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General Characteristics of Algae

Dinabandhu Sahoo and Pooja Baweja

1 Introduction

Algae are group of plants which are known since ancient civilizations. The term algae was first introduced by Linnaeus in 1753 and it was A. L. de Jussieu (1789) who classified the plants and delimited the algae from rest of the plant world to its present status. They are autotrophic, mostly aquatic and a few are terrestrial. The plant body ranges from unicellular to multicellular structures with no vasculature and little differentiation into various tissue systems thus they are referred to as thal-
lophytes lacking true roots, stem and leaves. There can be a single cell as small as 1 μ to large seaweeds which can grow up to more than 60 m (Fritsch 1935, 1945).

The branch of botany, dealing with the study of algae is known as **Algology/Phycology** (Gr. *Phycos* – seaweeds and *logos* – study).

2 Habitat

Algae are a group of ubiquitous organisms which are present in diverse habitats such as water (aquatic algae), land (terrestrial algae), they also grow as an epiphyte, endophyte, and as well as in extreme conditions, in other words it can be said that algae are of universal occurrence (Fig. 1).

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Fig. 1 Algae growing in a pond (Courtesy: Prof. Dinabandhu Sahoo)



Fig. 2 Algal bloom in narrow channel of Dal lake (Kashmir, India) (Courtesy: Prof. Dinabandhu Sahoo)



2.1 Aquatic Algae

Predominantly the algae are aquatic and are found in **fresh water** growing in ponds, pools, lakes (Fig. 2), rivers, tanks etc., in **brackish water** (which is unpalatable for drinking) as well as **marine water** (with moderate to very high salinity). The commonly found fresh water algae are *Nostoc*, *Oedogonium*, *Chara*, *Cladophora*, etc. Fresh water algae have been reported from both tropical (e.g., as *Cyclotella* sp., *Orthoseira roeseana*, *Cocconeis pediculus*; *Volvox* sp., *Oedogonium* sp., *Nostoc* sp., *Microcystis* sp. etc.) as well as temperate waters (*Pediastrum* sp., *Fragillaria* sp., *Nitzschia* sp.). Fresh water algae based on their habit may be free floating, or attached to the bottom and may be classified as:

2.1.1 Planktonic Algae

They float freely on the surface of water and can be further differentiated into (a) **Euplanktons**: True planktons which are free floating from the beginning and never get attached to the substratum e.g. *Volvox*, *Cosmarium*, *Microcystis*, *Chlamydomonas*, *Scenedesmus* etc. (b) **Tychoplanktons**: Initially these algae are attached to the substratum but later they detach and become free floating e.g. *Zygnema*, *Oedogonium*, *Cladophora* etc.

Fig. 3 *Ulva* (a marine green algae) and other green sp. growing on rocks (Courtesy: Prof. Dinabandhu Sahoo)



2.1.2 Benthic Algae

These algae are bottom dwellers i.e. attached to the bottom of shallow pools. Mostly they are filamentous or colonial forms and may be unicellular (Fig. 3).

The benthic algae may further be classified as **epizoic** growing on animal body surface (*Cladophora* grows on snail); **epilithic** attached to stones or rocks (*Ulothrix tenuissima*, *Tribonema minus*, *Batrachospermum monilisperme* etc.); **epipellic** attached to sand and mud (*Oedogonium sp*, *Clostrarium sp*, *Cosmarium sp*. etc.) and **epiphytic** growing on surface of plants (*Vaucheria sp.*, *Ulothrix sp.*).

2.1.3 Neustonic Algae

These algae grow at air water interface for e.g. *Botrydiopsis* (Xanthophyceae), *Chromatophyton* (Chlorophyceae), *Nautococcus* (Chlorococcaceae) etc.

The algae growing in sea water are commonly known as marine algae (seaweeds) and they may grow in supralittoral, sublittoral or littoral (intertidal or subtidal) zones.

2.1.4 Supralittoral

These algae grow above the water level and are found growing on the rocky shore where they are just dampened only by the splashes of high spring tide waves such as *Prasiola stipitata* (a green seaweed), *Ulothrix flacca* etc.

2.1.5 Sublittoral or Infra Littoral

These algae grow below the water level.

Some common example of algae growing in brackish water are *Oscillatoria*, *Anabaena* etc.

2.1.6 Littoral

These algae grow in the areas where there is periodic exposure of tides and is a junction between land and sea. Some of the examples of algae growing in this “subtidal zones” are *Dictyota* sp., *Rhodomenia* sp., *Grateloupia* sp., *Gracilaria* sp., *Polysiphonia* sp., *Chondrus crispus*, *Laminaria* sp. etc. Algae growing in Intertidal zones are *Porphyra* sp., *Euglena* sp., *Laminaria* sp., *Gigartina* sp., *Fucus* etc.

2.2 Aerophytes

Algae growing on the surface of leaves, bark, moist walls, flower pots, rocks, fencing wires are grouped as aerophytes. These algae have adapted for aerial mode of life and obtain their water supply from rain, dew and atmospheric humidity. Some of the examples of aerophytic algae are:

<i>Trentepohlia</i> , <i>Scytonema</i> , <i>Chroococcus</i> , <i>Pleurococcus</i>	Bark of trees (Epiphloeophytes)
<i>Phycopeltis epiphyton</i> , <i>Somatochroon</i> , <i>Cephaleuros</i>	Surface of leaves (Epiphylllophytes)
<i>Cyanoderma</i> , <i>Trichophilus</i> , <i>Trentopholia</i> , <i>Pleurococcus</i> , <i>Chlorococcales</i>	Rocks and stones

2.3 Cryophytic Algae

These algae grow in permanent or semi – permanent snow – capped mountain and polar regions of the world. These algae when grow imparts colour to the snow for e.g.

