

FUNDAMENTALS OF PHYCOLOGY

Dr. Eluri Komala

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(For UG & PG Students in Indian Universities)

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UNIT I: GENERAL ACCOUNT AND CLASSIFICATION OF ALGAE

Algae are chlorophyll-containing organisms that can have unicellular or multicellular reproductive structures. Each cell in these structures has the potential to function as a gamete, a feature that sets them apart from other green plants. They primarily inhabit aquatic environments, including both freshwater and marine ecosystems. However, they are also found on soil, moist rocks, wood, and even in symbiotic relationships with fungi and certain animals. Algae play a crucial role in ecosystems as primary producers, generating energy-rich organic compounds that support aquatic food chains. Planktonic algae, in particular, are essential contributors to aquatic ecosystems. It is estimated that nearly 90% of Earth's photosynthesis occurs in aquatic environments, with suspended algae being the primary contributors. Through photosynthesis, algae release oxygen into their surroundings, significantly increasing dissolved oxygen levels in water bodies. Additionally, certain blue-green algae (cyanobacteria) can fix atmospheric nitrogen, converting it into nitrogenous compounds that enrich soil and water. This process, known as nitrogen fixation, enhances fertility in their habitats.

1.1 INTRODUCTION TO ALGAE

Algae exhibit immense diversity, with approximately 1,800 genera and 21,000 known species. They vary widely in habitat, size, structure, physiology, biochemistry, and reproductive strategies. Their forms range from microscopic single-celled species to large, complex seaweeds found in marine environments.

Definition and History of the Term "Algae"

Algae are commonly observed as bright green or dark green patches on the surface of ponds, lakes, and ditches, often referred to as "pond scum." During the rainy season, similar green patches can be seen making playgrounds slippery. In marine environments, large brown or red-colored seaweeds float on the water surface.

The term "**algae**" was originally proposed by **Carl Linnaeus in 1753**, though he used it to describe organisms that are now classified as bryophytes. Later, **A.L. de Jussieu (1789)** applied the term to the organisms we now recognize as algae. In 1935, **Fritsch** provided a widely accepted definition, stating that.

"The designation 'algae' must include all holophytic organisms, as well as their numerous colorless derivatives, that fail to reach the level of differentiation characteristic of archegoniate plants."

In simpler terms, algae are **thallose, autotrophic, non-vascular plants** that have unicellular sex organs and do not form embryos.

The branch of botany that deals with the study of algae is called **phycology** or **algology**. The word "**phycology**" originates from the Greek word *phykos*, meaning "alga" or "seaweed." Scientists who specialize in the study of algae are known as **phycologists**.

History of Phycology

Phycology, the study of algae, has a history that dates back as far as the knowledge of other plant groups. The earliest references to algae can be found in ancient Chinese literature, as well as in Greek and Roman texts. The Greeks referred to algae as *Phykos*, while the Romans called them *Fucus* and used them for cosmetic purposes. However, not all ancient writers valued algae; the Roman poet Virgil dismissed them as "nihil vilior alga" (nothing is more worthless than algae). In China, algae were viewed aesthetically and referred to as *Tsao*. By the eighth century, multiple types of algae were documented under the term *Isao*. In Hawaii, algae have long been used as a food source under the name *Limu*.

Early Utilization and Observations

During the early centuries, algae were primarily studied in terms of their utility and taxonomy. Scientific progress in the understanding of algae remained stagnant until the invention of the microscope. However, as early as the 12th century, algae were being used as manure on the northern coast of France, and this practice later spread to Great Britain by the 16th century. The belief that algae arose from "putrefaction" persisted until 1583, when Cesalpino described them in this context.

Until 1800, most algae were classified into four major genera: *Fucus*, *Ulva*, *Conferva*, and *Corallina*. During this period, *Chara* was mistakenly grouped with horsetails. The 17th century saw the use of brown seaweeds as fertilizers in France, and at the same time, the techniques of agar extraction were emerging in China and Japan.

Development of Microscopy and Early Scientific Contributions.

The invention of the microscope in the mid-17th century revolutionized algal studies. Initially, algae were thought to lack sexuality, but within fifty years, R. Réaumur described the sex organs of *Fucus*. Almost a century later, Turner documented fertilization in *Fucus*.

In the early 19th century, J.P. Vaucher confirmed the reproductive process in *Spirogyra* in his book *Histoire des Conferves d'eau douce*. Around the same time, significant contributions to phycology came from Dillwyn, Vaucher, and Roth. Roth identified and described *Hydrodictyon*, *Batrachospermum*, and *Rivularia*. In marine phycology, Lamouroux (1805–1816) described several new genera, including *Laminaria*. The 19th century also saw the contributions of Lyngbye, Bory, and Greville in Great Britain and continental Europe. Greville introduced the well-known genera *Polysiphonia* and *Rhodymenia*.

Swedish phycologist C. Agardh advanced the classification of red algae, introducing *cystocarps* in taxonomy and forming divisions such as *Diatomaceae*, *Nostochineae*, *Confervoideae*, *Ulvaceae*, *Florideae*, and *Fucoideae*. His son, J.G. Agardh, continued his legacy by studying reproduction in *Conferva*, *Bryopsis*, *Fucus*, and *Griffithsia*.

In 1854–1855, Thuret published a monograph on fertilization in *Fucus*. Around the same time, W.H. Harvey published his marine algal floras: *Phycologia Britannica*, *Phycologia Australica*, and *Nereis Boreali-Americana*, classifying algae into *Chlorospermae*, *Rhodosperrmae*, and *Melanospermae*.

Advances in Algal Taxonomy and Physiology

By the late 19th century, Areschoug (1866–1884) described new genera and species, investigated zoospore and gamete formation in *Urospora* and *Cladophora*, and studied *Laminaria* and *Macrocystis*. During this period, algal classification systems were reassessed, improving the understanding of different groups. Between 1875 and 1900, Sirodot reorganized *Batrachospermaceae*, Gomont worked on *Myxophyceae*, Phillips classified *Rhodymeniales*, and Schmitz contributed significantly to *Rhodophyceae*. De Toni compiled all known algal species in his monumental *Sylloge Algarum*.

Significant breakthroughs in life cycle studies occurred in the late 19th century. In 1897–1898, Williams described the complete life history of *Dictyota*, and in 1899, Sauvageau worked out the life history of *Cutleria*. Berthold (1882) studied photoperiodism in *Bryopsis*, while Bonnier and Mangin (1894) initiated studies on algal respiration.

By 1899, Luther introduced the term *Heterokontae*. In 1900, Blackman and Tansley incorporated flagellar characteristics into algal classification. Blackman also identified three major trends in green algal evolution: *Volvocine*, *Tetrasporine*, and *Chlorococcine*.

20th Century Developments

The early 20th century saw advancements in fossil phycology. In 1910, Pia published studies on fossil algae in Europe, while Walcott worked on fossil algae in the U.S. (1914). Cotton (1912) pioneered algal ecological studies, while Fritsch, Salisbury, and Brenchley initiated research on soil algae. Transeau made significant contributions to freshwater algal ecology in the U.S. Kylin, Kniep, Pantanelli, and Harder advanced research in algal physiology and biochemistry. Jonsson, Borgesen, Collins, and Skottsberg published important floristic studies, and in 1915, the full life cycle of *Laminaria* was established.

Since 1930, cell biology, cytology, and molecular biology advancements have led to a deeper understanding of algae. X-ray photography, electron microscopy, and improved optical microscopy enhanced knowledge of algal cell structures, including flagella and nuclear division. Kylin, Papenfuss, Feldmann, and Svedelius introduced modern classification approaches for *Phaeophyceae* and *Rhodophyceae*. Pringsheim emphasized the significance of pure algal cultures in experimental studies.

Recent Advances and Future Perspectives

- **1950s–1970s:** Electron microscopy revealed ultrastructural details of algal cells, including pyrenoids, flagella, and organelles.
- **1980s–2000s:** Molecular techniques, including DNA sequencing and phylogenetics, revolutionized algal taxonomy.
- **2000s–Present:** Genome sequencing of algae, including *Chlamydomonas* and *Emiliana huxleyi*, provided insights into evolutionary relationships and metabolic pathways.
- **21st Century Applications:** Algal biotechnology has expanded to include biofuels, pharmaceuticals, nutraceuticals, and environmental applications such as carbon sequestration and wastewater treatment.

With ongoing advances in molecular biology, genomics, and synthetic biology, phycology continues to play a crucial role in understanding primary production, climate change mitigation, and biotechnological innovations.

Algology in India

The pioneering work in algology in India began with M.O.P. Iyengar, Y. Bharadwaja, Ghose, P. Bruhl, and K. Biswas in the early 20th century. Their contributions led to the establishment of two major research centers in algology at Madras and Banaras, spearheaded by M.O.P. Iyengar and Y. Bharadwaja, respectively. Over time, several other universities and research institutes, including those in Udaipur, Hyderabad, Delhi, Ranchi, Allahabad, Lucknow, Kanpur, Cuttack, Bombay, Bhavnagar, and Mandapam, developed algal research laboratories. Among these, the Banaras School of algology rapidly expanded, producing numerous eminent researchers engaged in algal studies across India.

Phases of Algological Research in India

First Phase: Algal Flora, Taxonomy, and Morphology (Before 1938)

The initial phase of algology in India focused primarily on the study of algal flora, taxonomy, and morphology of both freshwater and marine algae. This period concluded in 1938 when the Indian Science Congress celebrated its Silver Jubilee, marking the transition to more advanced research.

Second Phase: Morphology, Reproduction, Cytology, and Life Histories (1938–1969)

During this phase, research extended to morphology, reproduction, cytology, and life histories of various algae.

- Cytological studies on green algae were conducted by Y.S.R.K. Sarma (1964), who recorded aneuploid chromosome numbers (12, 14, 16, 18, and 22) in different genera of Ulotrichales (1963) and Oedogoniales (Y.B.K. Chowdhary, 1965).
- R.N. Singh (1961) isolated nitrogen-fixing algae like *Aulosira fertilissima* from rice fields and demonstrated its role in nitrogen economy and alkaline soil reclamation (1950).
- G.S. Venkataraman and his team (1962, 1969) showed that artificial inoculation of high-yielding rice varieties with nitrogen-fixing blue-green algae significantly increased grain yield.
- A.B. Gupta and K. Lata (1964) explored the beneficial effects of blue-green algal extracts in crop improvement.
- J.N. Misra (1959, 1966) studied ecological aspects of marine algae and freshwater diatoms.
- Several monographs on Indian algae were published by the Indian Council of Agricultural Research (ICAR), including.

Cyanophyta (T.V. Desikachary, 1959)

Zygnemaceae (M.S. Randhawa, 1959)

Role of Blue-Green Algae in Nitrogen Economy of Indian Agriculture (R.N. Singh, 1961)

Phaeophyceae in India (J.N. Misra, 1966) *Vaucheriaceae* (G.S. Venkataraman, 1962)

Cultivation of Algae (G.S. Venkataraman, 1969)

Charophyta (B.P. Pal, B.C. Kundu, B.S. Sundaralingam, and G.S. Venkataraman, 1962)

Chlorococcales (M.T. Philipose, 1967)

Ulotrichales (K.R. Ramanathan, 1964)

Third Phase: Molecular and Applied Algology (Post-1969)

This phase saw remarkable advancements in algal research, particularly in molecular biology and applied algology.

- R.N. Singh (1961) collaborated with H. Ris to study the ultrastructure of blue-green algae using electron microscopy, confirming their prokaryotic nature.
- In 1960, R.N. Singh elucidated the biochemical mechanism of nitrogen fixation in blue-green algae.
- E.R.S. Talpasayi (1962, 1967) investigated phosphorus metabolism and cellular differentiation in *Cyanophyta*.
- H.D. Kumar and colleagues (1960s) studied the genetics and photobiology of blue-green algae, discovering genetic recombination in *Anacystis nidulans* (1960) and later in *Cylindrospermum majus* (R.N. Singh and J.P. Sinha, 1965).
- R.N. Singh and H.N. Singh (1964) modified the photobiology of blue-green algae, isolating X-ray and ultraviolet-induced mutations.
- R.N. Singh and D.N. Tiwari (1969) reported UV-induced mutations in *Nostoc linckia*.
- R.N. Singh and his team (1966–1971) extensively studied genetic mechanisms of cellular differentiation in blue-green algae and their nitrogen fixation potential.
- R.N. Singh and P.K. Singh (1967) isolated blue-green algal viruses (Cyanophages), and in 1970, they demonstrated transduction of streptomycin resistance and lysogeny.

Recent Developments in Algology in India

In the 21st century, algal research in India has expanded significantly, with new areas of focus including.

- **Biotechnological applications:** Advances in microalgal biofuels, biofertilizers, pharmaceuticals, and nutraceuticals.

- **Climate change studies:** Investigations on the role of algae in carbon sequestration and climate mitigation.
- **Genetic and molecular research:** Application of CRISPR and genomic sequencing in algal improvement.
- **Aquaculture and wastewater treatment:** Use of algae in bioremediation, wastewater treatment, and aquaculture feed.
- **Algal biofilms and industrial applications:** Research into algal biofilms for industrial and medical use.
- **Marine algal biodiversity conservation:** Studies on coral reef-associated algae and marine ecosystem restoration.
- **Collaborative projects:** Institutions like CSIR, ICAR, and DBT have initiated projects integrating algal biotechnology into sustainable agriculture and energy sectors.

Algological research in India has evolved significantly from classical taxonomy and morphology to applied and molecular studies. The contributions of pioneering researchers have laid a strong foundation for modern-day algology, integrating cutting-edge technology for sustainable applications. With continued research and innovation, algology in India holds great promise for environmental sustainability, agriculture, and biotechnology.

1.2 Thallus Diversity and Life Cycles Habit and Habitat of Algae

The Earth's surface is predominantly covered by water, including freshwater and marine ecosystems. However, algae also thrive in diverse terrestrial and extreme environments. They can be found on tree trunks, telephone wires, rocks, walls, and even in hot springs. Some algae have adapted to unusual habitats, and their classification based on habitat is detailed below, with a special focus on freshwater algae.

Hydrophytes: Hydrophytic algae are either fully submerged or free-floating on water surfaces. These can be further classified as follows.

(i) **Benthophytes:** These algae are attached to substrates at the bottom of freshwater or marine environments. Examples include *Chara*, *Nitella*, *Cladophora*, *Gongrosira*, and *Charmosiphon*. Most brown algae (Phaeophyceae) are benthophytes in marine ecosystems.

(ii) **Epilithophytes:** These algae grow along lake and pond shores and can be difficult to distinguish from benthophytes. Examples include *Oedogonium*, *Chaetophora*, *Spirogyra*, *Mougeotia*, *Scytonema*, and *Rivularia*.

(iii) **Thermophytes:** Algae that thrive in hot springs, withstanding temperatures up to 85°C.

According to Copeland, 53 genera and 153 species of *Chroococcaceae* can survive at 84°C. Some *Oscillatoriaceae* species endure temperatures up to 85°C, supporting the idea that Myxophyceae (blue-green algae) are primitive.

(iv) **Planktophytes:** These free-floating algae exist in two forms: **Euplanktophytes:** Always free-floating (e.g., *Cosmarium*, *Closterium*, *Microcystis*, *Sphaeroplea*, *Scenedesmus*, *Pediastrum*, *Chlamydomonas*, *Volvox*, and various *Volvocales*). **Tychoplanktophytes:** Initially attached but later become free-floating (e.g., *Spirogyra*, *Zygnema*, *Cladophora*, *Oedogonium*, *Rhizoclonium*, *Tribonema*, *Microspora*, *Cylindrospermum*, *Tetraspora*, *Rivularia*, *Gloeotrichia*, *Sargassum*).

(v) **Halophytes:** These algae occur in saline environments. *Dunaliella* and *Chlamydomonas* inhabit salt lakes. Species of *Scenedesmus*, *Aphanocapsa*, *Pediastrum*, *Aphanothece*, and *Oscillatoria* are found in saline waters, while *Enteromorpha* species thrive in estuaries.

(vi) **Epiphytes:** Algae that grow on other plants or larger algae. Examples include *Aphanochaete*, *Bulbochaete*, *Oedogonium*, and *Microspora*, which grow on *Cladophora*, *Rhizoclonium*, *Vaucheria*, and *Hydrodictyon*.

(vii) **Epizoophytes:** These algae live on aquatic animals such as turtles, mollusk shells, and fish. Examples include *Cladophora* (on mollusk shells), *Protoderma* and *Basicladia* (on turtles), and *Characiopsis* and *Characium* (on *Branchipus* legs).

Edaphophytes (Terrestrial Algae): These algae grow on or inside the soil and are categorized as follows:

(i) **Saprophytes:** Surface-dwelling algae, including species of *Myxophyceae*, *Mesotaenium*, *Botrydium*, *Protosiphon*, *Oedocladium*, *Vaucheria*, and *Fritschiella*.

(ii) **Cryptophytes:** Subterranean algae found in soil. Examples include *Nostoc*, *Anabaena*, and *Euglena*, which fix atmospheric nitrogen in paddy fields, enhancing soil fertility.

Aerophytes (Aerial Algae)

These algae colonize trees, walls, rocks, and even animals.

(i) **Epiphyllphytes:** Grow on tree leaves, such as *Trentepohlia* (on trees, rocks, and fences), *Phycopeltis* (on *Rubus*), *Phyllosiphon* (on *Arisaema*), and *Rhodochytrium* (on *Asclepias* and *Solidago*).

(ii) **Epiphloeophytes:** Grow on tree bark alongside mosses and liverworts, including *Phormidium*, *Scytonema*, *Hapalosiphon*, and *Schizothrix*.

(iii) **Epizoophytes:** Algae growing on terrestrial animals, including *Chaetophorales* on sloth hair.

(iv) **Lithophytes:** Grow on rocks and walls, such as *Scytonema* (causing black spots on walls)

during the rainy season), *Vaucheria*, and *Nostoc* (on wet rocks).

Cryophytes

These algae thrive on ice and snow, contributing to phenomena like red, green, yellow, and violet snow. In the Arctic, *Chlamydomonas*, *Ankistrodesmus*, and *Mesotaenium* cause green snow, while *Chlamydomonas*, *Scotiella*, *Gloeocapsa*, and diatoms contribute to red snow.

Cryoalgae Classification and Other Ecological Associations of Algae

Certain species of *Ulothrix*, *Oedogonium*, *Pleurococcus*, and *Nostoc* are responsible for the yellow or yellow-green coloration of snow.

Alaskan's Classification of Cryoalgae (1942)

Alaskan (1942) categorized cryoalgae into four groups based on their habitat preferences:

1. **Algae that grow only on ice** – *Ancylonema*, *Mesotaenium*.
2. **Algae that grow only on snow** – *Scotiella*, *Chlamydomonas*.
3. **Algae that grow on both ice and snow** – *Cylindrocystis*, *Trochiscia*.
4. **Algae that grow on either ice or snow but are not true cryophytes** – *Gloeocapsa*, *Phormidium*.

Symbionts and Endophytes: Many algae form symbiotic associations with other organisms.

- **Lichens:** These are symbiotic partnerships between algae and fungi. Algal partners in lichens include species from *Myxophyceae* (e.g., *Chroococcus*, *Nostoc*, *Microcystis*, *Gloeocapsa*, *Scytonema*, *Rivularia*) and green algae (*Coccomyxa*, *Chlorella*, *Protococcus*, *Palmella*).

- **Endophytes:** Some algae live inside the tissues of other plants. Examples include:

Anabaena azollae inside *Azolla* leaves (a pteridophyte).

Anabaena cycadae in the coralloid roots of *Cycas*. *Nostoc* inside the tissues of *Anthoceros* and *Notothylas*.

Nostoc in the leaves of *Sphagnum* (a bryophyte) and certain angiosperms.

Chlorochytrium inside *Lemna*, *Ceratophyllum*, and some mosses.

Endozoic Algae: Certain algae inhabit the bodies of animals.

- *Zooxanthella* inside freshwater sponges.
- *Zoochlorella* inside *Hydra viridis*.
- According to Langeron (1923), about 14 species of *Oscillatoriaceae* are found in the

digestive and respiratory tracts of various vertebrates.

Parasitic Algae: Some algae act as parasites on plants. The most notable example is *Cephaleuros virescens*, which causes 'red rust of tea'—a serious disease affecting tea plants in Assam and neighboring regions.

Fluviatile (Stream-Dwelling) Algae: These algae thrive in fast-flowing waters:

- *Ulothrix* occurs in mountain waterfalls.
- *Stigeoclonium* and *Batrachospermum* are found in swift-running streams of Dehradun and other hilly regions.

Recent Developments in Algology

Recent studies highlight the increasing significance of algae in biotechnology and environmental sustainability. Research focuses on.

- **Algal Biofuels:** *Chlorella* and *Nannochloropsis* are being explored for sustainable biofuel production.
- **Carbon Sequestration:** Microalgae like *Spirulina* play a role in reducing atmospheric CO₂ levels.
- **Algal Biodiversity Conservation:** New species are being documented, emphasizing their role in aquatic ecosystems.
- **Industrial Applications:** Advances in algal bioplastics and pharmaceuticals are gaining attention.
- **Climate Change Resilience:** Algae are being studied for their adaptability to extreme conditions, including increasing temperatures and ocean acidification.

Nutrition in Algae: Algae are primarily **autotrophic**, meaning they synthesize their food using inorganic materials such as carbon dioxide, water, and minerals through **photosynthesis**. Chlorophyll, the most common pigment in algae, enables this process. However, in many algae, the green color of chlorophyll is masked by other pigments. (Table 1.1 and 1.2).

- **Fucoxanthin** – a yellow pigment dominant in **brown algae**
- **Phycoerythrin** – a red pigment found in **red algae**
- **Phycocyanin** – a blue pigment present in **blue-green algae**

Algae convert carbohydrates into **oils and proteins** and absorb soluble forms of nitrogen and

other essential minerals from their surrounding water. **Osmosis** helps them absorb water, while **diffusion** allows them to take in carbon dioxide. This process of nutrition in algae is like that of ordinary green plants.

Essential Nutrients for Algae: Like other chlorophyllous plants, algae require the following essential elements.

- **Macronutrients:** Carbon (C), Hydrogen (H), Oxygen (O), Phosphorus (P), Potassium (K), Nitrogen (N), Sulfur (S), Calcium (Ca), Iron (Fe), Magnesium (Mg)
- **Micronutrients (Trace elements):** Manganese (Mn), Boron (Bo), Zinc (Zn), Copper (Cu), Cobalt (Co)
- **Special Requirements:** Some algae require additional elements, such as **Silicon (Si) for diatoms** and **Molybdenum (Mo) for Scenedesmus**.

Types of Algal Nutrition

1. **Photoautotrophic Algae:** These algae grow in an entirely inorganic medium in the presence of light. They use **light energy** to synthesize their **protoplasm** solely from inorganic sources.
2. **Photoautotrophic Algae:** In addition to inorganic nutrients, these algae require certain **vitamins**, usually **Vitamin B-12, Thiamine, or Biotin**.
3. **Heterotrophic Algae:** These algae cannot synthesize their **protoplasm** solely from inorganic sources. They require some essential organic compounds, usually **carbon and nitrogen**.
4. **Phagotrophic Algae:** Some algae, such as certain species of **Ochromonas**, can **digest solid food particles**. These algae are called **phagotrophic** as they feed on external organic matter. Thus, while most algae are **autotrophic**, some species exhibit **heterotrophic** or **phagotrophic** modes of nutrition, depending on their environmental conditions and specific nutritional needs.

Table 1.1: Modes of Nutrition in Algae.

Type of Nutrition	Definition	Examples / Characteristics
Photoautotrophic	Algae synthesize their own food using light energy and inorganic sources.	Most algae; require C, H, O, P, K, N, S, Ca, Fe, Mg , and trace elements like Mn, Bo, Zn, Cu, Co .
Photoauxotrophic	Require light energy but also need additional vitamins like B-12, Thiamine, or Biotin .	Some algae depend on organic growth factors for survival.
Heterotrophic	Cannot synthesize protoplasm	Depend on external organic material

	solely from inorganic sources; require organic compounds (carbon, nitrogen).	for growth.
Phagotrophic	Algae that digest solid food particles.	Ochromonas species exhibit this type of nutrition.

Table 1.2: Nutrient Requirements in Algae.

