.

c) Elaborate the following points:

i) Colonisation of water bodies,

ii) Change in the odour and taste of drinking water,

iii) Diseases due to intake of toxic algae,

iv) Algal toxins move into human and other animals,

v) Parasitic algae, and

i) Plant diseases.

Terminal Questions

1. See Sections 8.2 to 8.9

2. Refer to Section 8.2. Some important ones are: *Chlorella*, *Porphyra*, *Ulva* and *Spirulina*. You may also include the names of some other algae familiar to you.

3. Refer to Section 8.5

Hint: i) Enrich soil with nitrogen and potassium (blue green algae and seaweeds)

ii) Soil reclamation (blue-green algae).

4. Refer to Sub-section 8.7.1

8.14 GLOSSARY

Agar	:	A gelatinous substance derived from certain red algae that is used in preparing solid media for growing cells, tissues, or micro-organisms under sterile conditions.
Algin	:	A polysaccharide present in the intercellular spaces of some members of Phaeophyta made of d-mannuronic acid and L-guluronic acid.
Alginate	:	General term for salts of alginic acid.
Carrageenan	:	A mucopolysaccharide in the wall of some red algae, sulphated polymer of galactose.
Diatomaceous earth	:	Deposits composed largely of walls of fossil diatoms.
Kelp	:	The common name for any of the large brown algae.

8.15 FURTHER READING

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