<i>Chlamydomonas nivalis</i> , <i>Scotiella</i> , <i>Gloeocapsa</i>	Red color
<i>Acyclonema</i>	Brown or purple color
<i>Chlamydomonas yellowstonensis</i> ,	Green color
<i>Euglena</i> <i>Enkistrodesmus</i> , <i>Mesotaenium</i>	
<i>Scitiella</i> , <i>Protoderma</i> , <i>Pleurococcus</i> , <i>Nostoc</i>	Yellow or yellowish green
<i>Raphidonema</i>	Black colour of snow

2.4 Endozoic Algae

Algae growing inside the body of vertebrates or aquatic animals are called endozoic algae for e.g.

Algae	Host
<i>Zoochlorella</i>	<i>Hydra viridis</i>
<i>Zooxanthella</i>	Fresh water sponges
<i>Oscillatoria, Simonsiella, Anabaeniolum</i>	Several vertebrates

2.5 Epizoic Algae

Many algal forms are known to grow on the surface of other aquatic animals (epizoic algae), such as:

<i>Oscillatoria, Protoderma, Bascicladia</i> and <i>Dermatophyton</i>	Turtles surface
<i>Cladophora crispata</i>	Shells of snails and molluscs
<i>Stigeoclonium</i>	Gills and nose of fish

2.6 Epiphytic Algae

These grow on other aquatic plants and are not host specific (Fig. 4) for e.g.

Algae	Host
<i>Coleochaete nitellarum</i>	<i>Chara</i> and <i>Nitella</i>
<i>Chaetonema</i>	<i>Tetraspora</i> and <i>Batrachospermum</i>
<i>Rivularia</i>	An angiosperm <i>Scirpus</i>
<i>Chaetophora</i>	Leaves of <i>Nelumbo</i> and <i>Vallisnaria</i>
<i>Cocconis, Achanthus</i>	<i>Lemna</i>

Fig. 4 *Oedogonium* filaments growing as epiphyte on another aquatic plant (Courtesy: Prof. Dinabandhu Sahoo)

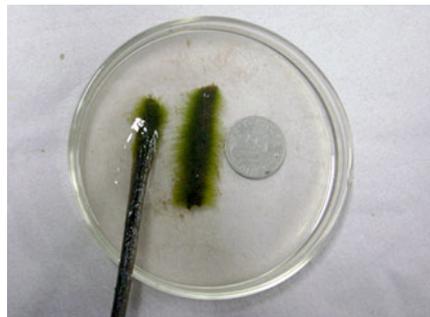




Fig. 5 *Dunaliella salina* growing in salt pans of sambhar lake, Rajasthan (algae growing in extreme halophytic conditions) (Courtesy: Prof. Dinabhandhu Sahoo)

2.7 *Halophytic Algae*

These algae grow in waters with very high salinity (Fig. 5) may be upto 70–80 ppt for e.g. *Dunaliella*, *Stephanoptera*, *Chlamydomonas ehrenbergii*, *Oscillatoria*, *Ulothrix*.

2.8 *Parasitic Algae*

Members of algae are known to live as parasite and semiparasite on other algae as well as higher plants, where they cause severe damage, for e.g.

Cephaleuros virescence (Chlorophyceae) grows on Tea plants (Causes Red rust of tea)

Cephaleuros virescence (Chlorophyceae) grows on *Coffea arabica*, *Rhododendron*, *Magnolia* and *Piper nigrum* causing Red Rust.

Rhodochytrium (Chlorophyceae) grows on ragweed (*Ambrosia*) leaves

Phyllosiphon (Chlorophyceae) grows on the leaves of *Arisarum vulgare*

Polysiphonia fastigata (Rhodophyceae) grows on *Ascophyllum nodosum* as semiparasite

Ceratocolax (Rhodophyceae) grows in *Phyllophora thallus*

2.9 Symbiotic Algae

Members of cyanophycean algae grow in association with several plants such as:

- *Nostoc* grows in association with *Anthoceros*, *Notothylas*, *Blasia*
- *Anabaena cycadaceae* grows in the corolloid roots of *Cycas plants*
- *Anabaena azollae* grows in *Azolla*

2.10 Terrestrial Algae

Algae growing on soils, logs, rocks etc. are grouped under terrestrial algae. Most of the terrestrial algal genera grow on or beneath the moist soil surface, for e.g.

<i>Vaucheria</i> , <i>Botrydium</i> , <i>Fritschiella</i> and <i>Oedocladium</i>	Grow on soil surface
<i>Nostoc</i> , <i>Anabaena</i> , <i>Euglena</i>	Subterranean habit

2.11 Thermophytic Algae

These algae grow in hot springs, where the temperature may go beyond 85 °C. Almost all thermophytic algae are known from Cyanophyceae.

<i>Cyanidium caldarium</i>	Acidic hot springs
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Other examples of thermophytic algae are *Synechococcus*, *Synechocystis*, *Phormidium*, *Scytonema* etc.

3 Thallus Organization

Range of algal thallus varies from unicellular to multicellular forms or microscopic to macroscopic structures, with their size ranging from a few microns to some meters. *Micromonas pusilla* is known to be smallest algae which is unicellular and is 1 μm (0.00004 in.), on the other hand giant kelps has longest thalli that reaches up to 60 m (200 ft) in length. The unicellular forms may remain solitary as a single unit which are capable of completing their life cycle by providing all physiological, biochemical, genetical requirements and may be motile or non-motile. When these unicellular forms are held together in a common gelatinous matrix, they constitute colonial forms, which are considered intermediate between unicellular and multicellular structures. The other intermediate stages considered in thallus organization of algae are palmella, dendroid, palmelloid, coccoid, filamentous, siphonaceous, heterotrichus, uniaxial, multiaxial etc. In colonial forms the individual cells are

independent in both structure and function. The multicellular form ranges from microscopic to macroscopic, where some of the macroscopic forms reported from phaeophyceae and rhodophyceae grow upto few meters. The multicellular forms may be parenchymatous or sometimes the thallus is differentiated (Round 1973).