Nutrient Type	Essential Elements	Additional Requirements (Specific Algae)
Macronutrients	Carbon (C), Hydrogen (H), Oxygen (O), Phosphorus (P), Potassium (K), Nitrogen (N), Sulfur (S), Calcium (Ca), Iron (Fe), Magnesium (Mg)	-
Micronutrients	Manganese (Mn), Boron (Bo), Zinc (Zn), Copper (Cu), Cobalt (Co)	Silicon (Si) for Diatoms, Molybdenum (Mo) for Scenedesmus, Vanadium (V) for Some Red Algae

Pigments Found in Algae

Algae are diverse photosynthetic organisms found in a wide range of aquatic environments. They possess various pigments that enable them to capture sunlight for photosynthesis. The dominant pigments differ among algal groups, influencing their coloration and ecological adaptation to light availability in aquatic habitats. (Table 1.3 and 1.4).

Types of Algal Pigments

- Algal pigments are classified into **three main groups**:
- 1. Chlorophylls (Green Pigments): Fat-soluble green pigments** found in all algae.
- Essential for **photosynthesis**.
- Properties of chlorophyll:** Green in color. Fluorescent in solution, emitting **red light**.
- Strongly absorbs **blue-green and green light**.
- 2. Carotenoids (Yellow, Orange, and Red Pigments): Fat-soluble pigments** found in various algae. Help in **light absorption** and **protection from UV radiation**.
- Divided into **three subgroups**.
- Carotenes: Unsaturated hydrocarbons.** Absorb **blue and green light**, transmit **yellow and red**. Fat-soluble and yellow in color.
- Xanthophylls (Oxycarotenes): Oxygen derivatives** of carotenes. Similar in properties to carotenes.
- Carotenoid Acids:** Consist of a **chain of carbon atoms**. Properties are similar to

carotenes and xanthophylls.

Phycobilins (Blue and Red Pigments): Water-soluble pigments found in Cyanobacteria and Red Algae. Strongly **fluorescent**, emitting **orange or red light**. Divided into **two subgroups**.

- **Phycocyanins (Blue Pigments):** Absorb **green, yellow, and red light**. Transmit **blue light**.
- **Phycoerythrins (Red Pigments):** **Absorb** blue-green, green, and yellow light. **Emit** red light.

Table 1.3: Summary of Algal Pigments and Their Functions.

Pigment Group	Color	Solubility	Function
Chlorophylls	Green	Fat-soluble	Photosynthesis
Carotenoids	Yellow, Orange, Red	Fat-soluble	Light absorption & UV protection
Phycobilins	Blue, Red	Water-soluble	Fluorescence & Light absorption

Algal pigments determine the color of algae in different environments. Chlorophylls are universal and essential for photosynthesis. Carotenoids protect algae and help in light absorption. Phycobilins are water-soluble, strongly fluorescent, and common in Cyanobacteria and Red Algae.

- **Green algae (Chlorophyta)** predominantly contain **chlorophyll a and b**, which give them their characteristic green color, along with accessory pigments like carotenoids.
- **Brown algae (Phaeophyceae)** are distinguished by the presence of **fucoxanthin**, a brown pigment that masks the green of chlorophyll.
- **Red algae (Rhodophyta)** owe their red coloration to **phycoerythrin**, which efficiently absorbs blue-green light, allowing them to thrive at greater depths.
- **Blue-green algae**, now classified as **cyanobacteria**, contain **phycocyanin**, a blue pigment, in addition to chlorophyll a and carotenoids.
- **Diatoms (Bacillariophyceae)** also contain fucoxanthin, giving them a golden-brown appearance.
- **Dinoflagellates** have **peridinin**, a golden-brown pigment associated with chlorophyll and c.
- **Euglenoids** typically contain chlorophyll a and b and also possess carotenoids such as β -carotene and various xanthophylls. These pigments not only play a vital role in light absorption but also contribute to the distinct coloration of different algal types, which is

often used in taxonomic classification.

Table 1.4 Pigments Found in Algae.

Algal Type	Dominant Pigment	Other Pigments Present	Example
Green Algae	Chlorophyll a & b (green)	Carotenoids Violaxanthin, (Lutein, Zeaxanthin)	<i>Chlorella, Spirogyra, Volvox</i>
Brown Algae	Fucoxanthin (brown/yellow)	Chlorophyll a & c, β -Carotene, Xanthophylls	<i>Fucus, Laminaria, Sargassum</i>
Red Algae	Phycocerythrin (red)	Phycocyanin, Chlorophyll a, Carotenoids	<i>Gracilaria, Gelidium, Porphyra</i>
Blue-Green Algae (Cyanobacteria)	Phycocyanin (blue)	Chlorophyll Phycocerythrin, a, Carotenoids	<i>Nostoc, Anabaena, Spirulina</i>
Diatoms	Fucoxanthin (golden-brown)	Chlorophyll a & c, β -Carotene	<i>Navicula, Cyclotella</i>
Dinoflagellates	Peridinin (golden-brown)	Chlorophyll a & c, Fucoxanthin, β -Carotene	<i>Ceratium, Gonyaulax</i>
Euglenoids	Chlorophyll a & b (green)	β -Carotene, Xanthophylls (Diadinoxanthin, Neoxanthin)	<i>Euglena</i>

Algae exhibit a remarkable diversity of vegetative structures, ranging from simple unicellular forms to highly complex parenchymatous bodies. This book explores the full spectrum of algal morphology, classifying vegetative structures into six key types: motile, palmelloid and dendroid, coccoid, filamentous, siphonous, and advanced forms. Each type is examined in detail, incorporating historical perspectives, modern taxonomic insights, and the latest research findings.

Range of Vegetative Structure in Algae

The vegetative structure of algae exhibits a wide range of forms, which can be classified into the following major types.

- 1. Motile Type** The simplest vegetative form is unicellular and motile, possessing flagella for movement. The shape and structure vary among species, and the body may be either naked or enclosed within a cell wall. Different motile variations exist, such as amoeboid forms, encapsulated colorless forms, colonial structures, and double individuals. Examples include *Volvox*, *Eudorina*, and *Chlamydomonas*. Some modern studies highlight the role of flagellar movement in phototaxis and nutrient acquisition, particularly in *Chlamydomonas*, making it an important model organism in cellular biology.

2. **Palmelloid and Dendroid Types** In some species, such as *Chlamydomonas*, the motile stage temporarily transforms into a non-motile palmelloid stage, where cells become embedded in a mucilaginous matrix. However, in species like *Tetraspora*, this becomes a permanent structural feature. The dendroid type is a variant where mucilage is secreted at the base of the cell, leading to dendroid colony formation, as seen in *Prasinocladus* of Chlorophyceae. Recent studies suggest that mucilage production in these forms aids in environmental stress tolerance and biofilm formation.
3. **Coccoloid Habit** In coccoloid algae, motility is lost, and the plant body assumes a non-flagellated, rounded form. These cells do not divide vegetatively but reproduce through specialized processes. The coccoloid habit is common in the order Chlorococcales, with *Chlorococcum humicola* being a well-known example. Recent findings indicate that some coccoloid algae play a role in carbon sequestration and biofuel production due to their high lipid content.
4. **Filamentous Habit** Filamentous algae arise from unicellular motile ancestors that lose motility and restrict their division to a single plane. Initially, cells remain connected by mucilaginous discs, but later true transverse septa develop. Filamentous forms exhibit several variations.

Simple filaments – Unbranched, as seen in *Ulothrix* and *Spirogyra*.

Heterotrichous filaments – Comprising both prostrate and erect systems, as in *Stigeoclonium*.

Foliaceous type – Sheet-like thallus with cell divisions in multiple planes, as seen in *Ulva*.

Tubular type – Hollow, one-cell-thick structures, such as *Enteromorpha*.

Discooid type – Flattened disc-shaped filaments, found in *Coleochaete*.

Recent studies emphasize the ecological importance of filamentous algae in aquatic ecosystems, where they contribute to oxygen production and provide habitat for microfauna.

Siphonous Habit Siphonous algae consist of large, branched, multinucleate filaments without partition walls. Cross-walls appear only during reproduction. Examples include *Vaucheria*, *Codium*, and *Caulerpa* from the order Siphonales. These algae exhibit remarkable adaptability, with *Caulerpa* being known for its invasive potential in marine ecosystems. Recent research highlights the unique cytoplasmic streaming and regenerative abilities of siphonous algae, making them a focus in biotechnology and regenerative biology.

Advanced Types The most complex algal forms include.

Uniaxial filamentous type – A single axial filament with closely packed branches forming a pseudoparenchymatous thallus, as in *Dumontia* (Rhodophyceae).

Multiaxial filamentous type – Multiple axial filaments forming a dense cortex, as seen in *Scinaia furcellata* (Rhodophyceae).

Parenchymatous type – True parenchymatous tissues with organized cell layers, found in brown algae like *Laminaria*, *Fucus*, and *Sargassum*.

Advances in molecular biology have revealed that complex parenchymatous algae share genetic similarities with higher plants, particularly in cell wall biosynthesis and stress adaptation mechanisms. These algae also play a crucial role in marine carbon cycles and climate regulation.

Reproduction and Perennation in Algae

Algae reproduce in three common ways.

1. **Vegetative Reproduction** – A part of the parent plant grows into a new individual without forming special reproductive cells.
2. **Asexual Reproduction** – New algae are formed from spores that do not need fertilization.
3. **Sexual Reproduction** – Male and female reproductive cells combine to form a new organism.

In addition, algae develop **perennating bodies**, which help them survive harsh conditions like extreme temperatures, drought, or nutrient deficiency.

Vegetative Reproduction

This occurs when a part of the algal body gives rise to a new plant. It happens in different ways.

(i) By Cell Division

- The mother cell divides into two daughter cells, which grow into new individuals.
- This is the only method of reproduction in some algae.
- **Examples:** *Pleurococcus*, *Euglena*, *Diatoms*, *Desmids*.

(ii) By Fragmentation

- The plant body breaks into small fragments, and each fragment develops into a new alga.
- Common in **filamentous algae**.

- **Examples:** *Ulothrix*, *Spirogyra*.
- **In blue-green algae**, entire colonies can break apart and form new individuals.
- **Examples:** *Aphanocapsa*, *Aphanothece*, *Nostoc*.

(iii) By Hormogone Formation

- In some blue-green algae, filaments break into short pieces called **hormogones**.
- Each **hormogone** develops into a new plant.
- **Examples:** *Oscillatoria*, *Nostoc*.

(iv) By Hormospores or Hormocysts

- These are **thick-walled hormogones** that form under dry conditions.
- They help algae survive unfavorable conditions and later grow into new plants.

(v) By Adventitious Thalli

- Some algae produce special reproductive structures to help in vegetative reproduction.
- These structures are called **propagula**.
- **Examples:** *Bryopsis*, *Sphacelaria*, *Nereocystis*.

(vi) By Hypnospores or Cysts

- In some algae, the filament breaks into several parts, and each part forms a thick-walled structure called a **hypnospore** or **cyst**.
- This structure allows the algae to survive unfavorable conditions.
- **Example:** *Gongrosira*.

(vii) By Microspores

- Some algae, especially **diatoms** (*Bacillariophyceae*), produce **very small spores** called **microspores** that help in reproduction.

Importance of Perennation in Algae

- Perennation helps algae survive harsh environmental conditions.
- Thick-walled structures like **hormospores, hypnospores, and cysts** protect the algae from drying out or extreme temperatures.
- Fragmentation and microspores allow rapid population growth in favorable conditions.

B. Asexual Reproduction in Algae

Asexual reproduction occurs **without fertilization** and **without nuclear fusion**. It involves the **protoplasm** of a single cell forming reproductive structures.

Characteristics of Asexual Reproduction:

- It produces **identical offspring (clones)** of the parent.
- It occurs **rapidly** under favorable conditions.

- Reproduction takes place through **spores and special structures**. **Types of Asexual Reproduction.**

1. Zoospores

- **Motile, flagellated spores** produced in a **zoosporangium**.
- Zoospores move in water and germinate to form new plants.
- Types of Zoospores:

Biflagellate (two flagella): *Chlamydomonas*. **Quadri-flagellate (four flagella):** *Ulothrix*, *Cladophora*. **Multiflagellate (many flagella):** *Oedogonium*.

- **Special Case:** In *Vaucheria*, a **compound zoospore** called **synzoospore** is formed.

2. Aplanospores

- **Non-motile spores** formed under **unfavorable conditions**.
- The protoplasm gets enclosed in a **thin cell wall** before release.
- Once conditions become favorable, they germinate into new plants.
- **Example:** *Ulothrix*.

3. Akinetes

- **Thick-walled, non-motile spores** that act as a **perennation** method (survival during harsh conditions).
- These remain dormant and germinate when conditions improve.
- **Example:** *Anabaena* (*Cyanobacteria*).

4. Hypnosporos

- **Highly resistant, thick-walled spores** formed in **extreme unfavorable conditions**.
- Under prolonged stress, **hypnosporos divide internally** to form **cysts**, which later grow into a new plant.
- **Example:** *Chlamydomonas nivalis*.

5. Tetrasporos

- **Non-motile spores** are formed in **Rhodophyceae (Red Algae)** and **Phaeophyceae (Brown Algae)**. These are produced in **tetrasporangia** by **reduction division** on special **tetrasporophytic plants**. **Example:** *Polysiphonia*.

6. Autosporos

- **Non-motile spores that resemble the parent cell**.
- These develop inside the parent and, before release, acquire **all the characteristics of the original cell**.
- **Examples:** *Chlorella*, *Scenedesmus*.

Asexual reproduction is **fast** and produces **identical offspring**. It happens through **various types of spores**.

Zoospores **are** motile, **while** aplanospores, akinetes, and autospores **are** non-motile. Akinetes and hypnospores **help in** survival during extreme conditions. Tetraspores are unique **to** Red and Brown Algae.

This explanation is **simpler, clearer, and well-structured**. Let me know if you need any modifications!

3. Sexual Reproduction in Algae

Sexual reproduction is an advanced method of reproduction. It is **not found** in **Myxophyceae (blue-green algae)** but is common in other algal groups.

There are **three main types** of sexual reproduction in algae.

1. Isogamy, Heterogamy, and Aplanogamy (Conjugation)

1. Isogamy

- This occurs when **two similar motile gametes** fuse to form a zygote.
- These gametes may come from **different individuals** or from **different cells of the same filament**.
- Thousands of gametes are released and form clumps before fusion.
- **Examples:** *Ulothrix*, *Chlamydomonas*.

2. Heterogamy

- The fusion of **two dissimilar gametes** (different in size or behavior).
- It has two variations.

(a) Anisogamy

- The **gametes differ in size (morphological anisogamy)** or in **physiological behavior (physiological anisogamy)**.
- **Example:** *Eudorina*.

(b) Oogamy

- A **small motile male gamete (antherozoid)** fuses with a **large non-motile female gamete (egg)**.
- This is the most advanced type of sexual reproduction.
- **Examples: Primitive type:** *Cylindrocapsa*. **Advanced type:** *Oedogonium*, *Vaucheria*, *Chara*, *Polysiphonia*.

3. Aplanogamy (Conjugation)

- Fusion occurs between **two non-motile, amoeboid gametes** (called aplanogametes).
- These gametes look similar but are **physiologically different**.
- Common in **Conjugales (Zygnematales)**.
- **Examples:** *Spirogyra*, *Zygnema*.

Perennation in Sexual Reproduction

- In freshwater algae, sexual reproduction is a **survival strategy**.
- It produces a **thick-walled zygote or zygospore**, which can withstand **harsh conditions** and germinate later when conditions become favorable.

Conditions Required for Sexual Reproduction

For sexual reproduction to occur, certain environmental conditions must be met:

1. **Nutrient Accumulation:** It happens after a period of high vegetative growth and **food storage**.
2. **Light Availability:** **Bright light** is essential for gamete production.
3. **pH Levels:** A **suitable pH** value is required for successful reproduction.
4. **Temperature:** **Optimal temperature** is necessary for gamete formation and fusion.

Special Cases of Sexual Reproduction

1. Parthenogenesis

- The **female gamete (egg) develops into a zygote without fertilization**.
- The resulting structures are called **apogametes, aplanospores, or parthenospores**.
- **Examples:** *Spirogyra*, *Oedogonium*.

2. Autogamy

- **Self-fertilization** occurs within a single cell.
- The **protoplasts or divided nuclei of a cell fuse** without being released.
- Common in **diatoms and colorless dinoflagellates**.
- Sexual reproduction in algae occurs in **isogamy, heterogamy, and aplanogamy (conjugation)**.
- **It helps in** genetic variation and survival during harsh conditions.
- **Zygospores and thick-walled gametes** allow perennation and adaptation.
- **Environmental factors** like light, temperature, and pH influence sexual reproduction.
- **Parthenogenesis and autogamy** are special cases where gametes develop without fertilization.

- **Pigmentation in Algae:** Algae exhibit a **wide range of colors** due to different types of **pigments** found in their cells. These pigments help in **photosynthesis** and give algae their characteristic colors in both **marine and freshwater habitats**.
- Pigments are stored in special plastids **called** chromatophores.
- However, in **Myxophyceae (Cyanobacteria)**, **chromatophores are absent**, and pigments are **dispersed in the peripheral chromoplasm**.
- Some algae are **colorless and saprophytic** (e.g., **colorless diatoms, dinoflagellates, Chlorophyceae, and Rhodophyceae**).

Origin and Evolution of Sex in Algae: Plants reproduce in two main ways: asexual and sexual reproduction. In asexual reproduction, no sex cells (gametes) are involved, and new plants grow from special cells called spores. Each spore can develop into a new plant. In sexual reproduction, two gametes fuse to form a zygote, which then grows into a new plant. Normally, individual gametes cannot grow into a plant on their own.

Origin of Sex: The simplest algae, called Cyanophyceae (blue-green algae), reproduce only asexually. Some examples include *Gloeocapsa* and *Chroococcus*, which reproduce by cell division, while *Oscillatoria*, *Nostoc*, and *Anabaena* reproduce through small cell groups called hormogonia. Some Cyanophyceae also form arthrospores, but they do not reproduce sexually. In other types of algae, both asexual and sexual reproduction exist. Scientists believe that gametes originated from motile asexual spores called zoospores. Unlike zoospores, gametes cannot grow into a new plant without fusion. In algae like *Chlamydomonas*, *Ulothrix*, and *Cladophora*, zoospores formed before gametes appeared. Under normal conditions, these algae produce uninucleate, biflagellate zoospores, which help in asexual reproduction. However, when conditions become unfavorable, gametes are formed instead of zoospores. These gametes resemble zoospores but are usually smaller and behave differently.

For example, in *Ulothrix*, both micro and macrozoospores are produced, and gametes form in the same way as zoospores. Some scientists believe that gametes in *Ulothrix* develop from zoospores that fail to escape and undergo further division. Similarly, in *Oedogonium*, gametes are smaller versions of zoospores.

From this, we can conclude that gametes formed due to aging cells and unfavorable conditions. They are essentially reduced forms of zoospores, and unlike zoospores, they

cannot reproduce alone. Instead, they must fuse with another gamete to form a zygote, which ensures survival and genetic variation.

Evolution of Sex: Cyanophyceae do not exhibit sexual reproduction, but in other algae, sexuality is well developed. Early gametes were likely identical in shape and size but had physiological differences. This type of reproduction, called **isogamy**, occurs in *Ulothrix* and some species of *Chlamydomonas*, where gametes are similar but belong to different mating strains (+ and -). Over time, **anisogamy** evolved, where gametes became different in size, as seen in *Chlamydomonas braunii* and *Pandorina*. Here, one gamete-producing cell divides more times than the other, resulting in unequal gametes. The next stage in evolution was **oogamy**, the most advanced form of sexual reproduction. In this process, one gamete becomes large and nutrient-rich (female egg), while the other divides many times to form small, motile male gametes. An example of this can be seen in *Polysiphonia*, where male gametes are non-motile and rely on water currents for transport.

Sexual evolution did not follow a single path but developed independently in different algae groups. In the Volvocales group, there is a gradual transition from isogamy to oogamy: *Gonium* (isogamous), *Pandorina* (slightly anisogamous), *Eudorina* and *Pleodorina* (anisogamous), and *Volvox* (oogamous). A similar pattern is seen in *Chlamydomonas*, where different species represent different stages of sexual evolution.

In more advanced green algae like *Spirogyra*, *Vaucheria*, and *Chara*, as well as in most brown and red algae, sex cells are produced inside specialized structures. In *Spirogyra*, gametes form inside ordinary cells called gametangia, which are not distinctly male or female. In *Vaucheria*, gametes develop in distinct male (antheridia) and female (oogonia) structures. In *Chara*, sex organs (globules and nucules) are specialized and grow only at specific points on the plant.

In brown algae like *Fucus* and *Sargassum*, sex organs are inside conceptacles. In *Fucus*, the oogonium contains eight eggs, while in *Sargassum*, only one of the eight eggs survives. The highest level of sexual evolution is found in red algae like *Polysiphonia*, where male spermatia are non-motile and rely on water currents to reach the female.

Sexual reproduction evolved due to environmental challenges, leading to the gradual transformation of zoospores into gametes. Over time, isogamy evolved into oogamy through

anisogamy. Oogamy ensures survival by producing a large female gamete with stored food and many male gametes to increase the chances of fertilization.

The most important function of sexual reproduction is the fusion of two gametic nuclei, creating genetic diversity through reshuffling of parental chromosomes. While asexual reproduction produces identical offspring, sexual reproduction introduces variations, accelerating evolution. This process is essential for adaptation and long-term survival.

Life-Cycle Patterns in Algae

Algae exhibit diverse life-cycle patterns, unlike higher plants, which have a fixed alternation of generations. In blue-green algae and some members of Chlorophyceae (e.g., *Protococcus*, *Scenedesmus*), reproduction is entirely asexual, with no alternation of generations.

Representative Life-Cycle Patterns in Algae

- 1. Haplontic Type:** This is the simplest and most primitive life-cycle pattern, from which other patterns have evolved. It is common in most Chlorophyceae and is also referred to as the *Ulothrix* or *Chlamydomonas* type. The somatic phase (plant) is haploid (n), while the diploid phase ($2n$) is represented only by the zygote. During germination, the zygote undergoes meiosis, producing haploid zoospores, which develop into individual plants. Examples: *Chlamydomonas* (unicellular), *Ulothrix*, *Spirogyra*, *Oedogonium*, *Chara* (filamentous).
- 2. Diplontic Type** This pattern is the reverse of the haplontic type. The somatic phase is diploid ($2n$) (sporophyte), while the haploid phase (n) is restricted to gametes formed by meiosis. Gametic fusion results in a diploid zygote, which develops into a diploid sporophytic plant. Examples: *Fucus*, *Sargassum*, *Codium*, *Bryopsis*.
- 3. Isomorphic Type** This pattern features two morphologically identical somatic phases alternating in generations. One phase is diploid ($2n$, sporophyte), and the other is haploid (n , gametophyte). The zygote forms a diploid sporophyte, which undergoes meiosis before zoospore (n) formation. These zoospores develop into haploid gametophytes, which produce gametes, leading to zygote formation. Found in: Ulvaceae, Chaetophoraceae, Cladophoraceae (Chlorophyceae), and orders like Ectocarpales, Cutleriales, Tilopteridales, Sphacelariales, Dictyotales (Phaeophyceae).
- 4. Heteromorphic Type** Similar to the isomorphic type but with morphologically distinct haploid and diploid phases. The diploid sporophyte produces haploid zoospores

(merospores) by meiosis. The haploid zoospores develop into gametophytes, which produce gametes. Fertilization results in a diploid sporophytic plant. Examples: *Laminariales*, *Sporochnales*, *Desmarestiales* (Phaeophyceae), *Urospora* (Chlorophyceae).

5. **Haplobiontic Type** This pattern includes three phases: two haploid (n) and one diploid ($2n$). Common in *Batrachospermum* (Rhodophyceae: Nemalionales) and *Coleochaete* (Chlorophyceae). In *Batrachospermum*, a haploid gametophyte produces gametes that fuse to form a diploid zygote ($2n$). The zygote undergoes meiosis to produce a haploid asexual phase (*carposporophyte*), which reproduces via haploid *carpospores* that develop into gametophytes.
6. **Diplobiontic Type** Found in most Rhodophyceae (except Nemalionales), this type involves three alternating generations. Example: *Polysiphonia* (Ceramiales). The cycle includes two diploid sporophytic generations (*carposporophyte* and *tetrasporophyte*) and one haploid gametophytic generation. The gametophyte produces gametes, which fuse to form a diploid zygote. The zygote develops into a diploid *carposporophyte* ($2n$), which forms diploid *carpospores*. The diploid *carpospores* germinate into a diploid *tetrasporophyte*, which produces haploid *tetraspores* via meiosis. The *tetraspores* germinate into haploid gametophytic plants. Algae exhibit a variety of life-cycle patterns with no fixed alternation of generations, as seen in higher plants. These patterns range from simple haplontic cycles to complex diplobiontic cycles, reflecting their diverse evolutionary adaptations.