3.1 Unicellular Forms

Unicellular or acellular forms can be motile or non-motile and are further grouped into three categories based on presence or absence of flagella. The motile forms are either rhizopodial or flagellates and non-motile forms are coccoid.

3.1.1 Rhizopodial

The rhizopodial forms lacks rigid cell wall and have a naked protoplast, cell envelope is periplasmic, soft and permits extensive changes in shape and size of thallus, lack flagella and instead possess cytoplasmic projections called Pseudopodia and Rhizopodia. These forms move in ameboid manner.

Examples: *Chrysamoeba* (Chrysophyceae), *Rhizochloris* (Xanthophyceae) and Dinophyceae.

3.1.2 Flagellates

The vegetative phase of many algae is a motile, flagellate unicell. Flagella may be one or two or many, equal or unequal, and tinsel or whiplash type. Motile unicells are commonly spherical, elongate, ovoid or round in cross section.

Examples: Flagellated forms are present in almost all groups of algae except Myxophyceae, Phaeophyceae, Rhodophyceae

3.1.3 Coccoid

Non motility predominates and motility is entirely absent or restricted only to reproductive stages. Occur in majority of algal classes and predominates in Xanthophyceae (70 %). Coccoid forms are provided with a rigid cell wall and are non-flagellated.

Example: *Prochloron*, *Aphanocapsa* and *Synechococcus*

3.1.4 Spiral

Unicellular, spiral filamentous.

Example: *Spirulina*

3.2 *Multicellular Forms*

3.2.1 *Colonial Aggregation*

A colony is a group of separate cells generally similar in structure and function and aggregated by a mucilaginous envelope. The colonial habit can be further differentiated into:

COENOBIUM: It has a definite number of cells arranged in a particular manner which is determined at the juvenile stage and does not increase during its subsequent growth even though the cells enlarge. It comprises aggregation of flagellate (*Volvox*) or non-motile cells (*Hydrodictyon*).

PALMELLOID: Colonial members in which “non – motile” cells remain embedded in an amorphous gelatinous or mucilaginous matrix. In this type neither the number, nor the shape and size of cells is constant. The cells are aggregated in a common mucilaginous envelope. All the cells are independent of each other and fulfil the function of an individual. Most normally flagellate or coccoid unicellular algae may enter (often temporary) palmella stage, a condition where the flagella are lost and the individuals undergo successive vegetative divisions while embedded in a common gelatinous matrix, named after the volvocalean (Chlorophyceae) genus *Palmella*. This term may be strictly applied to those algae where the cells will readily revert to a motile condition or may be expanded to include all algae where the palmelloid habit is more permanent. Example: *Palmella*, *Microcystis*.

TETRASPORAL: The motile stages (if present at all) are restricted to the reproductive cells. The regular colonies of the Cyanophyceae (e.g. *Merismopedia*, *Halopedia* as flat plates of cells and *Eucapsis*, with colonies in cubical masses) are included in the tetrasporal types. A feature of Tetrasporial form is the presence of mucilaginous pseudocilia.

DENDROID: The cells are united in a branching manner by localized production of mucilage at the base of each cell. The whole colony looks like a tree in habit. Examples: *Chrysodendron*.

RHIZOPODIAL: The cells of rhizopodial colonies are united through rhizopodia, as in *Chrysidiastrum* (Chrysophyta).

3.2.2 *Filamentous Forms*

Filaments are formed when vegetative divisions occur in a transverse plane. In a filament the Uniseriate row of cells are joined end to end in a transverse plane through middle lamella. In Cyanophyta, a filament includes both the trichomes (i.e. the uniseriate row of cells) and its sheath. The filament may be branched or unbranched.

Unbranched Filaments: Example: *Spirogyra*, *Zygnema*, *Oedogonium*, *Ulothrix*.

Branched Filaments: Example: *Cladophora*, *Pithophora*

The branching of the filament is either True or False.

FALSE BRANCHING: It occurs in *Scytonemataceae* (Cyanophyta), the trichome generally fragments due to the degeneration of an intercalary cell (or by the formation of biconcave separation discs) after which one or both of its ends adjacent to the dead cell grows out of the parent sheath, giving the resemblance of branching.

TRUE BRANCHING: It results from repeated transverse divisions of the lateral outgrowths produced by a few or many scattered cells of the main filament. The truly branched thalli are of four types:

- **Simple branched filament:** A branched upright filamentous thallus is attached by a simple disc derived from the basal cell Example: *Cladophora*.
- **Heterotrichous:** The thallus consists of two parts, a prostrate creeping base and an erect branched upright system. It is the most highly evolved type of filament construction. During its development, a system of branched creeping filaments is produced first and functions as the holdfast. These creeping system of filaments will further give rise to a system of erect and branched filaments Example *Stigeoclonium* (Chlorophyta) and *Ectocarpus* (Phaeophyta)
- **Parenchymatous forms:** This occurs when cells of the primary filament divide in all directions, any essentially filamentous structure is thus lost early. Example: *Porphyra*, *Ulva*, *Enteromorpha*. This type of organization is most common in Phaeophyceae (Fucales, Laminariales).
- **Pseudoparenchymatous forms:** This habit results from a close juxtaposition of the branched filaments of a single or many axial filaments. If branches from a single filament are involved as in *Batrachospermum*, the thallus construction is called as uniaxial. If branches of many axial filaments aggregates, the thallus is multiaxial e.g. *Nemalion*.

3.2.3 Siphonocladous Organization

It is restricted to members of chlorophyceae in which the unbranched (*Urospora*, *Chaetomorpha*) or branched (*Acrosiphonia*, *Cladophora*) filaments are composed of multinucleate (semi – coenocytic) cells. One of the siphonocladous algae *Valonia* occurs as a single, spherical vesicle upto 10 cm in diameter has been described as the largest plant cell.

3.2.4 Siphonous Organization

In a number of marine Chlorophyceae (order Siphonales, Bryopsidales, Dasycladales) and some Xanthophyceae (*Botrydium*, *Vaucheria*) enlargement and elaboration of the thallus proceeds in the absence of septa. Nuclear divisions are not

followed by cytokinesis (free nuclear division) and the result is a coenocytic, multi-nucleate thallus and a siphonous organization.

Siphonous organization ranges from Saccate (e.g. *Botrydium*) to uniaxial (e.g. *Vaucheria*, *Bryopsis*) and multiaxial (e.g. *Codium*) forms.

4 Plastids and Photosynthetic Pigments

The most prominent feature of an algal cell is the plastid, which makes an important characteristic of an algal cell for classification. Plastids which consist of chlorophyll a and chlorophyll b are called CHLOROPLASTS and the one which lacks chlorophyll b are called CHROMATOPHORES (Sharma 2011). Prescott (1969) has classified them as “the pigment containing body with chlorophyll in dominance is Chloroplast and when the pigments other than chlorophyll are dominant are called Chromatophores”.

In algae, different forms and shapes of plastids are observed such as (Fig. 6):

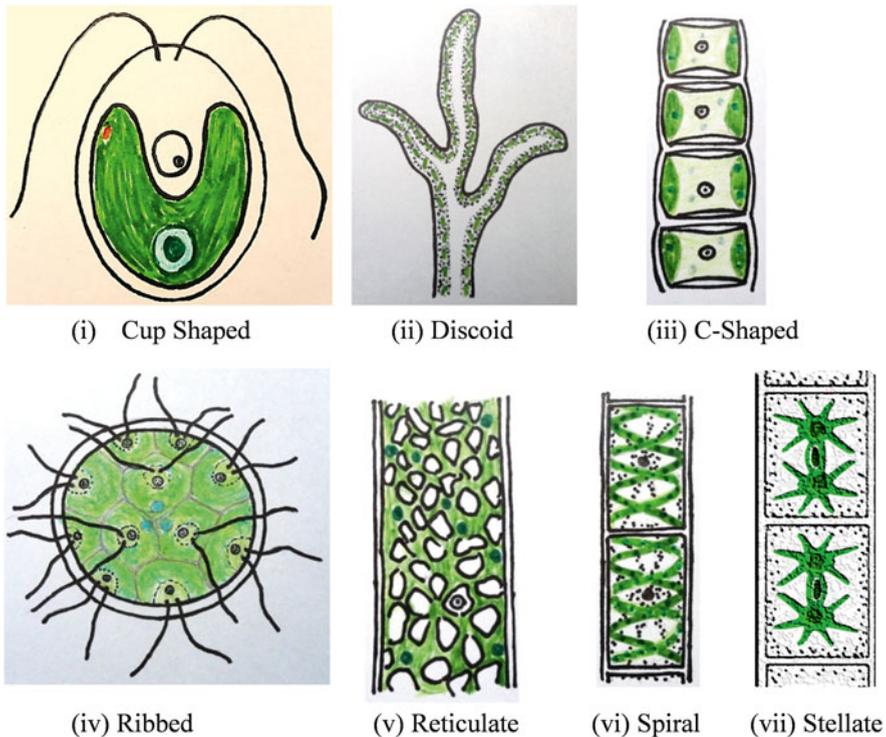


Fig. 6 Different shapes of algal chloroplast (i) *Chlamydomonas*, (ii) *Vaucheria*, (iii) *Ulothrix*, (iv) *Volvox* (v) *Cladophora*, (vi) *Spirogyra* (vii) *Zygnema*

- (i) Cup shaped: *Chlamydomonas*, *Volvox*
- (ii) Discoid: *Chara*, *Vaucheria*, Dinophyceae, Bryopsidophyceae and many diatoms
- (iii) Girdle or C shaped: *Ulothrix*
- (iv) Ribbed: *Volvocales*
- (v) Reticulate: *Oedogonium*, *Hydrodictyon* and *Cladophora*
- (vi) Spiral or ribbon shaped: *Spirogyra*
- (vii) Stellate: *Zygnema*

According to location the plastid may be

- (i) Parietal: Chaetophorales, Phaeophyta, Rhodophyta, Chrysophyceae, Pinnate Diatoms
- (ii) Axial: *Porphyridium*, *Bangia* (John et al. 2002)

The basic structure of chloroplast is similar throughout the plant kingdom with an envelope, stroma and internal lamellar membranes. Only the Cyanophycean members shows the typical prokaryotic structure, where the thylakoids are not bound in any envelope and they lie freely in cytoplasm.

In general, the following types of photosynthetic pigments (Table 1) have been reported in an algal cell (Round 1973):

- (i) Chlorophylls: There are five types of chlorophylls in algae a, b, c, d and e. Their occurrence in different algal groups has been reported in table 1.
- (ii) Carotenes: There are five types of carotenes reported in different algal groups as listed in table, and it is an accessory photosynthetic pigment. The different types of carotenes are α , β , γ , e, c and flavicin.
- (iii) Xanthophylls: There are about 20 xanthophylls reported in algae which are characteristic of different algal groups.
- (iv) Phycobilins: There are six types of phycobilins in algae.