Alternation of Generations in Algae

In algae, there is no regular and fixed alternation of generations as found in higher plants. In blue-green algae and some Chlorophyceae, such as *Protococcus* and *Scenedesmus*, reproduction is asexual, and alternation of generations is absent.

Life Cycle Variations in Algae

1. **Unicellular Chlorophyceae** In simple unicellular Chlorophyceae like *Chlamydomonas* and *Sphaerella*, reproduction occurs sexually, but there is no distinct sporophytic generation. In such cases, the zygote is considered the sporophyte because it is diploid ($2n$) and undergoes reduction division during germination to produce gametophytes. The life cycle consists of an alternation between a one-celled haploid phase and a one-celled diploid phase.
2. **Filamentous Algae (Haplontic Life Cycle):** In species like *Oedogonium*, *Ulothrix*,

Spirogyra, and *Zygnema*, the haploid filamentous plant (gametophyte) reproduces asexually by zoospores or aplanospores. The zygote represents the diploid phase but is short-lived, as meiosis occurs immediately upon germination.

3. Siphonales (Diplontic Life Cycle): In members of *Bryopsis* and *Codium* (Siphonales), a one-celled haploid phase alternates with a diploid coenocyte or siphonous filament, considered morphologically equivalent to a multicellular diploid generation (diplont).

4. Isomorphic Alternation of Generations: In some Ulvaceae (*Ulva*) and Cladophoraceae (*Cladophora*), a many-celled haploid generation alternates with a many-celled diploid generation. Both generations appear morphologically identical until reproduction occurs. In *Ulva*, meiosis occurs in all cells of the diploid plant, while in *Cladophora*, meiosis is restricted to branch apices. In *Cladophora glomerata*, meiosis occurs during gamete formation rather than zoospore production, leading to a different life cycle variation.

5. Heteromorphic Alternation of Generations (Brown Algae): In *Dictyota*, the haploid sexual plant (bearing antheridia or oogonia) is identical to the asexual diploid plant. This biphasic life cycle is termed isomorphic or homologous alternation of generations. In contrast, *Laminaria* exhibits a heteromorphic alternation of generations, where the large complex sporophyte alternates with small, simple gametophytes.

In *Fucus*, reduction division (meiosis) occurs during gamete formation in antheridia and oogonia, leading to a life cycle similar to that of higher plants and animals.

Alternation of Generations in Red Algae

1. Lower Red Algae (*Batrachospermum* and *Nemalion*): In these genera, the plant body is haploid (gametophyte). The cystocarp, derived from the zygote, appears sporophytic but is haploid due to reduction division in the zygote nucleus. This life cycle is triphasic, including a haploid gametophyte, haploid cystocarp, and diploid zygote, classified as a haplobiontic life cycle.

2. Higher Red Algae (*Polysiphonia*)

Here, the alternation of generations involves.

- **Haploid sexual plants (gametophytes)** bearing antheridia or oogonia.
- **Diploid zygote developing into an asexual tetrasporophyte** that produces tetraspores.
- **Tetraspores germinating into gametophytes**, completing the cycle.

This triphasic life cycle involves two diploid generations (tetrasporophyte and carposporophyte) and one haploid generation (gametophyte), known as a diplobiontic life cycle. The alternation of generations in algae varies greatly across different groups. It ranges from simple haplontic cycles in unicellular green algae to complex triphasic cycles in red algae, demonstrating the evolutionary diversity in reproductive strategies.

1.3 Cultivation of Algae

Growing freshwater algae in the Laboratory

Freshwater algae are widely distributed and can be found in various aquatic and damp habitats, including ditches, ponds, rivers, lakes, and marshes. They exist in both unicellular and multicellular forms. Some grow on damp earth or rocks, while others form greenish coverings on tree bark. Most species are independent, either free-floating or attached to substrates, but some are epiphytic or endophytic, living on or inside other plants.

Culturing Freshwater Algae: Many types of algae can be easily cultured in a laboratory setting. Some species grow well in containers of pond water or balanced aquariums, while others require nutrient solutions and pure culture techniques for long-term maintenance.

- **Culture Containers:** Jars work well for most algae, but robust species like *Spirogyra* and *Cladophora* thrive better in aquarium tanks.
- **Water Requirements:** Use the water in which the algae were originally growing, as sudden changes can be harmful. If additional water is needed, use distilled water and add it gradually to compensate for evaporation.
- **Density Considerations:** Overcrowding should be avoided to prevent decay and fermentation, which can kill the culture. Excess growth, particularly in species like *Cladophora*, should be periodically removed.

Starting Cultures: Cultures can be initiated at any time of the year. In winter, collect mud, sticks, or stones from environments where algae were previously growing and place them in jars with tap, distilled, or rainwater. Dormant spores in the mud may germinate and yield fresh cultures.

Even if algae seem to disappear, the culture should not be discarded. Dormancy periods vary among species.

- *Volvox* has a long dormancy period.
- *Oscillatoria* may revive in just a couple of months.

- *Cladophora* may not enter dormancy at all.

Refrigeration can extend the viability of some algae, allowing study over a week or more instead of just a day or two.

Collecting and Transporting Algae: While collecting algae, avoid metal containers, especially during long, warm trips. Ensure ample water supply if containers are sealed. Some species (*Spirogyra*, *Mougeotia*, *Zygnema*, *Cladophora*, *Hormiscia*, *Vaucheria*) can be transported wrapped in wet newspapers or magazines.

Culturing Specific Alga Types

Blue-Green Algae: Oscillatoria: Found in stagnant water, watering troughs, and damp earth. Easily maintained in laboratory cultures by covering the container and periodically adding water.

- **Nostoc:** Common in lakes and damp soil; keeps well under refrigeration.
- **Rivularia:** Attaches to aquatic plant stems and often occurs in laboratory aquaria.
- **Gloeocapsa:** Found in gelatinous masses in ponds or on wet rocks; easily maintained in cultures.

Green Algae

- **Volvocales:** Best grown in pure cultures using Knop's nutrient solution.
- **Chlorella:** Extensively studied for photosynthesis and potential as a food source. Cultured in Knop's solution or soil-water medium, with aeration using 5% CO₂ for maximum yield.
- **Spirogyra:** Found in quiet waters; grows well in balanced aquariums or soil-water medium.
- **Hydrodictyon:** Prefers direct sunlight in aquariums or soil-water medium.
- **Vaucheria:** Induces zoospore formation in darkness with a 2% cane sugar solution; sex organs form in bright sunlight with 2–4% cane sugar.
- **Cladophora:** Thrives in quiet water; excess growth should be trimmed.
- **Oedogonium:** Best maintained in soil-water medium for year-round cultures.
- **Pleurococcus:** Grows on tree bark; can be revived in a moist chamber or cultured on nutrient agar slants.
- **Chara & Nitella:** Cultured in aquariums with pond mud and natural water; fresh material should be placed in well-lit conditions.

Diatoms: Diatoms are abundant in ponds, ditches, and lagoons, often clinging to filamentous algae or submerged plants. Surface mud from ponds typically contains large numbers of diatoms.

Preparation of Nutrient Solutions Knop's Solution (Acid Medium, pH 6.4)

- **Magnesium sulfate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$)** – 0.25 gm
- **Potassium phosphate (KH_2PO_4)** – 0.25 gm
- **Potassium chloride (KCl)** – 0.12 gm
- **Calcium nitrate ($\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$)** – 1.00 gm
- Ferric chloride (FeCl_3 , 1% solution) – **1 drop**
- Dissolve chemicals separately in portions of distilled water and combine, adding calcium nitrate last.

Modified Knop's Solution (Neutral Medium, pH 7.6)

- **Magnesium sulfate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$)** – 0.1 gm
- **Potassium phosphate (KH_2PO_4)** – 0.2 gm
- **Potassium nitrate (KNO_3)** – 0.1 gm
- **Calcium nitrate ($\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$)** – 1.00 gm
- Ferric chloride (FeCl_3 , 1% solution) – **1 drop**
- Prepare as above.

Soil-Water Medium (Pringsheim Method)

1. In a gallon battery jar, add.

0.5 gm precipitated calcium carbonate

½ to ¾ inch layer of humus or garden soil Distilled water to within 1 inch of the top

2. Cover with a glass plate and steam in an autoclave for one hour on two consecutive days before inoculation.

3. Maintain under 40W fluorescent lamps, adjusting the distance after the first week.

Storage and Maintenance.

- Store cultures in rooms with ample daylight at **70°–75°F** (optimal temperature range).
- If artificial lighting is required, use **fluorescent culture lamps** at a **one-foot distance** from the culture shelf. Avoid contamination by covering culture jars with plates and properly sterilizing glassware. By following these methods, freshwater algae can be effectively cultured and maintained in a laboratory setting for research, educational, and

commercial purposes.

1.4 Economic Importance of Algae

Algae play a significant role in the ecosystem, impacting human life in both beneficial and harmful ways. While their importance is often overlooked, a thorough study reveals their immense value. The economic significance of algae can be classified into two categories: (A) Harmful Aspects and (B) Useful Aspects.

A. Harmful Aspects of Algae

- 1. Harmful to Aquatic Life** Algae can be detrimental to aquatic organisms, particularly fish. Certain groups, including Volvocales, Chlorococcales, and Myxophyceae, can proliferate excessively in water bodies, turning the water green or blue-green. This excessive growth depletes oxygen levels, especially at night, making respiration difficult for fish. Additionally, some blue-green algae produce toxins that can be fatal to livestock that consume the contaminated water.
- 2. Obstruction of Photosynthesis** Epiphytic algae, which grow on the surfaces of plants and trees, can block sunlight and hinder the process of photosynthesis. This negatively affects plant growth and productivity.
- 3. Parasitic Algae** Some algae act as parasites and cause diseases in plants. For instance, the disease known as 'red rust of tea' is caused by the algal species *Cephaleuros virescens*. This organism inflicts severe damage to tea plantations in Assam and also affects other economically important plants such as mango (*Mangifera*), rhododendron (*Rhododendron*), and coffee (*Coffea*). Such infestations lead to significant economic losses.
- 4. Mechanical Injury to Aquatic Life** Filamentous algae, when present in large quantities, form dense, net-like structures. These entangle fish and other aquatic organisms, causing injury and even death.
- 5. Water Contamination** Various species of algae, including blue-green and green algae, contaminate water supplies in reservoirs and other sources. This contamination results in foul odors and makes the water unfit for human and animal consumption. Additionally, mucilaginous secretions from these algae provide a breeding ground for harmful bacteria and pathogens, leading to waterborne diseases.
- 6. Fouling of Ships** Certain algae attach themselves to the surfaces of ships, a phenomenon known as 'fouling.' This algal growth increases friction and reduces the speed of ships,

necessitating regular cleaning and maintenance. To mitigate this issue, ships are periodically dried and painted with copper-based coatings.

- 7. Deterioration of Fabrics** During the rainy season, exposed wet fabrics can become infested with blue-green algae, leading to black spots and weakening of the fabric. This was a major concern during World War II, as algal growth often led to bacterial infections that destroyed textile fibers.

B. Useful Aspects of Algae

- 1. Food for Marine Animals and Fish** Algae serve as a direct source of food for various marine animals and fish. Rich in iodine and essential minerals, algae form the foundation of the marine food chain. Marine planktonic diatoms and dinoflagellates play a crucial role in sustaining ocean life. Given the ocean's vast productivity, marine algae significantly contribute to the global ecosystem.
- 2. Rich Mineral Content** Seaweeds contain a high mineral content, comprising up to 5% of their wet weight, making them a valuable dietary supplement. Essential minerals such as potassium, sodium, and chloride exist in an ionic form in seaweeds (Pillai, 1956). According to Black (1953), seaweed-derived iodine is superior to mineral iodine found in drinking water and iodized salt because it includes the precursor of thyroxine, an essential hormone.

In addition to iodine, seaweeds contain vital micronutrients such as iron, copper, manganese, and zinc, which are crucial for human metabolism. The highest copper content has been reported in *Sarconema furcellatum* and *Acanthophora spicifera*.

Currently, iodine extraction from seaweeds is a significant industry in Japan, France, Norway, and Java. Russia derives iodine from the red alga *Phyllophora nervosa*, found in the Black Sea, which contains 0.2%–0.5% iodine in its dry matter. However, around 80% of the global iodine supply comes from Chilean nitrate mines.

- 3. Algae as Food for Humans** Since prehistoric times, humans have consumed seaweed as food. Freshwater algae are also used in the production of vitamin-enriched foods, helping prevent nutritional deficiencies due to their high vitamin and mineral content.

In Japan and China, seaweeds are an integral part of the daily diet. Some believe that Japan's artistic and cultural advancements may be linked to the regular consumption of nutrient-rich seaweed. In South India, species of *Spirogyra* and *Oedogonium* are traditionally consumed.

Various algae-based food preparations exist worldwide.

Japan: *Suimono* – a dish made from dried fish and seaweed. *Mitsu* a mixture of seaweed, fruits, sugar, and dried kidney beans. *Laver (Nori)* made from *Porphyra*. *Kompu* – derived from various *Laminariales*.

England: *Dulse* prepared from *Rhodomenia*.

United States: *Seatron* made from *Nereocystis*.

Scotland and Ireland: *Ulva lactuca* used in salads and soups. *Laminaria saccharina* and *Rhodomenia palmata* used as food.

South India: *Green Laver* prepared from *Spirogyra* and *Oedogonium*.

China, Japan, Malaya, Indonesia, Burma, and Thailand: Various seaweeds are commonly consumed.

Chile, Hawaii, and New Zealand: *Durvillea antarctica* and *Ulva* species are popular. One of the most commercially important algae-based food products is **carrageenan**, primarily extracted from *Chondrus crispus*. Carrageenan is widely used in the food industry for its gelling properties, making it an essential ingredient in.

Ice creams, Confectionery, Fruit jellies (when mixed with fruit juice), Milk-based desserts

In Japan, *Porphyra tenera* is a highly valued edible algae, commonly processed into products such as **Amanori** and **Asakusa-Nori**, which are widely consumed.

7. Manufacture of Iodine Algae serves as a major source of iodine, fulfilling a significant portion of the global iodine supply. The extraction of iodine from seaweeds has been practiced for over a century. Iodine is an essential element used in medicine, dietary supplements, disinfectants, and the production of iodized salt to prevent iodine deficiency disorders such as goiter.

8. Production of Alginic Acid, Algin, and Mannitol Alginic acid, derived from the cell walls of brown algae (Phacophyceae), is an important industrial product. It is water-insoluble and forms a hard, durable material when dry. Sodium alginate, a derivative of alginic acid, has various applications, including.

Waterproofing materials, Textile and paper sizing, Dye production, Manufacturing buttons,

handles, and combs and Used as a sterilizing agent in everyday applications Algin is found in the form of calcium alginate and alginic acid, with the Fucaceae family being a primary source in India. The yield of algin from Fucaceae varies between 15.6% and 19.2% on an air-dry basis, while Padina yields about 10.4%. Additionally, the extraction of mannitol, a sugar alcohol, has been reported in various brown algae species. For instance, *Sargassum tenerrimum* yields about 9.4% mannitol, whereas *S. wightii* yields up to 73%.

9. Manufacture of Soaps and Alums By burning seaweed along coastal areas, alkaline substances are obtained from the ash. These alkalis are used in the manufacturing of soaps and alums. The high mineral content in seaweed ash makes it a valuable component in industrial applications.

10. Fodder for Livestock and Poultry Seaweeds serve as a nutritious fodder for dairy cattle, poultry, and livestock, significantly enhancing their productivity. When included in animal feed, seaweeds increase the iodine content in milk and eggs. Countries like Scotland, New Zealand, Norway, France, and the United States use seaweeds as a staple feed for hens and young livestock. Some nations have even established processing plants to manufacture seaweed-based cattle feed, primarily from brown algae. Studies have shown that dried seaweed in animal feed improves milk production in cattle and egg-laying capacity in poultry.

11. Manufacture of Potash Species of *Macrocystis* and *Nereocystis* (both belonging to Phacophyceae) contain up to 30% potash in their dry weight. Potash, a vital nutrient for plant growth, is extracted from seaweed and used in agricultural and industrial applications.

12. Use as Fertilizers Due to their rich content of potassium chloride (KCl), seaweeds are widely used as natural fertilizers in Japan, France, the United States, England, and South India. They provide an abundant supply of essential nutrients such as.

Potassium, Ionic sulfate, Trace elements and Growth-promoting substances

Seaweed-based fertilizers enhance soil fertility and improve plant resistance to diseases. The nutrients in seaweed exist in ionic form, allowing for quick absorption by crops. Unlike synthetic fertilizers, seaweed-based fertilizers minimize soil acidity and promote sustainable agriculture. Additionally, the application of seaweed manure enhances soil structure, microbial activity, and water retention capacity, making it a valuable organic alternative to chemical fertilizers.

7. Manufacture of Iodine: The world's iodine supply is predominantly sourced from seaweeds. The production of iodine has been ongoing for over a century. It is used in various industries, including pharmaceuticals, antiseptics, and food supplements.

8. Alginic Acid, Algin, and Mannitol: Alginic acid is extracted from the cell walls of Phaeophyceae and is insoluble in water. When dry, it becomes hard. Sodium alginate, derived from alginic acid, is used in waterproof materials, dyes, buttons, handles, combs, and as a sterilizer in daily-use products.

Algin is found in the form of calcium alginate and alginic acid, with Fucaceae being the chief source in India. The estimated yields of algin range from 15.6% to 19.2% in Fucaceae and 10.4% in Padina. Mannitol extraction from Sargassum species varies, with a yield of 9.4% from *Sargassum tenerrimum* and 73% from *S. wightii*.

9. Manufacture of Soaps and Alums: By burning seaweeds on the coast, alkalis are produced from seaweed ashes. These alkalis are used in manufacturing soaps and alums.

10. Fodder for Hens and Milk Cattle: Feeding seaweeds to milk cattle and poultry increases the iodine content in milk and eggs. Countries such as Scotland, New Zealand, Norway, France, and the United States use seaweeds extensively as fodder. Factories process brown algae into suitable cattle feed, which enhances milk yield and egg production.

11. Manufacture of Potash: Species of *Macrocystis* and *Nereocystis* (Phaeophyceae) contain 30% potash in their dry weight, making them valuable for potash production.

12. Use as Fertilizers: Seaweeds, rich in potassium chloride (KCl), are widely used as fertilizers in Japan, France, the United States, England, and South India. They serve as a storehouse of essential minerals, trace elements, and growth substances, improving plant growth and disease resistance. Seaweed manure retains water and air in the soil, enhancing soil structure. In addition to potassium, seaweed fertilizers contain sulfur, phosphorus, and calcium.

13. Manufacture of Lightweight Buildings: Germany has developed a technique where seaweeds are mixed with cement to create lightweight, heat-resistant building materials.

14. Manufacture of Paper: It has been suggested that rough-quality paper could be

produced from seaweeds, though this is not yet a common practice.

15. Ornamental Uses: Algae such as *Botrydium* and *Spirogyra* are cultivated in garden ponds for their aesthetic appeal.

16. Diatomaceous Earth: Diatomaceous earth, found in ocean beds, forms immense rock deposits over millions of years. Major deposits are in Lompoc and St. Maria oil fields in California, reaching depths of up to 3,000 feet.

Diatomaceous earth has diverse industrial applications, including.

- As an absorbent in dynamite production.
- As a filtration agent in the sugar industry.
- As a high-temperature resistant material (up to 1,500°C) for fire bricks used in blast furnaces.
- As an additive in cement to improve its bonding strength.
- As a mild abrasive in metal polishes, toothpaste, and car polishes.
- As a catalyst carrier in vegetable oil hydrogenation.
- As an ingredient in paints, lipsticks, and cosmetics.

17. Nitrogen Fixation by Blue-Green Algae (Cyanobacteria): Many cyanobacteria can fix atmospheric nitrogen in the soil. Studies have demonstrated that *Tolypothrix tenuis* and *Anabaena cylindrica* are particularly strong nitrogen fixers, contributing up to 2,900 lbs. of nitrogen per acre per year. Research at IARI, New Delhi, has confirmed that blue-green algae play a crucial role in soil fertility, particularly in tropical regions.

18. Reclamation of Alkaline (Usar) Soils: Certain blue-green algae, including *Nostoc*, *Scytonema*, and *Anabaena*, form thick layers on saline soils during the rainy season, improving soil conditions for agriculture. Experiments by Dr. R.N. Singh (1950) demonstrated that algal growth could reduce soil pH from 9.7 to 7.6, making the land arable again.

19. Utilization of *Chlorella*: The microalga *Chlorella* has gained prominence due to its high protein, fat, and vitamin content. It multiplies rapidly in the presence of nutrients, CO₂, and sunlight, making it ideal for mass production. Pilot-scale *Chlorella* farms exist in the U.S., Japan, Holland, Germany, and Israel. These farms do not require excessive water and may prove valuable in arid regions. Future applications include.

- Food production in space stations. Large-scale food supply for humans.
- Purification of sewage by increasing oxygen levels, aiding bacterial decomposition of organic matter.

Chlorella contains essential amino acids and vitamins, including thiamin, riboflavin, niacin, pyridoxine, pantothenic acid, choline, biotin, vitamin B₁₂, and lipoic acid. Studies indicate that a quarter pound of *Chlorella* provides nearly all essential vitamins for a person, except ascorbic acid. (Table 1.5).

Table 1.5 Biochemical Composition of Dried Chlorella.

Component	Percentage (%)
Crude Protein	44.00%
Amino Acids	0.01%
Arginine	2.06%
Histidine	0.62%
Isoleucine	1.75%
Leucine	3.79%
Lysine	2.06%
Methionine	0.36%
Phenylalanine	2.12%
Threonine	1.81%
Tryptophan	0.80%
Valine	2.47%
Carbohydrates	Up to 20%
Fats (Lipids)	20-25%
Main Fatty Acid	Palmitic Acid (Saturated)
Unsaturated Fats	65% of Total Fat Content

1.5 Classification of Algae

Classification of plants: Ancient Classification

- **Aristotle (382–322 B.C.)** and his student **Theophrastus (372–287 B.C.)**, known as the

Father of Botany, were the first to classify plants.

- They divided plants into **three groups** based on their form and texture:

Trees, Shrubs, Herbs

- In this classification, trees were considered the most highly evolved.

Artificial System by Linnaeus (1707–1778)

- Linnaeus proposed the **artificial sexual system of classification**.
- He divided the **plant kingdom into 25 classes (orders)** based on the number, arrangement, and form of reproductive organs (flowers).

- The **25th class, *Cryptogamia***, included plants with **concealed reproductive organs**.
- Linnaeus divided *Cryptogamia* into four subgroups:
 1. **Filices** – Ferns and Pteridophytes, 2. **Musci** – Mosses and leafy liverworts 3. **Algae** – including algae, lichens, and thalloid liverworts 4. **Fungi**

Natural System by A.L. de Jussieu (1748–1836)

- Jussieu proposed the **first natural system of classification** in the late 18th century.
- He divided plants into **three major groups**.
- 1. **Dicotyledones** 2. **Monocotyledones** 3. **Acotyledones** – Similar to Linnaeus' *Cryptogamia*

- This system was an improved version of Linnaeus' sexual system and considered more natural.

Cryptogamic Classification (1880)

- Non-flowering (cryptogamic) plants were classified into:
 - **Thallophyta** – Algae, fungi, and bacteria 2. **Bryophyta** Mosses and liverworts, **Pteridophyta** – Ferns and related plants, Four classes of algae were recognized:
 1. **Chlorophyceae** – Green algae 2. **Phaeophyceae** – Brown algae (included diatoms earlier)
 2. **Rhodophyceae** – Red algae 3. **Myxophyceae** (or **Cyanophyceae**) – Blue-green algae (now cyanobacteria). **Note:** Many motile algae were earlier placed under the **Mastigophora** class of the animal kingdom (*Protozoa*) due to their flagella. (Table 1.6)

Algal Classification (Before 20th Century) Dr. F. E. Fritsch classified algae into 11 classes based on pigmentation, flagella, and storage products.