5 Reserve Food

Polysaccharides and fats are two principle storage products in different members of algae as summarized in Table 2:

6 Cell Wall

Most of the members of algae consist of a cell wall, and cell wall consists of non-living material which are variously classified. In algae polysaccharides are chief constituent of cell wall with two major components (i) Fibrillar (Cellulose, Mannans, Xylans) and (ii) Amorphous (Alginic acid, fucoidan, galactans etc.) (Lee 2008). The fibrillar component forms the skeleton of cell wall and amorphous component

Table 1 Pigments in different algal groups

S. No.	Class	Thylakoid/Lamella	Chief pigment (chlorophyll)	Accessory pigments (carotenes)	Accessory pigments (xanthophyll)
1.	Chlorophyceae (green algae)	2 – many	a, b	α , β and c	Lutein, zeaxanthin, violaxanthin and neoxanthin
2.	Xanthophyceae (yellow – green)	3	a, e	β	Siphonein and siphonoxanthin (siphonales), Lutein, fucoxanthin, violaxanthin, vaucherioxanthin and neoxanthin
3.	Chrysohyceae (orange algae)	3	a, c	β	Lutein, fucoxanthin, neofucoxanthin
4.	Bacillariophyceae (diatoms/ yellow or golden brown algae)	3	a, c	α , β and e	Fucoxanthin, neofucoxanthin, diatoxanthin, diadinoxanthin
5.	Cryptophyceae (nearly brown)	2	a, c	α and e	Zeaxanthin, diadinoxanthin, cryptoxanthin
6.	Dinophyceae (dark yellow or brown)	3	a, c, Peridinin	β and e	Phycobilins – cryptomonad, phycoerythrin and phycoerythrin Dinoxanthin, neodinoxanthin, peridinin, neoperidinin, diadinoxanthin, neodiadinoxanthin, flavoxanthin
7.	Chloromonadinae (bright green)		a, c	β	Diadinoxanthin
8.	Euglenophyceae	3	a, b	β	Lutein, zeaxanthin, neoxanthin, astaxanthin
9.	Phaeophyceae (Brown Algae)	3	a, c	β and e	Fucoxanthin, flavoxanthin, Lutein, Violaxanthin and neoxanthin
10.	Rhodophyceae (red algae)	1	a, d	α and β	r-phycoerythrin, r – phycoerythrin, lutein, zeaxanthin, violaxanthin
11.	Myxophyceae (Cyanophyceae, blue green algae)	1	a	β and e, flavacene,	c-phycoerythrin, e-phycoerythrin, Myxoxanthin, myxoxanthophyll

Table 2 Reserve food in different algal groups

S. no.	Class	Food reserve	Location
1.	Chlorophyceae (Green algae)	Starch	Starch grains within chloroplast envelope
2.	Xanthophyceae (Yellow – green)	Oil, fats, leucosin	With in chloroplast
3.	Chrysophyceae (Orange algae)	Oil, fats, chrysolaminarin	Cytoplasm
4.	Bacillariophyceae (Diatoms/ yellow or golden brown algae)	Fats and leucosin	Vesicles
5.	Cryptophyceae (Nearly brown)	Starch	Outside chloroplast envelope
6.	Dinophyceae (Dark yellow or brown)	Oil and Starch	Outside chloroplast
7.	Chloromonadinae (Bright green)	Oils and fats	Cytoplasm
8.	Euglenophyceae	Paramylum, fats	Cytoplasm in close proximity to chloroplast envelope
9.	Phaeophyceae (Brown algae)	Laminarin, mannitol, oil	Food is formed in pyrenoids and diffuses into the vacuoles
10.	Rhodophyceae (Red algae)	Floridean starch	Cytoplasm outside chromatophore
11.	Myxophyceae (Cyanophyceae, blue green algae)	Myxophycean starch	Chromatoplasm

forms the matrix embedding the fibrillar part. Different groups of algae has differential nature of cell wall as summarized in Table 3:

7 Flagella

A flagellum is a thread like fine structure that originates from cytoplasm. The number and position of flagella varies in all algal cell as mentioned in Table 4. Flagella are meant for locomotion in algal cells. Flagella can be equal or unequal in length, can be inserted anteriorly or posteriorly and can also be inserted laterally.

When equal in length flagella are termed Isokont and unequal condition is termed Anisokont. In heterokont condition both tinsel and whiplash type of flagella are present. The whiplash flagellum is the smooth naked flagellum and is also known as acronematic or peitcheisel. Tinsel flagellum, which is also known as pantonematic or flimmer, is with minute hairs on its surface termed mastigonemes or flimmers.

Table 3 Cell wall composition in different algal groups

S. no.	Class	Nature of cell wall
1.	Chlorophyceae (Green algae)	Cellulose, pectin, rarely hemicellulose
2.	Xanthophyceae (Yellow – green)	Pectin
3.	Chrysophyceae (Orange algae)	Leucosin, fats, chrysolaminarin
4.	Bacillariophyceae (Diatoms/yellow or golden brown algae)	Silica, cell wall is split into two outer halves is silicified and inner is pectic
5.	Cryptophyceae (nearly brown)	Cell wall absent instead a firm periplast is present
6.	Dinophyceae (Dark yellow or brown)	Mostly cellulosic, some have a periplast
7.	Chloromonadinae (Bright green)	Cell wall absent
8.	Euglenophyceae	Absent, periplastic
9.	Phaeophyceae (Brown algae)	Cellulose, alginic acid, fucocinic acid
10.	Rhodophyceae (Red algae)	Cellulose, pectins, polysulphate esters
11.	Myxophyceae (Cyanophyceae, Blue green algae)	Pectin, hemicellulose, mucopeptide