Table 1.6: Modern Classification by F.E. Fritsch (1935–1945)

S.No	Class Name	Characteristics
1	Chlorophyceae	Green algae
2	Xanthophyceae	Yellow-green algae
3	Chrysophyceae	Golden algae
4	Bacillariophyceae	Diatoms
5	Cryptophyceae	Cryptomonads
6	Dinophyceae	Dinoflagellates
7	Chloromonadineae	Flagellated green forms
8	Euglenophyceae (Euglenineae)	Euglenoids
9	Phaeophyceae	Brown algae
10	Rhodophyceae	Red algae
11	Myxophyceae (Cyanophyceae)	Blue-green algae (Cyanobacteria)

Fritsch's System of Algal Classification: Dr. F.E. Fritsch (1935, 1944, 1945) classified alga: based on.

Major Criteria: Pigmentation, Assimilatory/metabolic food products and Type of flagella Minor characteristics were also considered for further distinction. Below are the details of six important algal classes.

1. Chlorophyceae (Green Algae): Genera: ~360 | Species: ~5,000

Major Features: Pigments: Chlorophyll **a** and **b**, xanthophylls, and carotenes (like higher plants), located in *chloroplasts* (chromatophores). Food reserve: **Starch**, formed in pyrenoids within chloroplasts. Flagella: **Isokont** type (equal length).

Minor Features: Unicellular to multicellular thallus. Cell wall: **Cellulose**. Sexual reproduction: **Isogamy to oogamy**. Life cycle: Mostly **haplontic**. No **parenchymatous** tissues. Mostly **freshwater**, few marine.

2. Xanthophyceae (Yellow-Green Algae): Genera: ~75 | Species: ~675

Major Features: Pigments: Chlorophyll **a**, β -carotene, and xanthophylls; gives yellow-green color. No starch or pyrenoids; food reserve: **Oils**. Flagella: **Heterokont** type (one long, one short).

Minor Features: Cell wall: **Pectic**, often with two overlapping halves (e.g., *Tribonema*).

- **Sexual reproduction is rare** (observed in only one species). Resting spores: With **two-piece membranes**; walls are **silicified**. Life cycle: **Haplontic**. Mostly **freshwater**, some marine.

3. Bacillariophyceae (Diatoms) Genera: ~170 | Species: ~5,300

Major Features: Pigments: Chlorophyll **a**, β -carotene, xanthophylls, and **diatomin** (gives golden-brown color). Food reserves: **Fats and volutins**. Flagellation: 1–2 flagella (in motile forms).

Minor Features: Mostly **unicellular**, some **colonial**. Sexual reproduction leads to **auxospore** formation. Life cycle: **Diplontic**. Found in both **marine and freshwater** habitats.

4. Phaeophyceae (Brown Algae): Genera: ~195 | Species: ~1,000

Major Features: Pigments: Chlorophyll **a**, β -carotene, and **xanthophylls** (especially fucoxanthin). Food reserve: **Mannitol** and **laminarin**. Motile cells: **Pyriform** with **two**

lateral flagella (one tinsel-type, one whiplash).

Minor Features: No unicellular forms. Presence of **excretory vesicles**. Sexual reproduction: From **isogamy to oogamy**. **No resting zygote**. Shows **alternation of generations**. Mostly **marine**; only 3 species are non-marine.

5. Rhodophyceae (Red Algae): Genera: ~400 | Species: ~2,500,

Major Features: Pigments: **r-phycoerythrin, c-phycoyanin**, chlorophyll **a**, β -carotene, and xanthophylls (gives red color). Food reserve: **Floridean starch** and **floridoside** (a sugar). No flagella at all.

Minor Features: Cells contain **plasmodesmata**. Sexual reproduction: **Highly specialized and advanced**. Life cycle: Clear **alternation of generations**. ~50 species are **freshwater**, the rest **marine**.

6. Myxophyceae (Cyanobacteria or Blue-Green Algae) Genera: ~150 | Species: ~1,500

Major Features. Pigments: **Chlorophyll a**, β -carotene, xanthophylls, **c-phycoyanin** (blue), and **c-phycoerythrin** (red); pigments are dispersed in the peripheral *chromatoplasm*. Food reserve: **Cyanophycean starch** (glycogen-like). No flagella.

Minor Features: **No sexual reproduction** known. Most are **freshwater**; some **marine** forms exist.

1. Pascher's and Smith's System (1955): This system follows a classical approach based on morphology, pigments, and reproductive structures.

Divisions and Classes

- 1. Chlorophyta:** *Chlorophyceae* (Green algae) *Charophyceae* (Stoneworts)
- 2. Euglenophyta** *Euglenophyceae*
- 3. Phyrrophyta:** *Desmophyceae, Dinophyceae*
- 4. Chrysophyta:** *Chrysophyceae* (Golden-brown), *Xanthophyceae* (Yellow-green), *Bacillariophyceae* (Diatoms)
- 5. Phaeophyta** (Brown algae): *Isogenerateae Heterogenerateae Cyclosporeae*
- 6. Cyanophyta** (Blue-green algae): *Myxophyceae*
- 7. Rhodophyta** (Red algae): *Rhodophyceae:* Also includes **algae of uncertain position**.

Chloromonadales, Cryptophyceae.

2. Papenfuss System (1953): This system uses “**phyta**” and “**phyceae**” consistently for divisions and classes. It recognizes 8 **phyla** based on pigment composition, flagella, and other

cellular features.

Phyla and Classes

1. **Chlorophycophyta:** *Chlorophyceae*
2. **Charophycophyta** *Charophyceae*
3. **Euglenophycophyta** – *Euglenophyceae*
4. **Pyrrophycohyta** *Dinophyceae, Cryptophyceae, Chloromonadophyceae*
2. **Phaeophycophyta** – *Phacophyceae* (Brown algae)
3. Chrysophycophyta

Chrysophyceae, Xanthophyceae, Bacillariophyceae

4. **Schizophycophyta** – *Schizophyceae*
5. **Rhodophycophyta** – *Rhodophyceae*
3. **Chapman's System (1962):** Chapman proposed a more evolutionary and biochemical-based system. He grouped related classes under larger groups.

Groups and Classes

- A. **Euphycophyta** *Charophyceae, Chlorophyceae, Phacophyceae, Rhodophyceae*
- B. **Myxophycophyta:** *Myxophyceae* (Blue-green algae)
- C. **Chrysophycophyta:** *Chrysophyceae, Xanthophyceae, Bacillariophyceae*
- D. **Pyrrophycohyta:** *Cryptophyceae, Dinophyceae*

Modern Trends in Algal Classification

- Emphasizes **phylogenetic relationships**, resulting in a **polyphyletic** system (multiple evolutionary origins).
- Based on **pigments, flagella, reserve food materials, and ultrastructure**.
- New systems aim for **monophyly** using **molecular tools** (DNA, RNA).
- Uses **standardized suffixes** (e.g., -phyta for divisions, -phyceae for classes).

Modern Divisional Structure (11 Divisions)

Cyanophycophyta (Blue-green algae), Chlorophycophyta (Green algae), Charophyta, Euglenophycophyta, Xanthophycophyta, Chrysophycophyta, Bacillariophycophyta,

EXERCISE

I Short Answer Questions (5–6 sentence answers expected).

1. What is the ecological role of algae in aquatic ecosystems?
2. Explain the historical development of the term “algae” and its scientific definition.
3. Classify algae based on their habitat and give examples of each type.

4. Describe the significance of blue-green algae in agriculture and nitrogen fixation.
5. What are the different modes of nutrition in algae?
6. Summarize the early development of phycology in India and mention key contributors.

II Essay Questions (2 pages answers expected)

1. Explain in detail the classification of algae based on their habitat, with suitable examples.
2. Trace the historical development of phycology from ancient times to the present, emphasizing major contributors worldwide and in India.
3. Describe the various nutritional types of algae and the essential nutrients required for their growth. Discuss the role of pigments in photosynthesis.
4. Discuss the different phases of algological research in India, highlighting key discoveries and their applications in agriculture and industry.
5. Describe the economic importance of algae, highlighting both its useful and harmful aspects.
6. Discuss the classification of algae according to F.E. Fritsch and explain the major characteristics of Chlorophyceae and Rhodophyceae.

UNIT II: CYANOBACTERIA (BLUE-GREEN ALGAE)

Cyanophycean Class (Cyanophyceae / Schizophyceae / Phycochromophyceae)

Members of this class exhibit a rich diversity of pigments, contributing to their distinctive blue-green coloration. The primary photosynthetic pigment is chlorophyll a, accompanied by accessory pigments such as β -carotene and various xanthophylls. These xanthophylls include antheraxanthin, aphanicin, aphanizophyll, flavacin, lutein, myxoxanthin, myxoxanthophyll, oscilloxanthin, and zeaxanthin. In addition to these, they contain phycobiliproteins like allophycocyanin, phycocyanin, and phycoerythrin, which assist in capturing light energy for photosynthesis.

The stored food reserves in these organisms mainly consist of cyanophycean starch, a carbohydrate that is similar in structure to glycogen, along with significant amounts of protein, serving as energy reserves for cellular processes.

A notable characteristic of this group is the complete absence of flagella. Unlike many other algal groups, these organisms do not possess flagella at any stage of their life cycle, relying instead on passive means such as water currents for movement and dispersion.

1.1 General Characters Diversity and Distribution.

- The class includes around **150 genera** and approximately **1,500 species**.
- These organisms are **ubiquitous**, thriving in **freshwater, marine, and terrestrial** habitats.

Habitat Preferences

These organisms exhibit remarkable ecological versatility, thriving in a wide range of habitats. Marine species are primarily represented in the order Chamaesiphonales, where they are abundant in both littoral and sub-littoral zones of the ocean. In freshwater ecosystems, members of the orders Chroococcales and Hormogonales are commonly found, often forming blooms in ponds, lakes, and rivers.

Terrestrial forms are also well-adapted to survive under harsh conditions. They colonize surfaces such as rocks, old walls, and even soils, penetrating to depths as great as eight feet. Notable examples include *Porphyrosiphon* and *Scytonema*, which are capable of surviving desiccation and extreme temperature fluctuations.

Some members are thermophilic, thriving in high-temperature environments such as hot springs. Genera like *Phormidium*, *Schizothrix*, *Lyngbya*, and *Rivularia* can tolerate temperatures as high as 85°C, making them some of the most heat-resistant organisms known.

Planktonic forms contribute significantly to the phytoplankton populations in both freshwater and marine ecosystems, playing a crucial role in aquatic food chains and oxygen production. Symbiotic associations are a notable feature of several genera. Species of *Nostoc* live endophytically within the thalli of bryophytes such as *Anthoceros* and *Notothylas*. *Anabaena cycadeae* is found in the coralloid roots of *Cycas*, while *Anabaena azollae* resides in the leaf cavities of the aquatic fern *Azolla*. These symbiotic relationships are often nitrogen-fixing and are ecologically and agriculturally important.

Ecological Roles

These organisms perform critical ecological functions in various environments. Through photosynthesis, they contribute significantly to primary production, releasing oxygen and forming the base of many aquatic food chains. In addition, many species possess the ability to fix atmospheric nitrogen, converting it into forms usable by other organisms. This dual capacity for photosynthesis and nitrogen fixation makes them essential players in nutrient cycling, especially in nutrient-poor environments.

Beyond their autotrophic lifestyle, some members engage in symbiotic and parasitic relationships. Certain species within the Chroococcales form mutualistic associations with protozoa such as rhizopods and *Cryptomonas*, providing photosynthetically derived nutrients. In contrast, some species of the family Oscillatoriaceae, comprising around 40 species across four genera, exhibit parasitic behavior. These forms may inhabit the digestive tracts of animals, including humans, where they survive by absorbing nutrients from the host.

Under favorable conditions, particularly in nutrient-rich and soft water bodies, some species can grow excessively, leading to the formation of algal blooms. These blooms often cover the water surface with a dense blue-green layer, which can block sunlight penetration, reduce oxygen levels in the water, and produce harmful toxins affecting aquatic life and water quality.

Geological Significance and Fossils

The geological significance of these organisms is profound, as they are considered among the earliest life forms to have shaped the Earth's biosphere. Although no direct fossil evidence of blue-green algae has been conclusively identified from the Archeozoic Era, the presence of extensive graphite deposits dating back to this period suggests biological activity. These deposits are believed to have originated from ancient photosynthetic organisms, potentially cyanobacteria, indicating their early role in the planet's oxygenation.

Fossil impressions resembling cyanobacteria have been documented from later geological periods, providing more concrete evidence of their existence in Earth's distant past. These fossilized forms, often found as stromatolites, layered sedimentary structures created by microbial communities, support the idea that cyanobacteria have played a crucial role in shaping both the biological and geological history of the planet. Their ability to perform oxygenic photosynthesis is thought to have significantly contributed to the formation of Earth's early atmosphere, paving the way for the evolution of more complex life forms.

Structural Diversity and Cellular Features of Cyanophyceae (Myxophyceae) Range of Thallus Structure.

Members of the Cyanophyceae class exhibit three main structural forms.

- 1. Unicellular Forms:** These are single-celled blue-green algae found predominantly in the order *Chroococcales*. Notable examples include **Chroococcus**, **Gloeocapsa**, and **Tetrapedia**, which are widespread and thrive in diverse habitats.
- 2. Non-Filamentous Colonial Forms:** Colonies are often **amorphous**, formed by the merging of gelatinous envelopes that surround individual cells. Examples include **Aphanocapsa** and **Aphanothece**.

The **shape** of the colony is influenced by the **planes of cell division**.

- **One-plane division** results in **plate-like** colonies (e.g., *Merismopedia*).
 - **Multiple-plane divisions** produce **cubical or irregular** colonies.
- 3. Filamentous Forms:** These develop through repeated cell division in a single plane, resulting in long, thread-like structures known as filaments. In Oscillatoriaceae (e.g., *Oscillatoria*), filaments consist of a trichome enclosed in a sheath. In *Schizothrix*, multiple trichomes may be enclosed in a common sheath. Branched filaments are seen in *Nostochopsis*. Heterocysts (specialized nitrogen-fixing cells) are found in many filamentous forms (excluding Oscillatoriaceae) and may be intercalary or terminal.

1.2 Cell Structure

- **Cell Wall:** Composed of two layers: An outer pectic layer and an inner cellulose layer.
- **Cytoplasm:** The cytoplasm lacks vacuoles and is gel-like. It is differentiated into:
 - **Chromoplasm:** The peripheral pigmented region containing phycobilins (phycocyanin, phycoerythrin), chlorophyll a, carotenes, and xanthophylls. Also contains glycogen granules and oil droplets. Pigments are dispersed and not enclosed in chromatophores.
 - **Centroplasm (Central Body):** Colourless, lacks a true nucleus, nucleoli, and nuclear membrane. Contains **DNA, RNA, and proteins** dispersed as **chromatin-like granules**. Views vary: it is considered by some to be a primitive nucleus or a storage area. According to West, it may be an incipient nucleus.
- **Pseudovacuoles (Gas Vacuoles):** Found mainly in the chromoplasm, these may contain gas or viscous fluid, aiding in buoyancy.

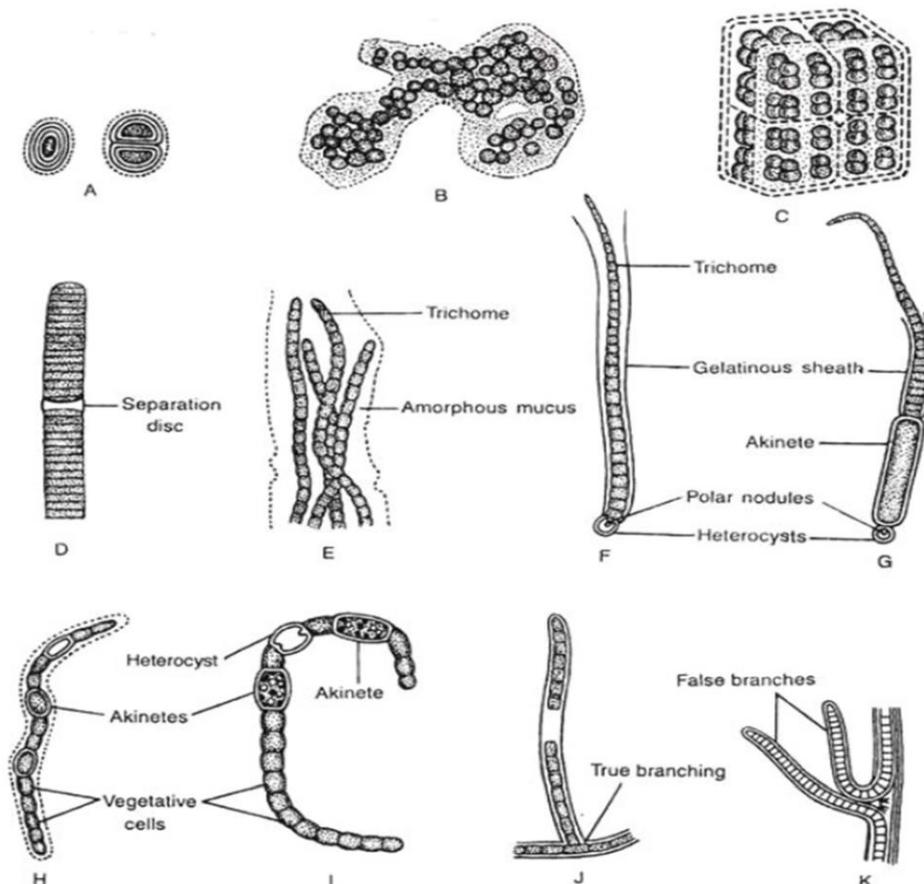


Fig-2.1 few members of Cyanophyceae showing thallus organization A. *Gloeocapsa* sp. B. *Microcystis* sp C. *Eucapsis alpina*. D. *Oscillatoria* sp. E. *Microcoleus* sp. F. *Rivulana poliotis*, G. *Gloeotrichia pisum*, H *Nostoc* sp., I. *Anabaena* sp. J. *Mastigocladus imilosus*, and K. *Scytonema* sp.

Cytological Insights

- Advanced studies confirm the presence of DNA and RNA within the chromatin material of the central body.
- These findings support the primitive nucleus theory, distinguishing cyanobacteria from higher plants while linking them evolutionarily with bacteria.

Movements in Myxophyceae

1. **Gliding Movement:** Trichomes move forward and backward within their mucilaginous sheath, a common phenomenon in filamentous forms.
2. **Oscillatory Movement:** seen in *Oscillatoriaceae*, where trichomes exhibit a pendulum-like swaying. Temperature and light intensity significantly enhance this movement.

Photosynthesis and Food Storage.

- Photosynthesis in Cyanophyceae operates similarly to other autotrophic organisms using chlorophyll-a and phycobilins.
- The main storage product is Cyanophycean starch, structurally similar to glycogen but distinct from true starch in higher plants.
- Lipids and proteins are also common reserve materials.
- A unique amino acid, diaminopimelic acid, found in their proteins, is also seen in bacteria, hinting at a shared evolutionary ancestry.

Nitrogen Fixation Ability.

Several species of blue-green algae possess the remarkable ability to fix atmospheric nitrogen, playing a crucial role in soil fertility and benefiting agricultural systems, particularly in paddy fields. These organisms contribute significantly to the nitrogen economy of the soil, enhancing crop productivity without the need for chemical fertilizers.

Earlier, it was believed that nitrogen-fixing bacteria residing within the mucilaginous sheath of the algae were responsible for this process. However, P.K. De, in 1939, conclusively demonstrated that the cyanobacteria themselves are the primary agents of nitrogen fixation in rice fields, thus highlighting their direct role in maintaining soil fertility.

Further research expanded the understanding of their potential. Watanabe (1951) reported that *Tolypothrix tenuis* could fix approximately 780 pounds of nitrogen per acre per year. Later, Allen (1955) documented that *Anabaena cylindrica* was capable of fixing as much as

2,900 pounds of nitrogen per acre per year. These findings illustrate the significant agricultural potential of cyanobacteria, making them valuable components of sustainable farming practices, especially in regions where rice cultivation predominates.

Reclamation of Alkaline Usar Soils: Blue-green algae grow naturally during rains on saline soils. Key species: *Nostoc*, *Scytonema*, *Anabaena*. R.N. Singh (1950) Showed soil pH drop from 9.7 to 7.6 and increased productivity (up to 2000 lbs/acre of paddy).

1. Vegetative Reproduction: This type of reproduction involves the development of new individuals from parts of the parent organism, without the formation of spores. (Fig 2.2)

a) **Cell Division:** Common in unicellular forms like those in the order **Chroococcales**.

- The single cell divides by binary fission (splitting into two), producing two identical daughter cells.

b) Fragmentation

- **Colonies** or **filaments** break into smaller pieces. Each fragment grows into a new individual. Common in **filamentous forms**, especially in the family **Oscillatoriaceae**.

c) Hormogonia (Hormogones)

- These are **short fragments** of filaments (trichomes) that separate from the parent filament. They glide out of the sheath and grow into new filaments. Seen in many **Nostocales** species.

d) Hormospores / Hormocysts

- When **hormogonia cells** accumulate food and develop thick walls under stress, they become **hormospores**. These survive adverse conditions and later germinate into new filaments. Example: *Wostiella*.

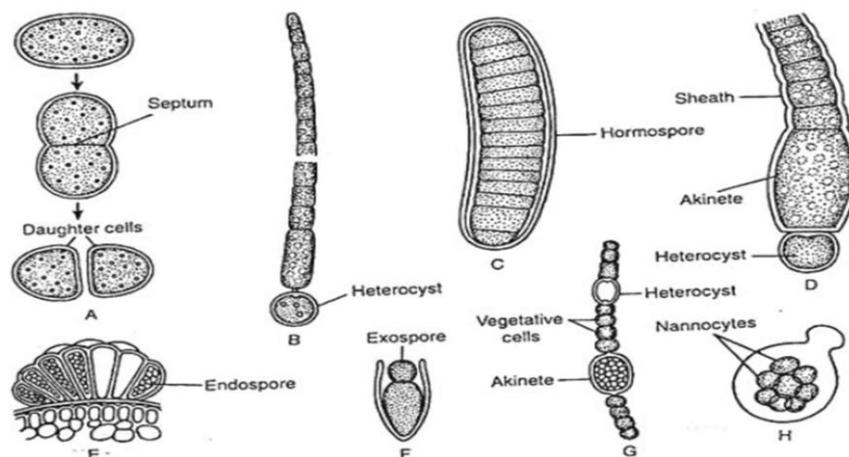


Fig. 2 .2 Fig-2.3 Vegetative and asexual reproduction in Cyanophyceae.

A. Cell division (*Synechococcus* sp.). Hormospore (*Vestiella lanosa*), D. Akinete B. Fragmentation of filament (*Cylindrospermum muscicola*), C. (*Gloeotrichia natans*). E Endospore (*Dermocarpa prasina*). F. Exospore (*Chamaesiphon incrustans*). G. Akinete (*Anabaena* sp.) and H. Nannocytes (*Aphanothece*).

e) **Akinetes:** These are **thick-walled, dormant vegetative cells** formed during **unfavourable conditions**. Rich in food reserves and help the organism survive drought or extreme heat. When conditions improve, akinetes germinate into new filaments. Also called **arthrospores** or **resting spores**. Example: *Nostoc*.

2. **Asexual Reproduction:** This involves the formation of **spores**, which develop into new individuals without fertilization.

a) **Endospores:** Produced **inside the parent cell**. The **cytoplasm** divides into several small units, each becoming an **endospore**. When released, they germinate into new individuals. Example: *Dermocapsa*.

b) **Nannospores:** These are **smaller-sized endospores**. Many are formed in a single cell. Each nannospore develops into a new cyanobacterial cell. Also found in *Dermocapsa*.

c) **Exospores:** Formed **outside the cell**, usually at the **terminal end**. The outer part of the cell constricts and pinches off as a spore. Spores are released successively. Example: *Chamaesiphon* (which grows on other algae like *Oedogonium*).

Heterocysts: Heterocysts are **specialized thick-walled cells** found in many filamentous cyanobacteria, with **important physiological functions**, especially **nitrogen fixation**.

Occurrence: Present in most filamentous cyanobacteria, **except** in the family.

Oscillatoriaceae.

Structure: Round or oval, thick-walled cells with two distinct layers: Inner investment: Thin inner wall. Outer investment: Thick, mucilaginous outer sheath.

Position in the Filament: Intercalary (between normal cells): Have **two pores** (bipored).

Terminal (at filament ends): Have **one pore** (monopored).

Examples: *Gloeotrichia*, *Rivularia*, *Cylindrospermum*: Terminal heterocysts. *Anabaenopsis*: Terminal heterocysts at both ends. *Nostoc*: May have mono- or bipored heterocysts.