Table 4 Nature of flagella in different groups of algae

S. no.	Class	Number of flagella	Point of insertion
1.	Chlorophyceae (Green algae)	2 or 4, equal, whiplash	Anterior
2.	Xanthophyceae (Yellow – green)	2, unequal, tinsel and whiplash	Anterior
3.	Chrysophyceae (Orange algae)	1 or 2, unequal, either both whiplash or one whiplash and other tinsel	Anterior
4.	Bacillariophyceae (Diatoms/ Yellow or golden brown algae)	1, tinsel	Anterior
5.	Cryptophyceae (Nearly brown)	2, equal or unequal, flimmergeissel i.e. both flagella bears lateral hairs, arranged in two opposite rows on longer flagellum and in one row on the shorter flagellum	Apical or lateral
6.	Dinophyceae (Dark yellow or brown)	2, unequal (heterokont)	Latero-ventral
7.	Chloromonadinae (Bright green)	2, equal (isokont)	Apical or lateral
8.	Euglenophyceae	1 rarely 2 or 3, tinsel	Anterior
9.	Phaeophyceae (Brown algae)	2, unequal, whiplash and tinsel	Lateral
10.	Rhodophyceae (Red algae)	Absent	
11.	Myxophyceae (Cyanophyceae, Blue green algae)	Absent	

8 Reproduction

Algae reproduces both asexually as well as sexually. The asexual method of reproduction includes reproduction by vegetative methods and reproduction by spores. The different methods of reproduction in algae are discussed below:

8.1 *Vegetative Methods*

The vegetative reproduction is a type of reproduction where a part of thallus becomes specialized and gets detached from the parent to form a new offspring. The new individual thus formed in this way is genetically identical to parent and no variation is observed. The different ways by which algae reproduces vegetatively are:

8.1.1 Budding

Some vesicles which get detached from the parent plant by the formation of a septum, and are cable of giving rise to a new thallus are called buds. For example: *Protosiphon* (Fig. 7).

8.1.2 Cell Division

Simplest method of reproduction, where, the unicellular algae divides into two by fission. For example: *Chlamydomonas* (Fig. 8), Diatoms.

Fig. 7 Budding in *Protosiphon*

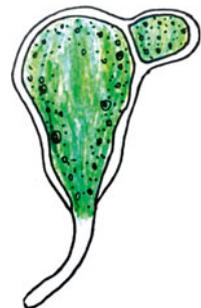


Fig. 8 Cell division in *Chlamydomonas*

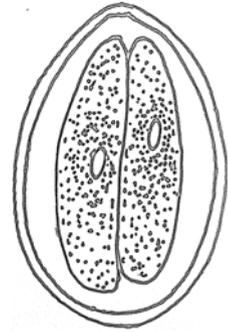
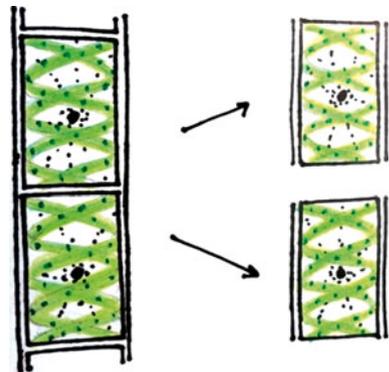


Fig. 9 Fragmentation in *Spirogyra*



8.1.3 Fragmentation

During this process the filamentous thalli breaks into two or many fragments (Fig. 9). Each fragment is capable of giving rise to a new filament. The fragmentation may result due to accidental breakage or formation of separation of disc. For example *Spirogyra*, *Nostoc*, *Oscillatoria*.

8.1.4 Bulbils

These are tuber like outgrowths developed mostly at the rhizoidal tips. In *Chara* they develop at the nodes. These bulbils when detach from the parent plant give rise to new thallus. For example: *Chara*.

8.1.5 Hormogones

These are short segments of filaments with in the sheath of parent filament. Hormogones are many celled segments and are commonly found in members of cyanophyceae.

8.1.6 Amylum Stars

Present on lower nodes in *Chara*. These are star shaped aggregation of starch.

8.2 Asexual Reproduction or Reproduction by Spores

8.2.1 Akinetes

These are thick walled spores with abundance of food reserve. They withstand the unfavourable conditions and germinate on the onset of favorable conditions. Example: *Nostoc*, *Gloeotrichia*, *Ulothrix*, *Cladophora*, *Pithophora*.

8.2.2 Autospores

During unfavourable conditions protoplast inside the sporangium divides and forms spores which are identical to parent plant are termed autospores. The autospores are non-motile, thick walled and abundant in food reserve. Example: *Scenedesmus*, *Chlorella* etc.

8.2.3 Aplanospores

They may be formed singly or by the repeated division of the sporangium of parent plant during drought (unfavourable conditions). Example: *Ulothrix*.

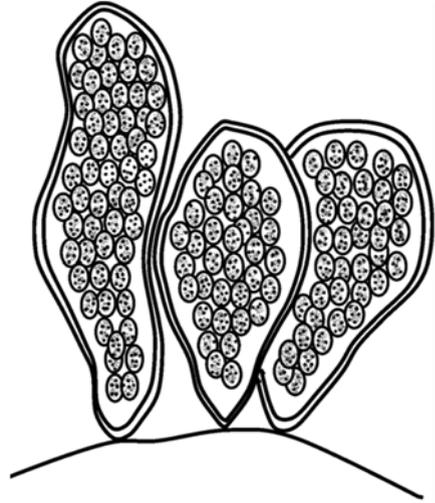
8.2.4 Bispores

When two spores are formed in a sporangium they are called bispores and the sporangium is termed as bisporangium (Fig. 12) as reported in *Grateloupia filicina* (Baweja and Sahoo 2002); *Porphyra* and in *Lithophyllum littorale* (West and Hommersand 1981).

8.2.5 Carpospores

These are formed in carposporangium during triphasic life cycle of rhodophycean members. They are formed from zygote and are diploid in nature. Example: *Polysiphonia*, *Gracilaria*, and *Grateloupia* (Baweja 2006).

Fig. 10 Endospores of *Dermocarpa*



8.2.6 Endospores

These are formed in the sporangium by successive repeated divisions of cell contents. All spores are formed first, then the sporangium opens to liberate the motile spores (Fig. 10). e.g. *Dermocarpa clavata*.

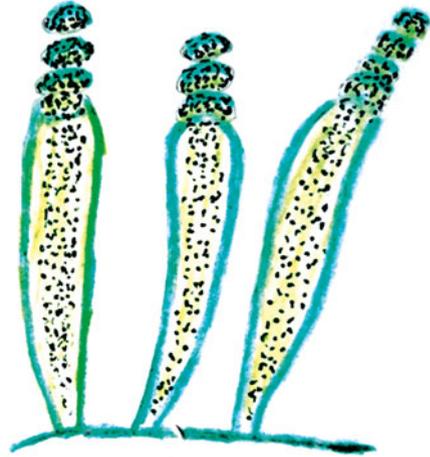
8.2.7 Exospores

During exospore formation in Cyanophycean members, the sporangium gets burst at the apex and is exposed to the external environment and further by successive repeated divisions of cell contents the spherical spores are formed which are termed exospores. All spores get liberated one by one. For example *Chamaesiphon*, *Stichosiphon* (Fig. 11).

8.2.8 Hypnospores

Aplanospores with thick walled and abundance of food reserve are known as hypnospores. They may germinate directly or their protoplast may divide further to form zoospores which germinate to new plant. Example: *Pediastrum*, *Sphaerella* etc.

Fig. 11 Exospores in *Chamaesiphon*



8.2.9 Monospores

Single spores formed in a sporangium are termed as monospores. Commonly monospores are found in Brown and red algae and are considered to be the commonest asexual spores of red algae (Dixon 1963; South and Whittick 1987).

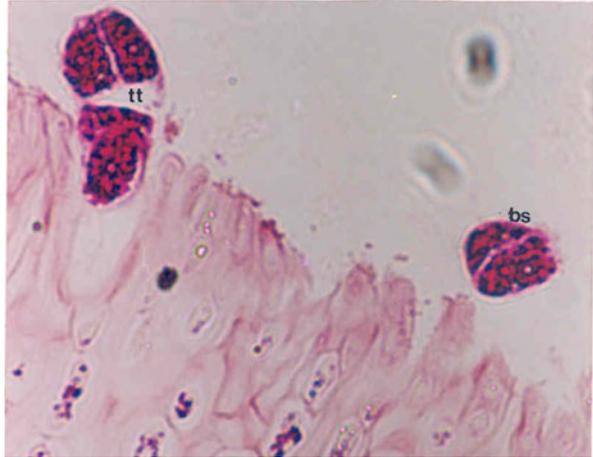
8.2.10 Neutral Spores

These are common in red algae for example *Bangia* where, the vegetative cells directly gets transformed into spores and such spores are termed neutral spores.

8.2.11 Paraspores

When more than four spores are formed because of reduction division in a sporangium in red algae, such spores are called as paraspores or polyspores for example: *Palmaria elegans*, *Ceramium* sp. (Whittick 1977; Rueness 1973; Sharma 2011).

Fig. 12 A bispore (bs) and Tetraspore (tt) of *Grateloupia filicina* (Courtesy: Dr. Pooja Baweja)



8.2.12 Statospores

Thick and ornamented smooth walled spores of bacillariophyceae are termed as Statospores. Example: *Chaetoceros* (Bacillariophyceae), Chrysophyceae, Xanthophyceae etc (Pienaar 1980; Sandgren 1983; Sharma 2011).

8.2.13 Tetraspores

Commonly found in red algae. These are formed in four in number in a tetrasporangium (Fig. 12). E.g. *Porphyra*, *Gracilaria*, *Grateloupia*.

8.2.14 Zoospores

The motile and naked spores are known as zoospores. They may be haploid or diploid and are formed in zoosporangium. The zoospores of *Vaucheria* are known as synzoospores as they are multinucleate and multiflagellate. Zoospores may have two, four or many flagella (Fig. 13) for example:

Biflagellate zoospores:	<i>Chlamydomonas</i> , <i>Ulothrix</i>
Quadriflagellate:	<i>Ulothrix</i>
Multiflagellate	<i>Oedogonium</i>

Fig. 13 Zoospores of *Oedogonium*

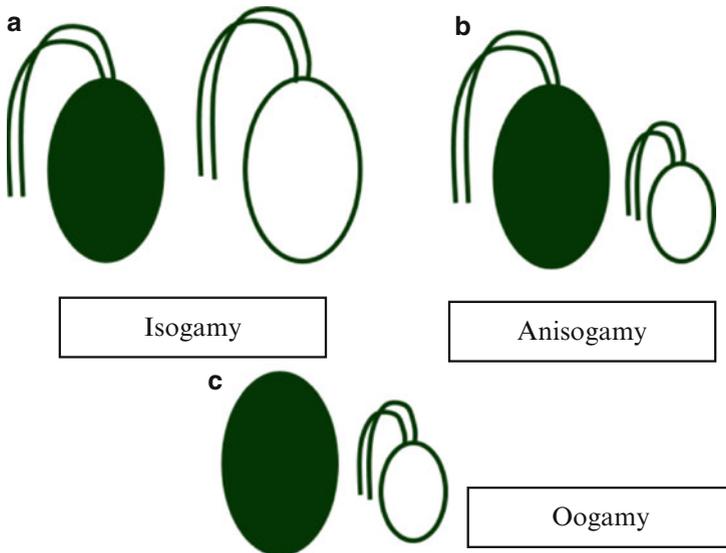
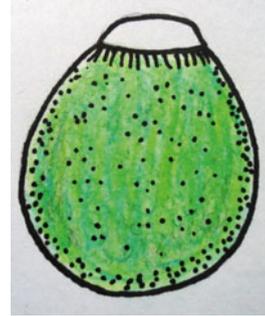