Functions (*Still debated*)

1. **Nitrogen Fixation** (Widely accepted): Heterocysts provide an anaerobic environment for the nitrogenase enzyme to convert atmospheric nitrogen into ammonia.

2. **Ancient Reproductive Cells** (Geitler's view): Suggested that heterocysts were

once reproductive structures, now largely non-functional in this role.

- 3. Storage of Food:** Some believe heterocysts act as **food storage sites** during unfavourable conditions.

Origin and Affinities of Monophysite

Ancient Nature: Myxophyceae are considered one of the earliest life forms on Earth due to their primitive characteristics, which include:

- **Absence of chromatophores** (no organized chloroplasts like in higher algae or plants).
- **Presence of an incipient nucleus** (no true nucleus, only a nucleoid region).
- **Lack of flagella** (no motile reproductive or vegetative cells).
- **No reproductive cells** (no gametes or zygotes).
- **Total absence of sexual reproduction** (only asexual and vegetative methods).

These features suggest a **very** primitive origin, possibly dating back to 3.5 billion years ago.

Habitat and Distribution: Myxophyceae have a cosmopolitan distribution and are found in almost every habitat: freshwater, marine, soil, rocks, hot springs, deserts, and even snow.

- Their ecological versatility supports the idea of an independent origin, not derived from any known algal group.

Uncertain Ancestry: Their lack of flagella and swarmer cells rules out the possibility of a flagellate ancestry (unlike green algae).

Affinities (Resemblances)

Red Algae (Rhodophyceae): Both lack motile reproductive cells. Some cyanobacteria have a red pigment similar to phycoerythrin in red algae. **With Bacteria:** No true nucleus or membrane-bound organelles. Absence of sexual reproduction. Ability to fix atmospheric nitrogen, just like some soil bacteria. Because of these similarities, cyanobacteria are also referred to as cyanobacteria (blue-green bacteria).

Classification of Myxophyceae: There are five orders in the class Myxophyceae. The first three orders do not produce hormogones (short reproductive filaments). The last two orders possess hormogones.

- 1. Chroococcales: Structure:** Unicellular or colonial. **Reproduction:** By cell division and endospores. Example: *Gloeocapsa*, *Chroococcus*.
- 2. Chamaesiphonales: Structure:** Unicellular or colonial; often **epiphytic** (growing on other plants) or lithophytic (growing on rocks). **Reproduction:** By endo- or exospores.

3. Pleurocapsales: Structure: Filamentous but **non-heterotrichous** (not differentiated into base and apex). Heterocysts: Absent. Reproduction: By endospores.

4. Nostocales: Structure: Non-heterotrichous filamentous types. Heterocysts: Present. Reproduction: By hormogones, hormospores, and akinetes.

Families in Nostocales: Oscillatoriaceae – *Oscillatoria* Scytonemataceae – *Scytonema*
Microchaetaceae Rivulariaceae – *Rivularia*

5. Stigonematales: Structure: Filamentous with true branching. Heterocysts: Mostly present. Reproduction: By hormogones, hormospores, and occasionally akinetes.

Economic Importance of Myxophyceae Positive Aspects

1. Food Source: Some species (e.g., *Nostoc*) are used as food. They are boiled in soups and consumed in various cultures.

2. Aquatic Ecosystems: Cyanobacteria are important components of **phytoplankton**, serving as food for aquatic animals. Fish that feed on these algae are consumed by humans.

3. Soil Fertility: Many cyanobacteria, especially in **tropical regions**, fix atmospheric nitrogen and **enrich soil fertility**. Common nitrogen-fixing genera include *Anabaena*, *Nostoc*, *Aulosira*.

Negative Aspects: Water Pollution: Excessive growth in lakes and rivers can lead to **eutrophication**, making the water **unfit for human use**.

1. Toxic Blooms: Species like *Aphanizomenon*, *Microcystis*, and *Anabaena* can cause **toxic algal blooms**, which: **Deplete oxygen** in water. **Kill fish and aquatic organisms**. Cause death of **cattle** that drink contaminated water.

2. Health Hazards: *Microcystis* produces potent neurotoxins that can damage the liver, heart, and lungs of animals. *Oscillatoria* when consumed by humans through water may cause: Skin itching, Conjunctivitis, Blocked nasal passages, Bronchial asthma.

Order: Chroococcales: (A group under the class Myxophyceae / Cyanobacteria)

Characteristic Features: Unicellular or Colonial Forms: Organisms in this order are **unicellular**. They may exist **singly** or be **united into colonies**. Colonies can be in **mucilaginous envelopes**, floating freely or attached to surfaces.

Reproduction: Takes place asexually, mainly by binary fission (cell division). Division can occur in one or more planes, resulting in characteristic colony shapes. Endospores may

occasionally be formed in some genera, but this is not a regular feature. Number of Genera and Species: Approximately 35 genera and 250 species have been described under this order. No Pseudofilaments: Even in colonial forms, there is no tendency to form filaments or pseudofilaments (false filaments).

Families under Chroococcales: There are **two families** under this order.

1. Chroococcaceae: Main Features: Most genera are colonial, although some are unicellular. Colonies consist of cells embedded in mucilage, but no true filament formation. Cells are generally rounded or oval, with a distinct cell wall. Pseudofilaments are absent, even when cells are closely packed. Examples: *Chroococcus*, *Gloeocapsa*, *Microcystis*, *Aphanocapsa*.

2. Entophysalidaceae: This family includes colonial and endophytic forms. Colonies may appear as layers or clusters of cells inside mucilaginous masses. Found embedded in rocks, bark, or other organisms (often endosymbiotic or epiphytic).

Genus: Microcystis

Systematic Position: Phylum: Cyanophyta, **Class:** Cyanophyceae, **Order:** Chroococcales
Family: Chroococcaceae.

Microcystis is a colonial blue-green alga commonly found in freshwater habitats such as ponds, lakes, and reservoirs. It usually forms free-floating colonies on the surface of water bodies, where it often causes algal blooms dense accumulations of algae that can rapidly spread and dominate aquatic environments. These blooms are not only visually unpleasant but also harmful, as *Microcystis* produces toxic substances that can affect animals, humans, and aquatic life. These toxins may pollute drinking water and disrupt the natural balance of aquatic ecosystems. (Fig-2.3).

Among the important species of this genus, *Microcystis aeruginosa* is known for producing a powerful toxin called the "fast death factor," which is highly toxic to fish, livestock, and humans. Another dangerous species, *Microcystis toxica*, has been reported to cause the death of thousands of cattle and sheep that consumed water contaminated by this alga.

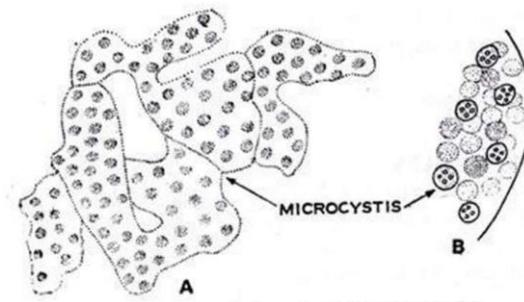


Fig-2.3 Microcystis. A. A colony; B. Part of colony.

The body or thallus of *Microcystis* is colonial and irregular in shape. These colonies are surrounded by a colorless, mucilaginous sheath that helps them float and stick together. Each colony consists of numerous small cells that may be spherical, oval, or ellipsoidal. A notable feature of the cells is the presence of gas vacuoles, which allow the entire colony to remain buoyant and float on the water's surface.

Structurally, each *Microcystis* cell has a distinct cell wall and internal protoplasm. The protoplasm is differentiated into two main regions. The outer region, known as the peripheral chromatoplasm, contains the photosynthetic pigments responsible for capturing sunlight and producing food. The central region, called the centropylasm or nucleoplasm, contains the genetic material and acts as a primitive nucleus, although it is not enclosed by a nuclear membrane as in higher organisms.

Reproduction: *Microcystis* occurs primarily through asexual means. The most common method is binary fission, in which individual cells divide in all directions to produce new cells. This process allows for rapid multiplication within the colony. In addition to binary fission, *Microcystis* colonies can also reproduce through fragmentation. During this process, larger colonies break apart into smaller fragments, each of which can grow independently into a new colony. In certain species, such as *Microcystis flosaquae*, reproduction may also occur through the formation of specialized small reproductive cells known as nannocytes. These methods together enable *Microcystis* to spread efficiently and form dense blooms in freshwater environments.

Occurrence

Genus: *Oscillatoria*

Systematic Position: **Phylum:** Cyanophyta **Class:** Cyanophyceae **Order:** Nostocales

Family: Oscillatoriaceae

Oscillatoria is a widespread genus of freshwater, blue-green algae represented by around 76 species. These algae are commonly found in various habitats such as ponds, streams, drains, and polluted water bodies, as well as damp soils and rocks. They form bluish-green scums on the surface or bottom of stagnant water. Some species, like *Oscillatoria princeps*, are found in seawater and terrestrial habitats, while others show remarkable temperature tolerance. For instance, *O. brevis* can survive sub-zero temperatures (up to -16°C), whereas *O. terebriformis* thrives in hot water springs, indicating thermal tolerance. Saprophytic forms may also exist in the digestive and respiratory tracts of animals.

Thallus (Body) Structure: The thallus of *Oscillatoria* is an unbranched, filamentous structure composed of long threads called trichomes. These trichomes may be free-floating or loosely attached, often forming tangled masses or spongy mats in water. Each filament is uniseriate, consisting of a single row of cells. The trichomes are naked or enclosed within a poorly developed sheath and may be either smooth or show constrictions at cross-walls between cells. (Fig. 2.4)

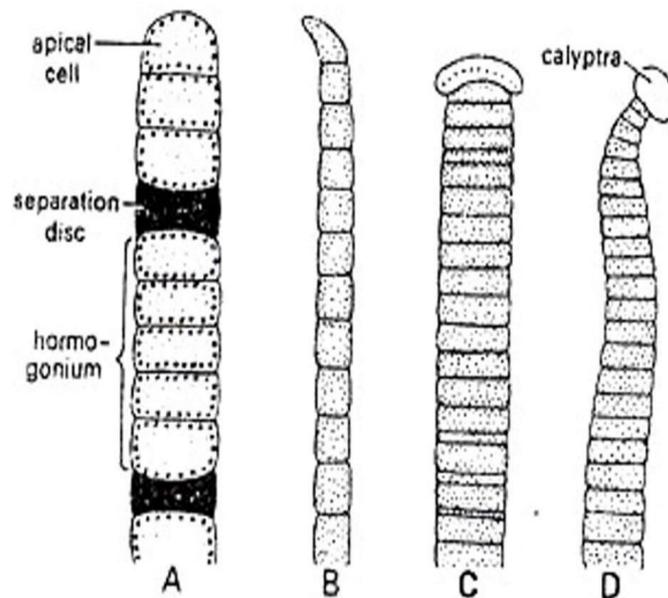


Fig. 2.4 (A-D): *Oscillatoria*: Trichomes.

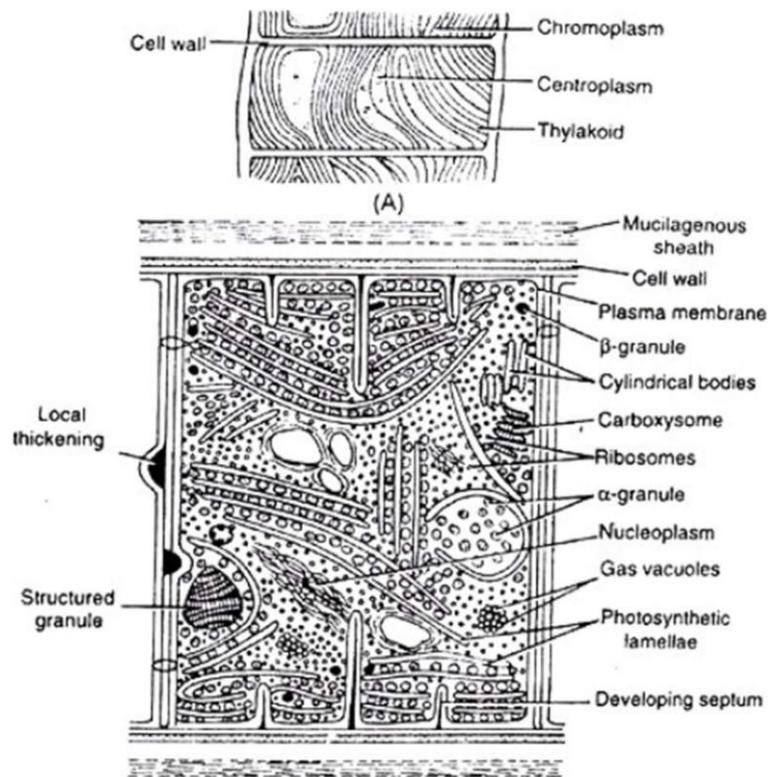


Fig 2.5. (A-B). Oscillatoria. (A) Single cell, (B) Ultrastructure of the cell.

Cell Structure: All cells within the filament are morphologically similar and possess a prokaryotic structure. Each cell has a mucopeptide cell wall, with an ultrastructure showing multiple layers, including pores that facilitate exchange. Inside, the protoplasm is divided into two regions: the outer **chromoplasm**, which contains pigments and photosynthetic lamellae (thylakoids), and the central **centrioplasm**, which houses the incipient nucleus or gonophore, composed of DNA fibrils. The chromoplasm contains thylakoids arranged parallel to one another, holding photosynthetic pigments like chlorophyll *a*, carotenes, xanthophylls, and phycobilins (such as C-phycoerythrin, allophycoerythrin, and phycoerythrin) within vesicles known as **phycobilisomes**.

The cells lack membrane-bound organelles like mitochondria, plastids, endoplasmic reticulum, and Golgi bodies. The cytoplasm contains ribosomes, reserve food materials such as cyanophycean starch, lipids, and cyanophycin granules. Two types of granules are observed: **α-granules** containing proteins and polysaccharides, and **β-granules** rich in lipids. In planktonic species, **gas vacuoles** or **pseudovacuaes** composed of hexagonal gas vesicles help maintain buoyancy, although these structures lack membranes. The trichome shows polarity. It possesses a characteristic apical cell. It may be cap-like (capitate) or covered by a thick membrane called calyptra. The apical cell may also be conical, dome-shaped,

acuminate, oval.

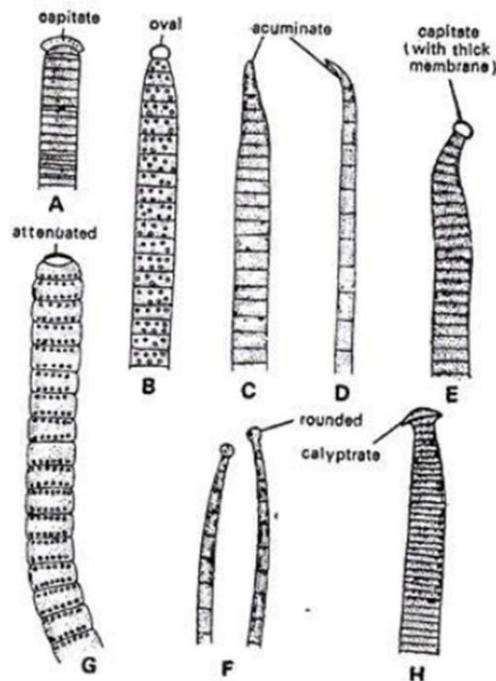


Fig. 2.6. (A-H). Oscillatoria. Apex of trichomes showing different shapes of the terminal cells. flattened, convex, or coiled, and accordingly to the shape of the cap cell, the species are identified (Fig. 2.6 A-H).

Reproduction and Movement in *Oscillatoria*

Oscillatoria reproduces exclusively through vegetative methods, primarily by **fragmentation** and the formation of **hormogonia**. Fragmentation occurs when the filament breaks into smaller pieces due to external factors such as water currents, accidental injury, or the feeding activity of insects and animals. Each resulting fragment can grow into a new individual filament. Another common method of reproduction is through **hormogonia**, which are short segments of the trichome made up of a few cells. These are produced when certain cells within the filament die and form **separation discs** mucilaginous, biconcave pads that help in the detachment of the hormogonia. The dead cells forming these separation points are known as **necridia**. Hormogonia are motile and eventually develop into full filaments under favorable conditions.

The genus *Oscillatoria* derives its name from its distinctive movement. The trichomes display a characteristic **oscillatory movement**, where the apical region swings in a slow, pendulum-like, jerky fashion. This movement is believed to aid in the orientation and relocation of the filaments in response to environmental stimuli. Apart from this, the

trichomes of *Oscillatoria* may also show gliding and twisting movements, contributing to their ability to spread over various surfaces in aquatic habitats.

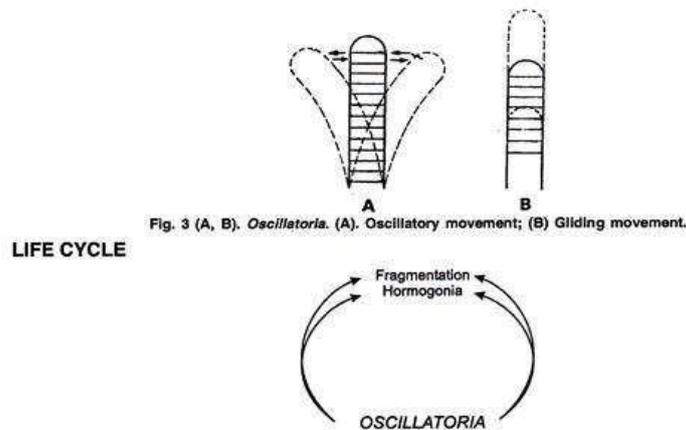


Fig 2.7 (A, B). *Oscillatoria*. (A). Oscillatory movement; (B) Gliding movement.

Genus: *Nostoc*

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

Nostoc is a genus of blue-green algae, also known as cyanobacteria, characterized by its prokaryotic cell structure and ability to perform oxygenic photosynthesis. These organisms are commonly found in freshwater environments where they form free-living colonies or attach to substrates such as rocks, the bottom of lakes, and even moist surfaces like tree trunks. *Nostoc* also exists in symbiotic relationships, notably as the algal partner in lichens and as an endosymbiont within certain bryophytes like *Anthoceros*. In these associations, they contribute nitrogen fixation, enriching the environment with bioavailable nitrogen.

As prokaryotes, *Nostoc* cells lack membrane-bound organelles, and their genetic material is dispersed within the cytoplasm. Due to their photosynthetic nature and cellular structure, they are classified within the cyanobacteria, a group often referred to as blue-green algae.

Notable Species of *Nostoc*.

***Nostoc commune*:** Edible species consumed as a salad in some cultures. ***Nostoc azollae*:** Forms a nitrogen-fixing symbiotic relationship with the water fern *Azolla*, enhancing its growth. ***Nostoc punctiforme*:** Engages in symbiotic relationships with *Anthoceros* and various higher plants, contributing to nitrogen input. ***Nostoc flagelliforme*:** Known as "Fat choy," it is a delicacy in China, where it is eaten as a vegetable. ***Nostoc pruniforme*:** Notable

for forming large gelatinous colonies that can reach up to 25 centimeters in diameter. *Nostoc* species play a vital ecological role in nitrogen fixation and primary production, making them essential components of both aquatic and terrestrial ecosystems.

Structure of the Thallus and Single Cell in *Nostoc*

The thallus of *Nostoc* is typically present in the form of a colony, often appearing as ball-like structures enveloped by a gelatinous sheath. These colonies are greenish to bluish-green in color and contain thousands of filaments or trichomes, which may be straight or twisted. Each trichome is enclosed within its sheath, collectively forming the filament. The trichomes are contorted and composed of numerous cells arranged in a beaded manner. Each cell is usually cylindrical or spherical. Among these cells are specialized, large, colorless cells known as **heterocysts**, which are generally intercalary but may be terminal in younger filaments. These heterocysts are characterized by the presence of two polar nodules. In addition, some cells become enlarged and serve as **akinetes**, which are thick-walled, food-filled resting cells, typically arranged in chains. (Fig 2.8).

A single cell of *Nostoc* is surrounded by a cellulose-based cell wall. The internal protoplast displays a typical Myxophyceean structure, with an inner, colorless **centroplasm** and an outer, pigmented **chromoplasm**. The chromoplasm contains photosynthetic pigments, proteinaceous cyanophycin granules, and cyanophyceean starch, while the centroplasm houses the incipient nucleus. This cellular arrangement supports the alga's photosynthetic activity and survival in varying environmental conditions. (Fig. 2.9 and 2.10).

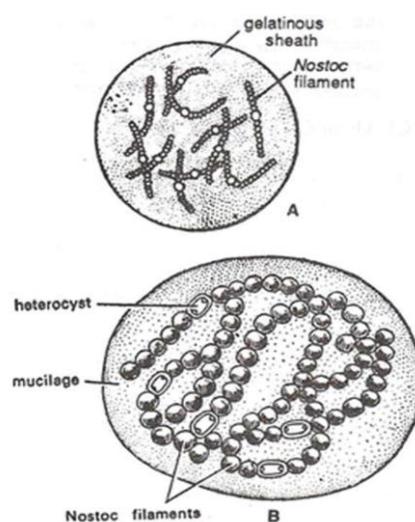


Fig. 2.8. *Nostoc*. A, Part of a colony under low power; B, Part of a colony under high power.

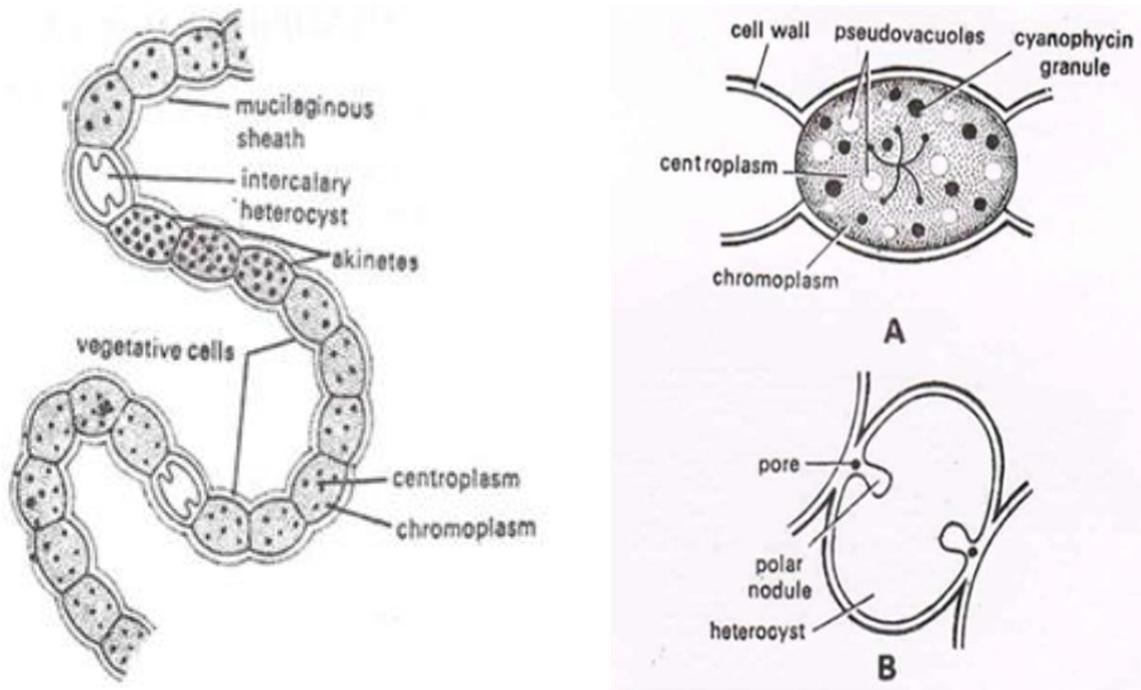


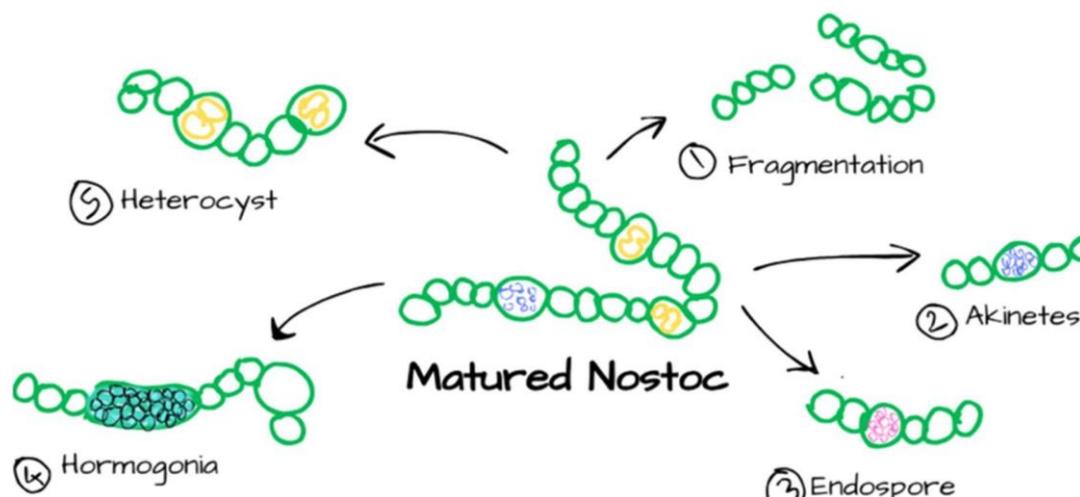
Fig. 2.10. *Nostoc*. A Single Vegetative Cell B. A Heterocyst.