Fig. 14 Sexual reproduction in algae (a) Isogamy: Fusing gametes are morphologically identical; (b) Anisogamy: Fusing gametes are morphologically dissimilar; (c) Oogamy: Female gamete becomes immobile, larger in size and male gamete is mobile and smaller in size

8.3 Sexual Reproduction

Sexual reproduction has been reported from all members of algae except cyanophyceae. In sexual reproduction two opposite mating types (gametes) fuse to form a zygote. Depending on the structure and behaviour of fusing gametes (Fig. 14) it can be classified as:

8.3.1 Isogamy

In it the fusing gametes are iso gametes (iso – similar) i.e. they are morphologically and physiologically similar. Example: *Chlamydomonas*, *Ulothrix* etc.

8.3.2 Anisogamy

In it the fusing gametes are aniso gametes (aniso – dissimilar) i.e. they are morphologically and physiologically not similar and are different. In some algae physiological anisogamy has been reported where the gametes are morphologically similar but physiologically different (e.g. *Spirogyra*). Example: *Chlamydomonas braunii* etc.

8.3.3 Oogamy

It is an advanced type of sexual reproduction and has been observed in higher plants and animals too. In algae, usually the male partner is motile and female partner is non-motile with exception in Rhodophyceae where male partners are too non-motile and reaches female by the water currents. In algae the male antherozoids are formed in Antheridium and female gametes are formed in oogonium. Example: *Chlamydomonas*, *Oedogonium*, *Chara*, *Polysiphonia*, *Porphyra* etc.

8.3.4 Autogamy

It is commonly reported in Diatoms, where the fusing gametes are formed from the same mother cell and are haploid. After fusion they form a diploid zygote with no genetic variation.

9 Perennation or Survival Strategies in Algae

The freshwater and sub aerial algae are unprotected and are frequently exposed to the risk of desiccation and extremes of temperature, on the other hand, marine algae live in conditions where variations in external environmental conditions of life are rare but still they are exposed to tidal fluctuations. To combat this, algae has developed certain methods to carry over the period of severe conditions till the next growing season. Thus, perennation can also be defined as a temporary rest for algae, where all the metabolic activities are ceased till the onset of favourable season. However, fresh water and sub aerial algae undergo perennation by producing asexual thick walled spores, the marine algae avoids the tidal fluctuations by secreting a lot of mucilage which keeps them dehydrated during the low tides (Vashishtha et al. 2007).

Main methods of perennation in fresh water and sub aerial algae are (a) Akinetes (2) Aplanospores (3) Palmella Stage (4) Cysts (5) Oospore or Zygote (6) Hormospores (7) Hypnosporos (8) Tubers.

9.1 *Akinetes*

Akinetes are specially modified vegetative cells with thick, resistant cell wall and abundance of food reserve. These are formed during conditions of drought, when the whole thalli or filament dries and die but akinetes remains to overcome the unfavourable conditions. As the favourable conditions returns, they develop into new plants. Example: *Ulothrix*, *Cladophora*, *Pithophora*, and *Nostoc*.

9.2 *Aplanospores*

These are thick walled non motile spores which are formed during unfavourable conditions. They are formed by the rounding off cytoplasmic contents and development of thick wall. Aplanospores are liberated by the separation of parent wall. After a period of rest and on the approach of favourable conditions they develop into new plants. Example: *Chlamydomonas*, *Ulothrix*, *Coleochaete*, *Oedogonium*.

9.3 *Palmella Stage*

In *Chlamydomonas* during adverse conditions the vegetative cell divides and form new daughter cell. Which further increase in number by repeated cell divisions. All daughter cells thus formed remain clustered together inside a mucilaginous envelop. This envelope is formed by the gelatinisation of parent cell wall of the successive generations. This is called Palmella stage, which is of short duration and represents milder method of perennation.

9.4 *Cysts*

During unfavourable conditions the plant body of certain algae like *Euglena*, *Vaucheria*, *Protosiphon* produces cysts, which separates. Each cyst germinates directly into a new plant on the approach of favourable conditions. In *Vaucheria* and *Protosiphon*, the cysts are termed Coenocysts as in these algae cysts are formed of multinucleate segment of thallus.

9.5 *Oospore or Zygospor*

In algae zygote or zygospor do not germinate directly and undergo a resting period before the onset of favourable conditions, therefore formation of zygotes is considered a method of perennation in green algae. The zygote which is formed as a result of sexual fusion are thick walled structure with plenty of food material.

9.6 *Hormospores*

During unfavourable conditions, hormogones in blue green algae gets separated from the tips of trichomes. These hormogones gets rounded off, secretes a thick wall and are termed hormospores.

9.7 *Hypnospores*

When aplanospores secretes a thick wall around them to withstand extreme stressful conditions such as winter and draught, are termed as hypnospores. These spores remain in quiescent condition for some time, and as the favourable conditions approaches they germinate into a new plant for e. g. *Westiella* (Cyanophyceae).

9.8 *Tubers*

These are commonly reported in *Chara* and *Cladophora* and are outgrowth of rhizoids. They are formed from specialised rhizoidal cell which divides a number of time, gets thick walled and store abundance of food reserve material. As these are produced from the subterranean part of the plant, these are able to withstand the extremes of drought and temperature.

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