Reproduction in *Nostoc*

Nostoc reproduces asexually, mainly through vegetative methods, as sexual reproduction is absent in cyanobacteria. The most common mode of reproduction is by fragmentation, where the filaments break into smaller pieces, each capable of growing into a new colony. Fragmentation often occurs naturally or due to external mechanical disturbances such as water currents, drying, or grazing by animals. Another important method of reproduction is through hormogonia, which are short segments of the trichome. These are formed by the degeneration of certain intercalary cells called necridia, which lead to the separation of the filament into smaller parts. These hormogonia are motile and can glide away from the parent colony to establish new colonies.

Nostoc also reproduces through **akinetes**, which are thick-walled, enlarged vegetative cells filled with food reserves. Akinetes are resistant to desiccation and harsh environmental conditions, and under favorable conditions, they germinate and develop into new filaments. Another reproductive structure seen in *Nostoc* is the **heterocyst**, which, although primarily involved in nitrogen fixation, may also help in the differentiation and survival of filaments. However, heterocysts do not directly produce new individuals. (Fig. 2.11)

Overall, *Nostoc* ensures its propagation and survival through simple yet effective vegetative means, especially suited to freshwater and moist terrestrial habitats.



Genus: Anabaena

Domain: Bacteria Kingdom: Eubacteria Phylum: Cyanobacteria Class: Cyanophyceae Order: Nostocales Family: Nostocaceae Genus: Anabaena.

Anabaena is a genus of filamentous blue-green algae, or cyanobacteria, distinguished from green algae by several key features. Unlike green algae, Anabaena lacks a true nucleus and membrane-bound organelles, as it is prokaryotic in nature. Its pigments, including green chlorophyll and blue phycobilins, are uniformly distributed throughout the cytoplasm rather than contained within specialized plastids. Morphologically, Anabaena forms unbranched filaments resembling a string of beads. These filaments are composed of barrel-shaped or bead-like vegetative cells, interspersed with larger, thick-walled, pale cells called heterocysts, which are specialized for nitrogen fixation.

A clear distinction between Anabaena and Nostoc is observed in their external structures. While both genera produce bead-like filaments, Anabaena's filaments are generally free-floating or attached to substrates, whereas Nostoc's filaments are embedded within a gelatinous matrix.

Anabaena Meaning and Ecological Role: Anabaena is commonly found as plankton in shallow water bodies and moist soils. It plays a vital ecological role in nitrogen fixation, contributing to soil fertility, particularly in aquatic and semi-aquatic environments. Species of Anabaena form symbiotic associations with certain plants, notably the mosquito fern (*Azolla*), where they fix atmospheric nitrogen to benefit the host plant.

Anabaena is one of the few cyanobacteria capable of producing neurotoxins, which are

harmful to wildlife, livestock, and pets. These toxins are believed to provide a defensive mechanism for the symbiotic plant partners by deterring herbivory.

Agriculturally, *Anabaena* has been effectively used as a **biofertilizer in paddy fields**, enhancing nitrogen availability and promoting sustainable agriculture. Its consistent nitrogen-fixing ability makes it a reliable natural fertilizer in rice cultivation.

From a research perspective, *Anabaena* serves as a model organism for studying cellular differentiation, particularly in the formation of heterocysts, which are key to understanding prokaryotic nitrogen fixation and cellular specialization.

Anabaena Structure

Anabaena is a genus of filamentous cyanobacteria (blue-green algae) characterized by its ability to perform both photosynthesis and nitrogen fixation. The structure of *Anabaena* is highly specialized to support these dual metabolic functions.

Anabaena filaments, also called **trichomes**, are long chains of connected cells that form the basic unit of its structure. These trichomes resemble a string of beads, where each bead is an individual cell. The filaments can be straight or gently curved, floating freely in water or forming mats.

The majority of the cells within a trichome are **vegetative cells**. These cylindrical cells contain chlorophyll-a and other pigments that capture light energy for photosynthesis, producing energy and glucose to sustain the colony. Vegetative cells also possess **gas vesicles**, which help regulate buoyancy, allowing the filament to position itself at optimal light levels in the water column.

Scattered among the vegetative cells are specialized nitrogen-fixing cells called **heterocysts**. These cells are typically larger and possess thickened walls. Heterocysts provide an anaerobic environment essential for nitrogen fixation, a process that converts atmospheric nitrogen (N_2) into ammonia (NH_3), making nitrogen available for the organism's metabolism. The thick cell wall and reduced oxygen permeability protect the oxygen-sensitive nitrogenase enzyme, ensuring the efficiency of nitrogen fixation.

The formation of heterocysts is regulated by environmental nitrogen availability. When nitrogen is abundant, fewer heterocysts are present. In contrast, under nitrogen-deficient

conditions, the number of heterocysts increases to meet the organism's nitrogen requirements. This specialized cellular arrangement enables *Anabaena* to thrive in nutrient-poor aquatic environments and engage in symbiotic relationships, making it an ecologically and agriculturally important genus.

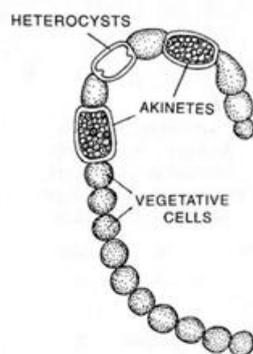


Fig 2.12 Filament.

Anabaena Characteristics

Anabaena is a genus of filamentous cyanobacteria, commonly known as blue-green algae, widely found in planktonic and freshwater environments. These organisms play an essential role in aquatic ecosystems and agricultural systems due to their ability to fix atmospheric nitrogen. The key characteristics of *Anabaena* include.

Anabaena forms elongated filaments called **trichomes**, composed of a series of bead-like cells aligned in a linear arrangement. These filaments give *Anabaena* its characteristic appearance, resembling a string of beads.

One of the most remarkable features of *Anabaena* is its ability to perform **nitrogen fixation**. This process converts atmospheric nitrogen gas (N_2) into ammonia (NH_3), a form of nitrogen that can be utilized by plants and other organisms. Nitrogen fixation plays a crucial role in enriching nutrient-deficient environments.

Specialized cells called **heterocysts** develop at regular intervals along the trichomes. These cells are larger and paler than vegetative cells and provide an anaerobic environment necessary for nitrogen fixation. Heterocysts protect the nitrogenase enzyme from oxygen, which would otherwise inhibit its function.

Anabaena is also capable of **photosynthesis**, producing its own food by capturing sunlight

and converting it into chemical energy. The photosynthetic pigments, including chlorophyll-a and phycobilins, give *Anabaena* its blue-green coloration.

Anabaena frequently forms **symbiotic relationships** with plants such as the mosquito fern (*Azolla*). In these mutualistic associations, *Anabaena* supplies the plant with fixed nitrogen, while the plant offers a protected habitat and nutrients.

Some species of *Anabaena* produce **toxins** that are harmful to humans, livestock, and wildlife. These toxins can cause various health problems such as liver damage, neurological disorders, respiratory issues, and skin irritation when contaminated water is ingested or contacted.

Anabaena commonly inhabits **freshwater environments**, such as ponds, lakes, and rivers, and may also grow in damp soils and wetlands.

Under nutrient-rich conditions, *Anabaena* can reproduce rapidly, leading to **algal blooms**. These blooms may form thick surface layers that discolor the water, reduce oxygen levels, and negatively impact other aquatic organisms, sometimes producing harmful toxins.

Anabaena: Prokaryotic or Eukaryotic?

Anabaena is a **prokaryotic** organism. Like all cyanobacteria, it belongs to the domain **Bacteria**, making it fundamentally different from eukaryotic organisms such as green algae. Prokaryotic cells, including *Anabaena*, possess the following characteristics.

- They can exist as **single-celled organisms or form colonies** (in the case of *Anabaena*, as filaments of cells).
- They **lack a true nucleus**; their genetic material (DNA) floats freely in the cytoplasm without a surrounding nuclear membrane.
- They **do not contain membrane-bound organelles**, such as mitochondria or chloroplasts.
- Their **cell wall** is simple and contains peptidoglycan, which gives structural support and protection.

Table 2.1: Examples of Anabaena Species.

Species	Key Features	Applications/Impact
<i>Anabaena azollae</i>	Forms symbiosis with <i>Azolla</i> fern; fixes atmospheric nitrogen.	Used as green manure in rice paddies to improve fertility.
<i>Anabaena variabilis</i>	Nitrogen-fixing filamentous cyanobacteria; forms heterocysts.	Studied as a biofertilizer and nitrogen-fixer.
<i>Anabaena flos-aquae</i>	Forms harmful algal blooms in freshwater; produces anatoxin-a toxin.	Monitored to prevent water pollution and health hazards.
<i>Anabaena cylindrical</i>	Cylindrical-shaped cells; efficient nitrogen fixation through heterocysts.	Important in aquatic nitrogen cycles; biofertilizer use.
<i>Anabaena sphaerica</i>	Spherical cells in chains; forms heterocysts for nitrogen fixation.	Used in research on cell differentiation and nitrogen fixation.

Anabaena Reproduction

Anabaena reproduces **asexually** through the following mechanisms.

- 1. Fragmentation:** The most common mode. Trichomes (filament chains) break into fragments, each capable of developing into a new filament, allowing rapid multiplication.
- 2. Akinete Formation:** Under harsh conditions (nutrient deficiency, desiccation), some vegetative cells transform into akinetes—thick-walled, dormant cells. Akinetes can survive unfavorable environments and regenerate into active filaments when conditions improve.
- 3. Heterocysts (Not reproductive but functionally essential):** Specialized cells for nitrogen fixation. Heterocysts create a micro-anaerobic environment essential for nitrogenase enzyme activity, helping Anabaena thrive in nitrogen-poor habitats.

Though primarily asexual, some **horizontal gene transfer** has been observed, allowing genetic material exchange between strains, but this is not considered true sexual reproduction.

Functions of Anabaena

Anabaena, a genus of filamentous cyanobacteria (blue-green algae), plays a crucial role in both ecological balance and agricultural productivity. These free-living prokaryotic organisms inhabit freshwater, saltwater, and moist terrestrial environments. Their primary biological functions include **nitrogen fixation** and **photosynthesis**, which contribute significantly to nutrient cycling and energy production in ecosystems.

1.3 Significance of Nitrogen Fixation

1. Nitrogen Fixation

One of *Anabaena*'s most important ecological functions is its ability to fix atmospheric nitrogen (N_2) into ammonia (NH_3), a form of nitrogen that plants and other organisms can use. This process helps replenish nitrogen levels in ecosystems where nitrogen is often a limiting nutrient.

Heterocysts: Specialized, thick-walled cells called heterocysts provide an anaerobic environment essential for nitrogen fixation. These cells protect nitrogenase, the oxygen-sensitive enzyme, from inactivation.

- **Nitrogenase Enzyme:** Within heterocysts, the nitrogenase enzyme breaks the strong triple bond of nitrogen molecules (N_2), converting them into ammonia (NH_3). This ammonia is then used by *Anabaena* and other organisms to build amino acids and proteins.
- Ecological Role.

Nitrogen Cycle: *Anabaena* contributes to the nitrogen cycle by replenishing bioavailable nitrogen in aquatic and soil ecosystems.

Symbiosis: In symbiotic relationships (e.g., with the aquatic fern *Azolla*), *Anabaena* supplies nitrogen to the host plant while benefiting from shelter and nutrients.

Usage: The fixed nitrogen is incorporated into essential biomolecules like amino acids, nucleic acids, and chlorophyll.

2. Photosynthesis: *Anabaena*, like other cyanobacteria, performs oxygenic photosynthesis, contributing to primary production in aquatic ecosystems.

- **Vegetative Cells:** Most of the filament consists of vegetative cells containing chlorophyll-a and phycobiliproteins that capture light energy.
- Photosynthetic Process.

Uses **sunlight**, **water (H_2O)**, and **carbon dioxide (CO_2)** to produce **glucose** and other carbohydrates through the **Calvin cycle**.

As a byproduct, oxygen (O_2) is released into the environment, supporting aerobic life forms. Additional Ecological Impact.

Toxin Production: Some *Anabaena* species can produce harmful toxins under certain environmental conditions, which may negatively affect wildlife and humans. However, their

primary ecological contributions are positive.

Environmental Significance: By fixing nitrogen and producing oxygen, *Anabaena* enhances soil fertility, sustains aquatic food chains, and contributes to ecosystem productivity.

Nitrogen Fixation by *Anabaena*

Anabaena demonstrates a specialized mechanism for nitrogen fixation that allows it to thrive in nitrogen-poor environments. This process involves the differentiation of vegetative cells into **heterocysts**, which create an environment suitable for nitrogenase activity. The overall process is a fine example of cellular specialization and metabolic cooperation.

When nitrogen becomes scarce in the environment, certain vegetative cells along *Anabaena*'s filament transform into **heterocysts**, typically spaced at regular intervals. These heterocysts lose the ability to divide and photosynthesize oxygen but gain the ability to fix atmospheric nitrogen (N_2) into **ammonium** (NH_4^+).

Several adaptations in heterocysts create a **micro-oxic (low oxygen) environment**, essential because nitrogenase—the enzyme complex responsible for nitrogen fixation—is inactivated by oxygen. These adaptations include.

Inactivation of Photosystem II (PSII): Prevents the production of oxygen through photosynthesis.

Increased respiration rates: Consumes any residual oxygen.

Thickened cell walls: Act as a barrier to oxygen diffusion.

Inside heterocysts, nitrogenase uses energy in the form of ATP and reducing power (electrons) from carbohydrate metabolism to convert atmospheric nitrogen gas into ammonium. This energy is derived from **Photosystem I (PSI)** activity, and the necessary carbohydrates (likely in the form of glucose) are synthesized in the surrounding vegetative cells and transported into the heterocysts.

Once fixed, the nitrogen is converted into amino acids and transported back to the vegetative cells, where it supports protein synthesis and growth. This **metabolic exchange** allows the entire filament to benefit from nitrogen fixation, even though only a few cells perform the process.

Symbiosis with Azolla

The fern **Azolla** forms a symbiotic relationship with **Anabaena azollae**, which resides in cavities of Azolla's leaves. Anabaena azollae fixes atmospheric nitrogen, supplying the plant with essential nutrients, while Azolla provides carbohydrates and shelter. This relationship allows Azolla to rapidly colonize freshwater environments, sometimes doubling its biomass every **1.9 days**, especially in phosphorus-rich waters caused by chemical runoff. Unique among plant-microbe partnerships, the Azolla-Anabaena symbiosis is vertically transmitted: the cyanobacterium is passed from one plant generation to the next, and over time, many of Anabaena's genes have been either lost or transferred to the host's nucleus, reflecting their mutual dependence.

Fatty Acid Composition in Anabaena and Nostoc

To differentiate between strains of nitrogen-fixing cyanobacteria such as **Anabaena** and **Nostoc**, researchers analyzed their cellular fatty acids. Using gas-liquid chromatography-mass spectrometry (GLC-MS), they identified distinct fatty acid profiles across 20 strains cultured for 12 days in BG-110 medium, a nitrogen-free medium commonly used for cyanobacteria. Fatty acid profiling serves as a biochemical marker, helping classify and understand the diversity of cyanobacteria involved in nitrogen fixation.

EXERCISE

I Short Answer Questions (5–6 sentence answers expected).

1. What are the main pigments found in Cyanophyceae, and how do they help in photosynthesis?
2. What are heterocysts, and what is their function in nitrogen fixation in Cyanophyceae?
3. Mention the economic importance of Cyanophyceae in agriculture and food production.
4. What is an algal bloom, and how do Cyanophyceae contribute to water pollution?
5. What is the geological significance of cyanobacteria in the early history of the Earth?
6. Differentiate between vegetative and asexual reproduction in Cyanophyceae with examples.
7. What is the ecological impact of Microcystis blooms in freshwater bodies?
8. Describe the role of gas vacuoles in the buoyancy of Microcystis colonies.
9. Explain the structural differences between the cells of Oscillatoria and Microcystis.
10. What are heterocysts in Nostoc, and how do they contribute to nitrogen fixation?
11. Describe the significance of hormogonia formation in the reproduction of Oscillatoria and

Nostoc.

12. How do Anabaena and Azolla form a symbiotic relationship, and what is its agricultural importance?

II Essay Questions (Write 1–2 pages each)

1. Describe the classification, thallus organization, and structural diversity of Cyanophyceae.
2. Explain the nitrogen fixation process in Cyanophyceae and its ecological importance.
3. Discuss the ecological and economic importance of Cyanophyceae in detail.
4. Write an essay on the modes of reproduction in Cyanophyceae and their survival advantages.
5. Explain the evolutionary origin of Cyanophyceae and their affinities with other algal and bacterial groups.

UNIT III: CHLOROPHYCEAE (GREEN ALGAE)

Chlorophyceae, commonly called green algae, are a group of simple, photosynthetic eukaryotic organisms that exhibit a bright green coloration. This green color results from the abundance of chlorophyll pigments, particularly chlorophyll a and chlorophyll b, which overshadow other pigments such as carotenoids and xanthophylls. These pigments enable green algae to capture sunlight efficiently and carry out photosynthesis, contributing significantly to oxygen production and primary productivity in aquatic ecosystems.

The classification of green algae has been revised by several scientists over time. Originally, in 1935, Fritsch categorized them under the class Chlorophyceae. Later, taxonomists including Smith in 1938, Tippo in 1942, and Bold in 1950 proposed elevating green algae to the division level, naming it Chlorophyta. In subsequent years, Prescott in 1969 and Round in 1973 treated this group as a phylum, calling it Chlorophyta. An alternative name, Chlorophycophyta, was suggested by Papenfuss in 1946, using the suffix "-phyco," a classification approach that was later supported by Bold and Wynne in 1978. Despite these various proposals, for clarity and continuity, the present discussion follows the original classification of Fritsch, maintaining Chlorophyceae as a class.

The group Chlorophyceae is extensive and diverse, comprising roughly 425 genera and about 6,500 species. However, the actual number of species may be significantly higher. According to Prescott in 1969, the total number of green algae species could reach up to 20,000, as many new species are still being discovered through ongoing taxonomic studies. This diversity reflects the ecological adaptability and evolutionary success of green algae in a wide range of environments across the globe.

1.1 General Account Occurrence of Chlorophyceae

Green algae are widely distributed across various habitats, with nearly **90% of species** found in **freshwater** environments such as ponds, lakes, and rivers.

1. Aquatic Habitats

Green algae belonging to the class Chlorophyceae predominantly inhabit aquatic environments, showing considerable diversity in their habitat preferences. Some groups are strictly confined to freshwater bodies such as ponds, lakes, rivers, and streams. Notable examples include members of the order Conjugales, such as *Spirogyra* and *Zygnema*, and the

order Oedogoniales, represented by the genus Oedogonium. These algae thrive in freshwater ecosystems and contribute significantly to the primary productivity of these habitats.

In contrast, certain groups of green algae are predominantly marine and are commonly found in coastal waters and shallow seas. The Ulvaceae, which includes the sea lettuce *Ulva*, and members of the Siphonales, are typical examples of green algae adapted to marine conditions, where they form important components of marine algal communities.

Some green algae exhibit remarkable ecological flexibility and can be found in both freshwater and saline environments. This adaptability is observed in members of the Volvocales, Chaetophorales, and Cladophorales. These algae are capable of tolerating varying salinity levels, allowing them to colonize a wide range of aquatic habitats, from freshwater bodies to brackish and even coastal marine waters.

2. Terrestrial and Other Habitats

Apart from aquatic habitats, green algae of the class Chlorophyceae are also found in various terrestrial and specialized environments. Some species grow on damp soil surfaces, where moisture is sufficient to support their growth. These algae are referred to as subaerial forms, and common examples include *Ulothrix* and *Vaucheria*, which form green coatings on moist soil, rocks, and walls.

Certain green algae live on the surfaces of plants, a habitat known as epiphytic. *Trentepohlia* is a well-known epiphytic genus often found covering tree trunks and leaves with an orange or reddish layer, a coloration caused by the presence of carotenoids. These algae do not harm the plants they grow on but use them as a surface for attachment.

In some cases, green algae are found living on animals, known as epizoic algae. *Characium* and *Cladophora* are examples of such algae that attach themselves to the bodies of aquatic animals like snails and turtles, without causing harm.

A few green algae live inside the tissues of higher plants, referred to as endophytic forms. *Chlorella* is one such genus that can be found inhabiting the internal spaces of aquatic plants like *Hydrilla*, where it exists in a symbiotic relationship.

Some green algae are parasitic or pathogenic, infecting plant tissues and sometimes causing visible disease symptoms. *Cephaleuros* is a parasitic alga responsible for red rust disease in

tea and other crops. Similarly, Rhodochytrium and Phyllosiphon invade plant tissues, living parasitically and sometimes disrupting the normal functioning of the host plants.

These diverse habitats reflect the adaptability of Chlorophyceae, allowing them to thrive in a wide range of ecological niches beyond aquatic environments.

Pigmentation

Members of the class Chlorophyceae possess a distinct set of pigments that give them their characteristic green color and enable them to perform photosynthesis efficiently. The primary pigments present in these algae are chlorophyll a and chlorophyll b. These pigments play a central role in capturing light energy, with chlorophyll b extending the range of light wavelengths that the algae can use for photosynthesis.

In addition to the primary pigments, Chlorophyceae contain accessory pigments that assist in light absorption and also protect the cells from photodamage. These accessory pigments include β -carotene and various types of xanthophylls such as lutein, neoxanthin, violaxanthin, and zeaxanthin. These pigments help absorb additional light wavelengths that chlorophylls cannot capture effectively, enhancing the algae's ability to photosynthesize under different light conditions.

Some species of green algae produce special pigments, which may vary depending on the ecological habitat or the physiological state of the organism. Examples of such special pigments include astaxanthin, siphonoxanthin, and siphoncin. These pigments often serve protective functions, helping the algae survive under conditions of intense light or other environmental stresses. Together, these pigments not only support photosynthesis by capturing and transferring light energy but also protect the algal cells from the harmful effects of excessive light exposure, ensuring the algae's survival and productivity in diverse environments.

Storage Products

In members of the Chlorophyceae, the primary storage product of photosynthesis is starch. This starch consists of two polysaccharides, amylose and amylopectin, and is stored within the chloroplasts. The accumulation of starch serves as an energy reserve, which the algae utilize during periods of low light or unfavorable conditions.

In addition to starch, some species of green algae, particularly those adapted to stressful or

variable environments, also store oils. These oils act as alternative energy reserves and may help the cells maintain buoyancy or cope with osmotic stress. The presence of both starch and oils as storage products highlights the adaptive strategies of Chlorophyceae to survive in a wide range of ecological conditions.

Flagellation: Motile cells bear:

- **1 to several flagella**, typically of equal length
- Flagella are **apically or subapically inserted** and of **whiplash (acronematic) type**
- Flagella exhibit the **9+2 microtubule arrangement** under electron microscopy

Diversity and Distribution: Estimated **360 genera** and **5,700+ species**, **90%** are freshwater; **10%** marine. Examples: *Vaucheria* rocks in mountain streams, *Coleochaete* – on aquatic plants and *Cladophora* on mollusc shells *Trentepohlia* aerial, on rocks and tree trunks, *Chlamydomonas nivalis* red snow in cold regions, *Cephaleuros* – parasitic, causes red rust of tea *Siphonales* – marine, shallow water.

Range of Thallus Structures: Chlorophyceae show great variability in body structure:

1. **Motile Unicellular Forms** *Chlamydomonas*, *Phacotus*
2. **Colonial Forms:** *Gonium* (4–16 cells), *Pandorina* (8 cells), *Eudorina* (32 cells), *Volvox* (500–50,000 cells; most advanced)
3. **Palmelloid Forms:** Temporary: *Chlamydomonas*, Permanent: *Tetraspora*
4. **Cocoid (Non-motile Unicellular) Forms:** Common in *Chlorococcales* **Filamentous Forms:** **Unbranched:** *Ulothrix*, *Spirogyra*, *Oedogonium* **Branched:** *Cladophora* **Heterotrichous:** *Chaetophorales*
5. **Siphonous (Coenocytic) Forms:** Large, multinucleate, aseptate: *Valonia*, *Caulerpa*, *Codium*
6. **Uniaxial Forms:** Seen in *Chara*, with a single axis surrounded by a sheath
7. **Parenchymatous Forms:** Sheet-like structures, e.g., *Ulva* ("sea lettuce")

Cellular Structure

The cellular structure of Chlorophyceae displays a range of adaptations suited to their aquatic and occasionally terrestrial lifestyles. The cell wall in these algae is typically composed of two to three distinct layers. The innermost layer is made up of cellulose, providing structural support, while the middle layer consists of pectin, which contributes to the cell wall's flexibility and permeability. In some species, the outer layer may vary in composition: it may

be chitinous, as observed in *Oedogonium* and *Cladophora*, or mucilaginous, as seen in *Spirogyra*, which helps protect the cells from desiccation and external damage. In a few primitive forms of green algae, a true cell wall is absent, reflecting their simpler structure.

The protoplasm of Chlorophyceae cells contains various organelles essential for cellular function. A large central vacuole is present in filamentous forms, helping to maintain cell turgor. In contrast, motile cells possess contractile vacuoles, which are involved in osmoregulation and the removal of excess water. In colonial forms like *Volvox*, plasmodesmata connect the cells, allowing cytoplasmic continuity, although such structures are typically absent in most filamentous algae.

Chloroplasts, the photosynthetic organelles, display a wide variety of shapes that are often characteristic of the genus. In *Chlamydomonas*, the chloroplast is cup-shaped; in *Zygnema*, it is stellate; in *Spirogyra*, it forms spiral or ribbon-like structures. Reticulate chloroplasts are seen in *Oedogonium* and *Cladophora*, discoid chloroplasts in *Ulva*, and *Mougeotia* exhibits a unique chloroplast that can rotate within the cell to optimize light absorption.

Pyrenoids, which are associated with starch synthesis, are present in most Chlorophyceae species. These structures vary in form, ranging from simple pyrenoids to compound types found in *Tetraspora* and *Enteromorpha*. Some species, such as *Chara* and *Vaucheria*, lack pyrenoids entirely. In certain cases, polar pyrenoids with an incomplete starch sheath are observed.

The pigments found in Chlorophyceae include primary pigments chlorophyll a and b, which are essential for photosynthesis. Accessory pigments such as β -carotene and various xanthophylls like lutein and zeaxanthin broaden the spectrum of light absorption. Some species contain special pigments; for example, *Trentepohlia* has haematochrome, giving it an orange-red coloration, while *Zygnema pectinatum* may contain fucoxanthin, a pigment more commonly associated with brown algae.

The nucleus in Chlorophyceae is usually uninucleate, with each cell containing a single nucleus. However, some genera, such as *Cladophora* and members of the order Siphonales, are multinucleate. Both mitosis and meiosis occur during the algae's life cycle, facilitating growth and reproduction. In motile forms, the flagellar and sensory apparatus are well-developed. Flagella arise from the neuromotor apparatus at the anterior end of the cell.

Typically, two acronematic (whiplash) flagella are present, and electron microscopy reveals a characteristic 9+2 arrangement of microtubules, with nine doublets surrounding two central singlets. The base of the flagella consists of components such as the blepharoplast, paradesmose, and rhizoplast, which support the flagellar structure and function.

An eyespot or stigma is present in motile unicellular forms like *Chlamydomonas* and colonial forms like *Volvox*. This photoreceptive organelle enables the algae to detect light, allowing them to move towards or away from it in a response called phototaxis. Contractile vacuoles, found in these motile forms, serve important roles in osmoregulation and excretion. They are usually located at the anterior end of the cell, near the flagella.

These structural adaptations enable Chlorophyceae to survive and thrive in a variety of ecological niches, performing essential biological functions necessary for their growth, reproduction, and environmental interaction.

Reproduction in Chlorophyceae (Green Algae): Chlorophyceae exhibit **three types of reproduction**.

Vegetative, Asexual, and Sexual

1. Vegetative Reproduction: This is the **simplest form of reproduction**, involving the **division or fragmentation** of the thallus without the formation of spores or gametes.

Modes of Vegetative Reproduction.

- **Fragmentation:** The thallus breaks into two or more parts, each growing into a new individual. *Examples: Ulothrix, Spirogyra, Oedogonium.*
- **Cell Division:** In unicellular forms, simple mitotic division produces new individuals.

Example: Chlorella, Protococcus.

- **Bulbils:** Small, bulb-like outgrowths that separate and grow into new plants.

Seen in: Chara.

- **Amylum Stars:** Star-shaped starch-storing bodies function as vegetative propagules.

Seen in: *Chara*.

- **Protonemal Outgrowths:** Secondary protonema can develop into mature individuals.

Seen in: *Chara*.

- **Tubers:** Underground storage bodies that sprout into new plants. *Example:* *Chara*.
- **Hormogonia** (in some cyanophycean members associated with Chlorophyceae-like traits): Short filaments that detach and grow independently.
- **Akinetes** (also classified under asexual in some texts): Thick-walled resting cells capable of germination.

2. Asexual Reproduction

This method involves **spore formation** and occurs during favorable or sometimes unfavorable conditions.

Types of Asexual Spores.

- **Zoospores: Flagellated, motile spores** formed inside a sporangium. May be biflagellate (2), quadriflagellate (4), or multiflagellate. Capable of swimming and settling to develop into a new thallus. *Examples:* *Chlamydomonas*, *Ulothrix*, *Oedogonium* (*stephanokont type*), *Vaucheria* (*compound/coenozoospores*).
- **Aplanospores:** Non-motile spores formed under stress or unfavorable conditions. May be spherical or ovoid. Germinate directly into new plants. *Seen in:* *Chlorella*, *Ulothrix*.
- **Autospores:** Non-motile spores that resemble the parent cell. Produced inside the parent cell and released after cell wall rupture. *Seen in:* *Scenedesmus*, *Chlorococcum*, *Chlorella*.
- **Hypnospores:** Thick-walled, resting aplanospores adapted to survive harsh conditions.

Germinate under favorable conditions. *Example:* *Pediastrum*.

- **Palmella Stage:** Occurs when motile cells lose their flagella and become embedded in mucilage. Can act as a temporary or permanent reproductive strategy. *Temporary:* *Chlamydomonas*; *Permanent:* *Palmella*.
- **Daughter Colonies:** New colonies formed within the mother colony, released after its rupture. *Example:* *Volvox*.
- **Coenobia:** Fixed number of cells in a colony, reproducing asexually to form similar colonies. *Example:* *Pediastrum*, *Scenedesmus*.

3. Sexual Reproduction

This type involves the **fusion of gametes** and shows great diversity in Chlorophyceae.

Types of Sexual Reproduction.

- **Isogamy:** Gametes are **morphologically identical**, usually flagellated. Fusion produces a zygote that forms a zygospore. *Examples: Chlamydomonas reinhardtii, Ulothrix.*

Anisogamy: Fusion of **dissimilar-sized gametes**, both usually motile. Larger = female, smaller = male. *Example: Chlamydomonas braunii.*

Oogamy: Advanced type of sexual reproduction. Large, non-motile egg (female) fuses with small, motile sperm (male). Zygote forms a thick-walled zygospore. *Examples: Volvox, Oedogonium.*

Aplanogamy (Conjugation): Non-flagellated amoeboid gametes fuse by physical contact or conjugation tube. No motility involved.

Typical of **Conjugales** (Zygnematales). *Examples: Spirogyra, Zygnema.*

- **Parthenogenesis:** Development of a female gamete **without fertilization**. Results in **parthenospores** or **azygospores**. *Seen in: Ulva lactuca, Spirogyra (sometimes).*

Post-Fertilization Stage: Zygospore Formation: The result of gamete fusion. Often thick-walled, resistant, and acts as a **resting spore**.

Germination: Zygospore undergoes **meiosis** to form haploid cells. Each can develop into a new thallus.

Classification of Chlorophyceae (Green Algae)

Chlorophyceae belongs to the **Division: Chlorophyta**, characterized by:

- Chlorophyll a and b, Starch as food reserve, Cellulose in the cell wall, Flagella when present are equal and apical

1. Classification by Dr. F. E. Fritsch (1944)

This is one of the classical and widely accepted classifications. It is **based on vegetative structure and reproductive features**.

Class: Chlorophyceae: Contains **nine orders**:

1. **Volvocales** – Motile unicellular and colonial forms (e.g., *Volvox, Chlamydomonas*)
2. **Chlorococcales** – non-motile unicellular/colonial forms (e.g., *Chlorella, Scenedesmus*)
3. **Ulotrichales** – Simple unbranched filaments (e.g., *Ulothrix*)
4. **Cladophorales** – Branched filaments with multinucleate cells (e.g., *Cladophora*)

5. **Oedogoniales** – Filaments with apical growth and stephanokont flagella (e.g., *Oedogonium*)
6. (Missing in list but commonly added) **Chaetophorales** – Branched filaments with setae (e.g., *Draparnaldia*)
7. **Conjugales** – Aplanogamous sexual reproduction via conjugation (e.g., *Spirogyra*, *Zygnema*)
8. **Siphonales** – Tubular coenocytic (multinucleate) thalli (e.g., *Caulerpa*, *Codium*)
9. **Charales** – Complex structures with nodes, internodes, and reproductive organs (e.g., *Chara*)

Note: Fritsch treated **Charales** under Chlorophyceae, but later phycologists considered it as a separate class (Charophyceae).

Table 3.1: Comparison of Classifications of Algae.

Classification	Chlorophyceae Orders	Charophyceae Orders	Key Features
F.E. Fritsch (1944)	9 Orders (e.g., Volvocales, Oedogoniales, Cladophorales, Conjugales, Charales)	(Included Charales in Chlorophyceae)	Based on vegetative & reproductive bodies
G.M. Smith	10 Orders	1 Order (Charales)	Structural and reproductive distinctions
V.J. Chapman (1962)	8 Orders	1 Order (Charales)	Charales separated for its complexity

2. Classification by Gilbert M. Smith He divided **Division Chlorophyta** into **two distinct classes**:

A. Class: Chlorophyceae (10 Orders)

1. Volvocales, 2. Tetrasporales 3. Ulotrichales 4. Oedogoniales 5. Ulvales 6. Schizogoniales 7. Chlorococcales 8. Siphonales 9. Siphonocladales 10. Zygnematales

B. Class: Charophyceae: Contains only one order.

Charales: Note: Gilbert Smith emphasized the reproductive and structural uniqueness of Charales to separate them from true Chlorophyceae.

3. Classification by V. J. Chapman (1962): Chapman also divided **green algae** into two classes: **A. Class: Chlorophyceae**

1. Volvocales 2. Chlorococcales 3. Ulotrichales 4. Oedogoniales 5. Chaetophorales 6. Siphonocladales 7. Dasycladales 8. Conjugales

B. Class: Charophyceae

1. Charles

Note: Chapman emphasized separating Characeae from other green algae due to their advanced thallus organization and reproductive structures like higher plants.

1.2 Economic Importance of Green Algae (Chlorophyceae)

Although green algae do not play a major role in direct human food consumption, they contribute significantly to various sectors such as food, agriculture, industry, environment, and biotechnology. Below are the key areas where green algae are economically important.

1. As Food: Limited but Growing Use in Human Diets.

***Ulva lactuca* (Sea lettuce):** Eaten as a salad or cooked as a leafy vegetable in coastal regions.

Enteromorpha species: Also used in salads and soups. **Spirogyra** and **Oedogonium:** Filamentous green algae occasionally used in soup preparations, especially in rural or traditional cuisines.

Nutritional Potential: Green algae are rich in proteins, vitamins (especially B12), essential amino acids, minerals, and antioxidants. *Chlorella* (a unicellular green alga) is cultivated commercially and consumed as a nutritional supplement in powder or tablet form due to its high protein and chlorophyll content.

Future Food Source: With growing concerns about global food security, research is underway to include green algae like *Chlorella* and *Scenedesmus* as alternative protein sources in human diets. Countries like Japan, Thailand, and Israel are investing in mass cultivation of green algae as a sustainable food solution.

2. In Aquaculture and Animal Feed: Algae are used as a primary food source in aquaculture: Fed to fish larvae, mollusks, and crustaceans in hatcheries. *Chlorella* and *Scenedesmus* are particularly important in aquaculture for enhancing growth and survival of aquatic organisms. Incorporated into poultry and livestock feed to improve digestibility, immunity, and nutritional quality.

3. Industrial and Pharmaceutical Applications

Pigments and Dyes: Green algae contain chlorophyll and carotenoids, which are used in natural food colorants, cosmetics, and medicines.

Bioactive Compounds: Extracts from green algae show antioxidant, antimicrobial, and antiviral properties, offering potential in drug development and herbal formulations.

4. Agriculture and Soil Fertility: Algal biofertilizers (like *Chlorella*) are used to enhance soil fertility by: Fixing atmospheric nitrogen (indirectly), Adding organic matter to the soil, promoting microbial activity. Some green algae also act as weed suppressors and help in soil reclamation of saline and degraded lands.

5. Environmental Importance: Oxygen Production: Through photosynthesis, green algae contribute significantly to the **oxygenation of water bodies**, supporting aquatic life.

- **Wastewater Treatment:** Green algae help in the **bio-removal of heavy metals and toxins** from industrial effluents and sewage. Used in **algal ponds** for **eco-friendly water purification**.

6. Research and Biotechnology: Green algae serve as **model organisms** in scientific studies related to: Photosynthesis, Cell biology, and Genetic engineering

Chlamydomonas reinhardtii, a green alga, is extensively used in **genetic and molecular research**.

7. Biofuel Production: Green algae like *Chlorella* and *Scenedesmus* are being studied for biofuel production (algal biodiesel) due to their high **lipid content** and fast growth rates.

Order: Volvocales

The order **Volvocales** belongs to the class **Chlorophyceae** of green algae. It includes a wide range of organisms, from unicellular to colonial forms, and is considered significant in studying the evolution of multicellularity.

General Characteristics

1. Diversity: The order comprises approximately **60 genera and 500 species**. The members of this order show a wide range of structural organization—from unicellular forms to highly organized colonies.

2. Thallus Structure: The thallus may be **unicellular** (e.g., *Chlamydomonas*) or **colonial** (e.g., *Volvox*, *Pandorina*, *Eudorina*, *Pleodorina*). Colonies may range from a few cells to thousands of cells organized in specific patterns.

3. Habitats: Most members are **freshwater** organisms, found in ponds, ditches, and lakes.

4. Motility: In the sub-order **Chlamydomonadineae**, the forms are **motile throughout life**. In the sub-order **Tetrasporineae**, they form **sedentary palmelloid colonies**. In the sub-order **Chlorodendrineae**, they form **dendroid or branched colonies**.

5. Chloroplasts: Each cell typically contains a **basin-shaped or cup-shaped**

chloroplast with **one or more pyrenoids**, which are involved in starch storage.

- 6. Asexual Reproduction:** Occurs through **biflagellate zoospores, aplanospores**, or palmelloid stages.
- 7. Sexual Reproduction:** Shows a range of reproductive strategies from **isogamy** (fusion of morphologically similar gametes) to **oogamy** (fusion of a large non-motile egg with a small motile sperm). Most species are **haploid**, and the **zygote formation is followed by meiosis** during germination.

Classification of Volvocales: The order is divided into three sub-orders.

Sub-order: Chlamydomonadineae (Motile forms) Families: *Chlamydomonadaceae* (e.g., *Chlamydomonas*, *Volvox*, *Eudorina*), *Sphaerellaceae*, *Polyblepharidaceae*, *Phacotaceae*.

Sub-order: Tetrasporineae (Sedentary, palmelloid forms) Families: *Tetrasporaceae* *Palmellaceae*.

Sub-order: Chlorodendrineae (Dendroid forms) Family: *Chlorodendraceae*

Family: Volvocaceae: This family includes **motile colonial green algae**. **Characteristics.**

- Colonies may be **disc-shaped or spherical**, with a **definite number of cells**, usually a **multiple of two** (e.g., 4, 8, 16, 32, etc.).
- All or certain cells of the colony may undergo division simultaneously to form **daughter colonies**.
- Sexual reproduction may be **isogamous, anisogamous, or oogamous**.

3.2 Structure and Reproduction in Selected Genera

- Pandorina*, *Volvox* – Colonial, motile, oogamous reproduction
- Oedogonium* – Filamentous, oogamous, macrandrous/nannandrous types *Chara*
Complex thallus, reproductive organs resemble higher plants

3.3 Structure and Reproduction in Selected Genera

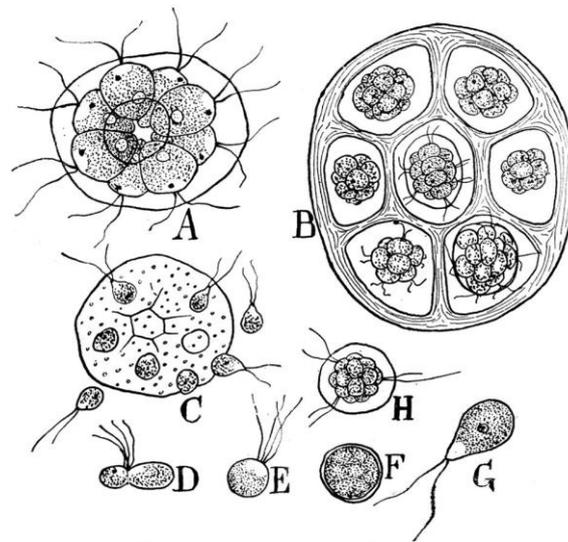
Habitat and Occurrence

Genus: *Pandorina*

Kingdom: Plantae Division: Chlorophyta Class: Chlorophyceae Order: Volvocales Family: Volvocaceae Genus: *Pandorina*

Pandorina, named after the mythical "Pandora's box" due to the compact arrangement of its

cells within a mucilaginous envelope, is a small genus of green algae. It includes approximately three recognized species that inhabit freshwater environments such as ponds, ditches, and temporary water bodies. These algae prefer stagnant or slow-moving water where they can float freely. Despite their wide geographical distribution, *Pandorina* colonies are generally found in low densities and are not typically dominant in algal communities. Their presence is seasonal and may vary depending on environmental factors like nutrient availability and temperature.



3.1 *Pandorina* life cycle in a simple format with just the stage names (A to H).

A. Colony of plants (Vegetative colony) **B.** Each plant divides to form a new colony (Asexual reproduction). **C.** Plants of a colony escape as gametes (Gamete formation) **D.** Conjugation of two gametes of unequal size (Anisogamy). **E.** Later stage of conjugation (Zygote formation) **F.** Gametospore or resting spore **G.** Large zoospore formed from the gametospore (After germination) **H.** Colony formed by the division of the zoospore (New vegetative colony)

Structure and Morphology: The organism forms coenobia (colonies) of 4, 8, 16, or 32 biflagellate cells.

- These cells are embedded in a gelatinous matrix, often surrounded by an outer watery sheath.
- The colonies are usually spherical or ellipsoidal in shape.
- Cells are arranged in a hollow sphere within the colony and are often flattened laterally due to compression.
- Each cell is obpyriform (inverted pear-shaped), with the anterior end bearing two flagella

and a distinct eyespot.

- The chloroplast is large and cup-shaped, usually with one or more pyrenoids.
- Cells are interconnected by protoplasmic strands.

Asexual Reproduction in *Pandorina*

- All cells in a colony divide simultaneously to form daughter coenobia.
- Before reproduction, the colony becomes inactive, sinks to the bottom of the water body, and the gelatinous matrix becomes waterier and more swollen.
- Each cell forms a plakea (a bowl-shaped cell plate).
- The plakea inverts, and the new colony becomes spherical with the phialopore (opening) closed.
- Each daughter cell develops two flagella and swims out of the parental matrix as a new colony.

Genus: *Volvox*

The salient features of *Volvox* are as follows

Division: Chlorophycophyta, **Class:** Chlorophyceae, **Order:** Volvocales, **Family:** Volvocaceae, **Genus:** *Volvox*, *Volvox* is a genus comprising approximately 20 known species. The plant body of *Volvox* is a multicellular, motile coenobium, characterized by a globose or spherical hollow structure. The coenobium consists of numerous biflagellate, pear-shaped cells that are arranged in a single peripheral layer. These cells are interconnected by protoplasmic strands, allowing coordination among them. In the young coenobium, only vegetative cells are present, which function mainly in food production and locomotion. As the coenobium matures, both vegetative and reproductive cells are found, with reproductive cells differing in structure and function from the vegetative ones. Starch serves as the reserve food material in *Volvox*. Asexual reproduction takes place through specialized, enlarged cells known as gonidia. Sexual reproduction is oogamous, meaning it involves the fusion of distinct male and female gametes. Depending on the species, the coenobia may be homothallic, as seen in *Volvox globator*, or heterothallic, as in *Volvox aureus*. Female gametes are large, non-motile cells produced singly within the oogonium. Male gametes are spindle-shaped, narrow cells with a pair of apical cilia, produced in bunches within the antheridium.

Occurrence of *Volvox*

Volvox is a genus of about 20 species, which occur in colonies. It grows as plankton on the

surface of water bodies like temporary and permanent freshwater tanks, ponds, pools, and lakes. The Volvox colonies appear as minute floating balls on the surface of the water. During the spring and rainy seasons, the water surface becomes green due to its rapid growth.

Thallus Structure of Volvox

The plant body of Volvox is a motile coenobium (a colony with a definite shape and number of cells). The coenobium is a hollow sphere of mucilaginous substance.

At the periphery of the hollow sphere, a specific number of cells are arranged in a single layer. The number of cells may vary from 500 to 60,000 or more in different species (500-1,000 in *V. aureus*, 1500-20,000 in *V. globator*). (Fig. 3.2)

A Volvox cell is typical of the Chlamydomonas type in structure (except for a few like *V. rouseletti* and *V. globator*, which are of the Sphaerella type). Each cell is biflagellate and spherical, elliptical, or oval, with a narrow anterior end and a broad posterior end. The two flagella are equal, whiplash-type, and are attached to the anterior end.

The cell has a thick cell wall differentiated into an outer firm and an inner gelatinous layer. The protoplasm of the cell is embedded within a plasma membrane.

In the cytoplasm, each cell contains a cup-shaped chloroplast with one or more pyrenoids, an eyespot, 2–6 contractile vacuoles, and a single nucleus.

- The contractile vacuoles are found near the surface of the protoplast.
- The cup-shaped or curved plate-like chloroplast contains photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids, and xanthophylls) characteristic of green algae. There are 1 or 2 pyrenoids associated with the chloroplast.
- The single nucleus is situated in the center portion of the cytoplasm inside the cavity of the cup-shaped chloroplast. It relates to neuromotor apparatus consisting of blepharoplast, rhizoplast, and centromere.
- A single eyespot is present at the anterior end.

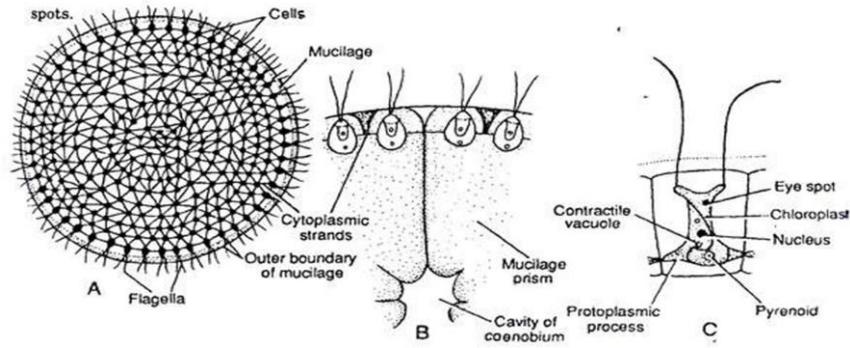


Fig. 3.2 (A-C) Volvox. A. A colony; B. A part of a colony; C. Single cell.

The cells of the anterior region of the coenobium possess larger eyespots than those of the posterior region, indicating the clear polarity of the coenobium.

The cells are interconnected to each other through cytoplasmic strands. In some species of Volvox, such as *V. tertius* and *V. mononae*, the cytoplasmic strands are absent. The cytoplasmic strands connect the cells through the mucilage. The central region of the coenobium is generally hollow but, in some species, it is filled with water (*V. globator*) or gelatinous materials (*V. aureus*).

Each cell of the coenobium independently carries out its photosynthesis, respiration, and excretion. The movement of the coenobium occurs through coordinating flagellar movement.

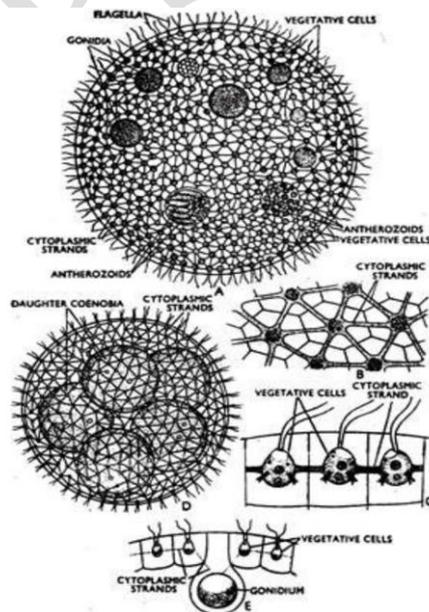


Fig 3.3: Volvox sp. A. A mature coenobium bearing vegetative cells with cytoplasmic strands, gonidia, and antherozoids. B. Details of cytoplasmic strands existing between adjacent cells.

C. *Individual* vegetative cells of the coenobium with a cytoplasmic strand. D, A parent coenobium bearing daughter coenobis, E. A portion of the coenobium showing the position of vegetative cells, gonidium, and cytoplasmic strands.

Reproduction in Volvox: Volvox reproduces by both asexual and sexual methods. Asexual reproduction occurs under favorable conditions during spring and early summer. Whereas sexual reproduction takes place under unfavorable conditions towards the end of the summer months.

In Volvox, generally, the cells of the coenobium's posterior end take part in reproduction. These reproductive cells are recognizable by their larger size, prominent nucleus, dense granular cytoplasmic content, more pyrenoids, and lack of flagella.

Asexual Reproduction: During the summer, asexual reproduction occurs very rapidly. Some cells from the posterior side of the coenobium become reproductive. These cells enlarge up to 10 times, withdraw their flagella, and become round. These cells are referred to as gonidia, or parthenogonidia, or autocolony initials. The number of pyrenoids increases as the gonidia lose their eyespots. The gonidia are enclosed by a gelatinous sac and are pushed inside the colony.

Development of the daughter Colony

The gonidium undergoes repeated divisions, about 15 or more times, and can produce more than 3,200 cells. Those cells ultimately form a colony. (Fig-3.4) Initially, the gonidium undergoes longitudinal division in the plane of the colony and forms 2 cells. The second division is also longitudinal but at a right angle to the first division, forming four cells. These 4 cells again divide longitudinally to form 8 cells, of which 4 cells are central and 4 are peripheral.

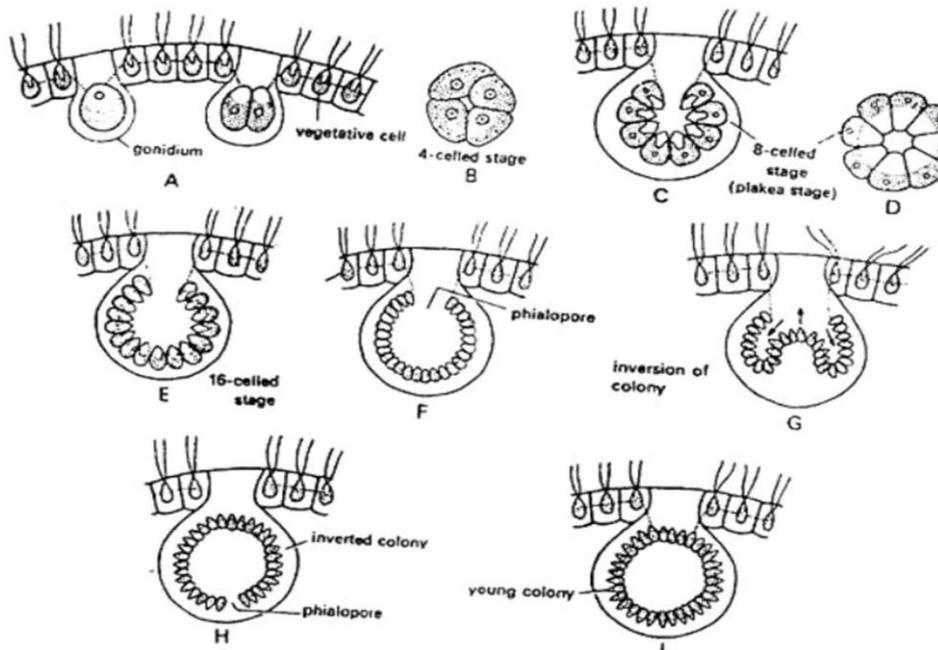


Fig 3.4 (A-I) Asexual reproduction in Volvox.

These 8 cells are arranged in such a manner that their concave inner surface faces toward the outer side of the colony to form a curved plate-like structure. This stage is called the **plakea stage**, or the **cruciate plate stage**. Each of these 8 cells, divided by longitudinal division, forms a 16-celled stage. At this stage, the cells are arranged in the form of a hollow sphere with an opening towards the exterior side, called a phialopore (a small aperture). At this stage, the cells continue to divide longitudinally until the number of cells reaches the number specified for a particular species.

The cells are naked and in close contact with one another. The anterior end of the cells is directed towards the center and the posterior end towards the outside. This group of cells then undergoes **inversion** through the phialopore, resulting in the normal pattern of the colony being achieved.

Inversion of Colony: The inversion of the colony begins with the formation of a constriction opposite to the Phialopore. The cells of the posterior end, along with constriction, are pushed inside the sphere. At the same time, the phialopore becomes enlarged, through which the lower part comes out, and the edges of the phialopore hang backward. (Fig-3.4)

With the help of inversion, the anterior end of the cells changes its position from inner to outer, and the position of the phialopore becomes reversed, i.e., it changes its position from outer to inner. The phialopore gradually closes, forming a completely hollow sphere.

After completion of the inversion, the cells generate a gelatinous cell wall, flagella, and an eyespot. As a result, the daughter colony develops. Many such colonies may form in a coenobium. The daughter colonies initially remain attached to the gelatinized wall of the mother coenobium, swimming freely inside the gelatinous matrix.

Later, the daughter colonies are released into the water after the rupture or disintegration of the mother coenobium. In some species, such as *V. carteri* and *V. africanus*, daughter colonies of 2-4 generations may remain inside the mother coenobium.

Sexual Reproduction

In *Volvox*, sexual reproduction is of the oogamous type. Some species are homothallic or monoecious (e.g., *V. globator*), where the antheridia and oogonia develop in the same colony. Other species (e.g., *V. rouseletii*) are heterothallic or dioecious, as antheridia and oogonia develop in separate colonies.

Most homothallic species are of the protandrous type, i.e., antheridia develop and mature earlier than oogonium. Some species are protogynous types, i.e., oogonia develop and mature before antheridia. *V. aureus* is usually heterothallic, but it can also be homothallic.

Some specialized cells at the posterior end of the coenobium enlarge in size, withdraw their flagella and develop into reproductive bodies called gametangia. The male gametangia are called antheridia or androgonidia, and the female gametangia are called oogonia or gynogonidia.

Antheridium

The development of the antheridium begins with the formation of the antheridial initial or androgonidial cell, mainly at the posterior end of the coenobium. Similar to gonidia, the initial cells enlarge, lose flagella, the protoplasm becomes dense, and the nucleus becomes larger. The antheridial initial shifts inside the cavity and remains connected to other vegetative cells through cytoplasmic strands.

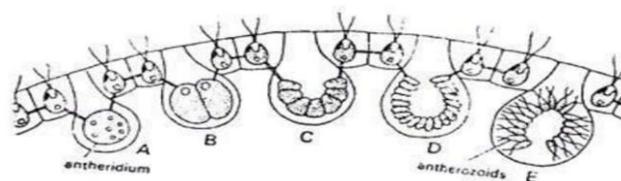


Fig 3.5 (A-E) Development of Antheridium in Volvox.

The protoplast of the antheridial initial undergoes repeated longitudinal divisions, similar to the asexual stage, and forms approximately 64-128 cells (though the number varies from 16-512 depending on the species). Like in the asexual stage, the cells remain in a plate-like structure or are grouped into a hollow sphere and then undergo inversion in which the anterior side of the cells faces the outer side. Each cell develops into an antherozoid or spermatozoid. The antherozoid is a spindle-shaped, bi-flagellated, elongated, pale yellow or green-colored structure. It contains two contractile vacuoles, a nucleus, a cup-shaped chloroplast with pyrenoids, and an eyespot. Individually or sometimes in groups, the antherozoids are liberated from the antheridium by rupturing the antheridial wall. (Fig. 3.5)

Oogonium

The development of the oogonium begins with the formation of the oogonium initial or gynogonidial cell (single vegetative cell) at the posterior end of the coenobium. The oogonial initial enlarges, loses its flagella, and the eyespot disappears, and develops into an oogonium. In oogonium, the protoplasm and nucleus become dense.

The oogonium is an enlarged, flask-shaped structure. Without undergoing any division, the entire protoplast of an oogonium forms a uninucleate egg or oosphere or female gametophyte.

The oosphere is spherical, uninucleate, non-flagellated, green in color, and contains a parietal chloroplast. It possesses a large amount of reserve food and many pyrenoids.

The beak of the flask-shaped oogonium opens towards the outer surface of the coenobium and functions as a receptive spot. (Fig. 3.6)

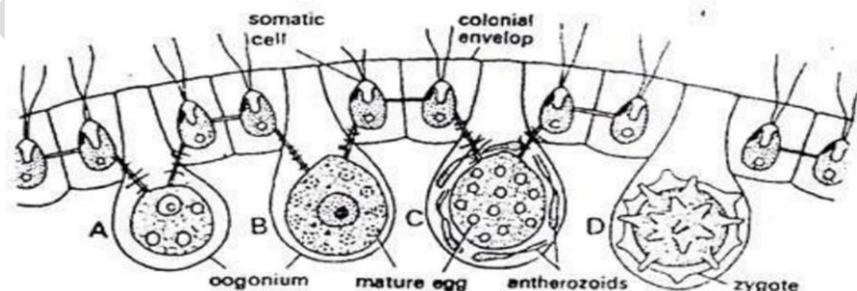


Fig 3.6 (A-E) Development of Oogonium in Volvox.

Fertilization: After liberation from the antheridium, the antherozoids swim freely on the surface of the water. Due to the chemotactic stimulation, they get attracted to the surface of

the oogonium. The antherozoids secrete a proteolytic enzyme. With the help of the proteolytic enzyme, some antherozoids enter the egg by breaking the oogonial wall. Only one antherozoid fertilizes the egg. After fertilization (plasmogamy and karyogamy), a diploid zygote or oospore is formed.

Zygote: The zygote secretes a three-layered (exospore, mesospore, and endospore) thick wall. The outer exospore is quite thick. It may be smooth (*V. monanae*, *V. globator*, etc.) or spiny (*V. spermatophora*). Whereas the exospore and endospore are relatively thin and smooth.

The wall accumulates the pigment haematochrome, and it becomes red. The zygote is liberated by the disintegration of the gelatinous matrix of the parent colony and remains dormant for a long period.

Germination of Zygote: Under favorable conditions, at the end of the resting period, the zygospore begins to germinate. During germination, the diploid zygote nucleus (2n) undergoes meiosis to form 4 haploid cells. The inner layer of the zygote emerges as a vesicle after the outer two layers of the zygote break. The four haploid cells migrate with the vesicle.

The development of the zygote varies among different *Volvox* species

- In *V. minor* and *V. aureus*, the protoplasm of the zygote divides repeatedly and forms a new colony, like asexual reproduction.
- In *V. campensis*, the protoplast of the zygote divides to produce numerous biflagellate zoospores. Only one zoospore survives, while all the others disintegrate. The surviving one comes out of the vesicle, and, by repeated mitotic division, it forms a new colony.
- In *V. rouseletti*, the protoplast of the zygote divides to form 4 zoospores, but only one survives. The outer wall of the zygote bursts, and the inner wall comes out in the form of a vesicle containing a single biflagellate meiospore. The meiospore is liberated by breaking the inner wall. As in asexual reproduction, the protoplast of the meiospore divides and forms a colony.

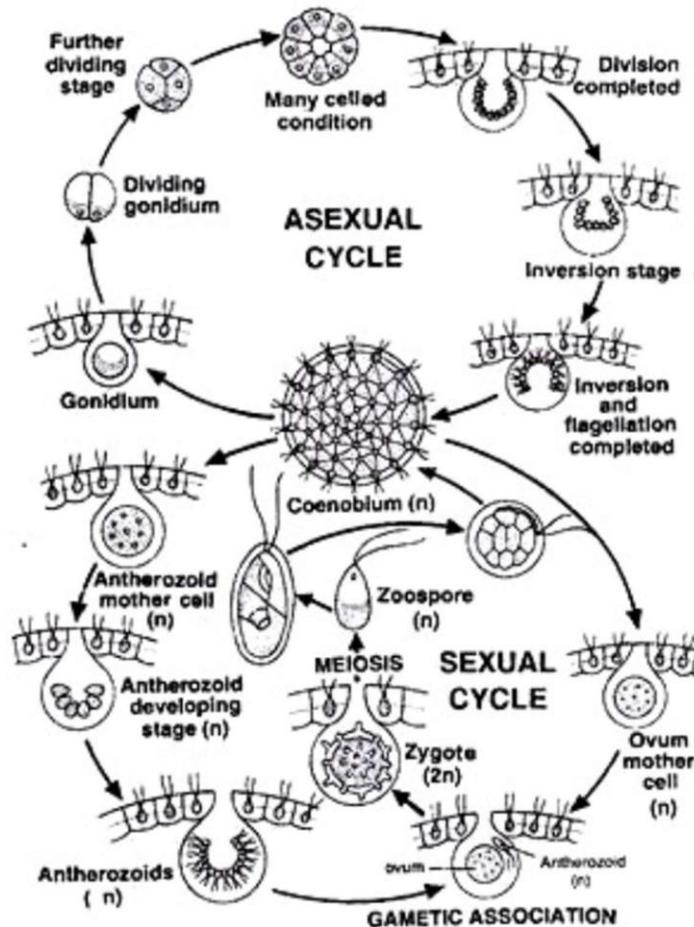


Fig 3.7 (A-E) Life Cycle in Volvox.

Genus: Hydrodictyon

Occurrence of Hydrodictyon

Domain: Eukaryota Kingdom: Plantae Division: Chlorophyta Class: Chlorophyceae Order: Sphaeropleales Family: Hydrodictyaceae Genus: *Hydrodictyon* Hydrodictyon, a non-motile coenobium, is a macroscopic and beautiful alga. Due to its net-like plant body, it is commonly known as ‘water net’. It is represented by 5 species. Only two species of Hydrodictyon, i.e., *H. reticulatum* and *H. indicum*, are reported from India. *H. reticulatum* is cosmopolitan in distribution.

The species are commonly found between spring and rainy season in slow running water or still water of ponds, pools and lakes. It generally floats on the surface of the water but may also lie on the bottom. Very often due to profuse growth, the nets assume big size and cover the entire pond.

Thallus Structure of Hydrodictyon

A mature coenobium consists of a hollow cylindrical network which is closed at both the ends (Fig. 3.8). It is flat and saucer shaped and its maximum size is generally 20-30 cm. Rarely it reach up to a length of 60 cm. The mature net of coenobium is made up of a few hundred to several thousand cells.

These cells are joined at the end and form pentagonal or hexagonal structures. These structures are called meshes. Each mesh interspace is generally bounded by 5-6 or rarely three cells. At each angle of the net or mesh meet three cells (Fig. 3.9 A, B).



Fig-3.8 Hydrodictyon coenobium.

Cell Structure of Hydrodictyon

Each cell is long, cylindrical, or ovoid. Its internal structure can be differentiated into two parts: the cell wall and the protoplasm. The cell wall is two-layered and is made up of cellulose. It encloses protoplasm. When young, the cells are uninucleate, but at maturity they become multinucleate (coenocytic).

Cells contain reticulate chloroplasts with many pyrenoids (Fig. 3.9C). All the typical structures of green algae, like ribosomes, mitochondria, and dictyosomes, are also present. As the cell matures, a central vacuole appears, and the protoplasm becomes peripheral.

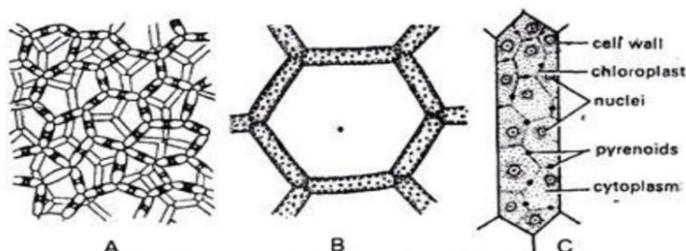


Fig 3.9 (A-C). Hydrodictyon. Vegetative structure. A. A part of the net; B. Hexagonal mesh; C. A cell.

Reproduction in Hydrodictyon:

It is of three types: Vegetative, asexual and sexual.

Vegetative Reproduction: It takes place by fragmentation. Coenobium breaks up into small pieces called fragments. Which have the capability to grow into new colonies. It may be due to water currents and the movement of aquatic animals.

Asexual Reproduction: It takes place by the formation of auto colonies or daughter colonies (Fig. 3.10 A-G). These colonies are formed by the biflagellate, uninucleate zoospores. Under favourable conditions, each coenocytic cell behaves as zoosporangium. Its nuclei undergo mitotic divisions to form a large number of nuclei (7000-20000).

Protoplasm gets segmented into as many segments as there are nuclei. Each segment gets surrounded by a small amount of cytoplasm, a limiting membrane, and develops two whiplash- type equal flagella and represents a biflagellate zoospore (Fig. 3.10 A-C). In Hydrodictyon, a peculiar phenomenon is observed. The zoospores thus formed are never liberated outside the parent cell.

They remain motile within the restricted region, i.e., within the cell. After swimming inside the cell, they ultimately withdraw their flagella and get themselves arranged into characteristic hexagonal or pentagonal fashion to form a new net (Fig. 3.10 D, E). This new net is called an auto colony or daughter colony (Fig. 3.10 F, G).

The auto colonies are liberated by the disintegration of the parent cell wall. The number of cells in the daughter colony is fixed. Further growth of the coenobium is entirely due to an increase in the cell size and not the number of cells.

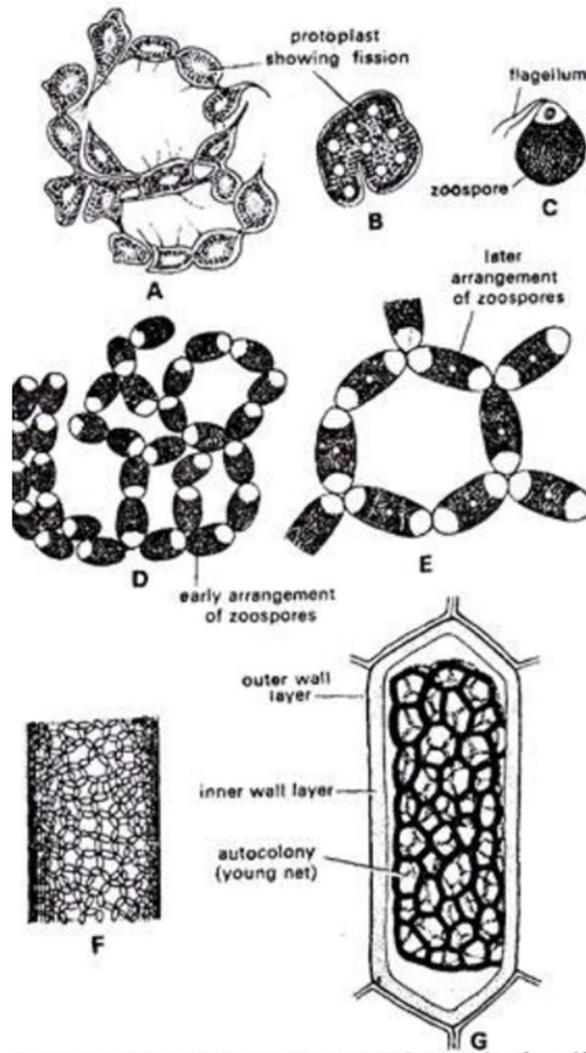


Fig. 3.10: (A-G). Hydrodictyon. Asexual reproduction. (A, B). Zoospore formation. C. A zoospore (D, E). Arrangement of biflagellated zoospores into a net: F. Formation of new net (autocolony) within parent cell. G. A autocolony in the parent cell.

Sexual Reproduction

It is isogamous. Any vegetative cell of the coenobium can function as a gametangium. The biflagellate gametes are produced by the cleavage of the protoplasm of the gametangia, like that of zoospores (Fig. 3.11 A, B). They are produced in large numbers and are smaller in size than the zoospores. They are liberated individually through a hole in the parent cell wall and swim freely in water.

The gametes are uninucleate and biflagellate. Hydrodictyon is monoecious. The gametes from the same or different connubia, after liberation, fuse to form quadriflagellate zygotes (Fig. 3.11C).

Soon, they lose their flagella and settle down. The immobilised zygote enlarges in size, becomes spherical, and develops a thick wall to form a zygospore. First, it is green, but it becomes red because of the development of a red pigment, haematochrome.

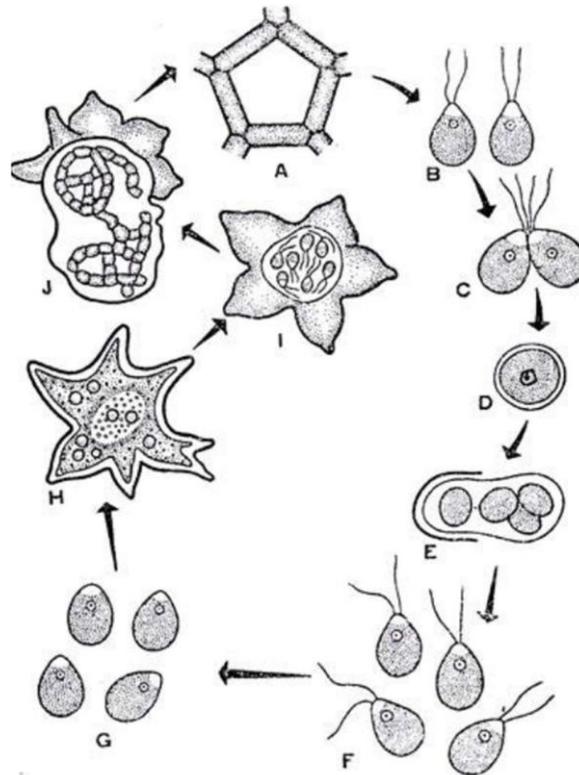


Fig. 3.11 (A-J). Hydrodictyon. Sexual reproduction.

Germination of zygospore

Zygospore is capable to tide over the low winter temperature. At the onset of the spring season, its diploid nucleus undergoes zygotic meiosis to form four haploid, uninucleate, biflagellate gonozoospores (Fig. 3.12 D- F). The zygospore wall bursts, and the meiospores are liberated in the surrounding water. After swimming for some time, these meiospores come to rest.

They retract their flagella, enlarge, and form the thick-walled angular cells called polyhedrons or polyhedral (Fig. 3.12 G, H). This stage is known as the polyhedron stage. The single nucleus of the polyhedron divides and re-divides several times and ultimately forms the second generation of zoospores (Fig. 3.12 1). These zoospores are also uninucleate and are anteriorly biflagellate.

The wall of the polyhedron cracks down, and the zoospores emerge into a thin vesicle (Fig.

3.12J). These zoospores do not escape outside in the water but actively swim within the vesicle for some time.

They withdraw their flagella and arrange themselves in the form of a net of Hydrodictyon. It is a daughter or juvenile colony. It is released in water by the dissolution of the vesicle. Its cells grow in size and produce new coenobia where the cell number typical of the species is stored.

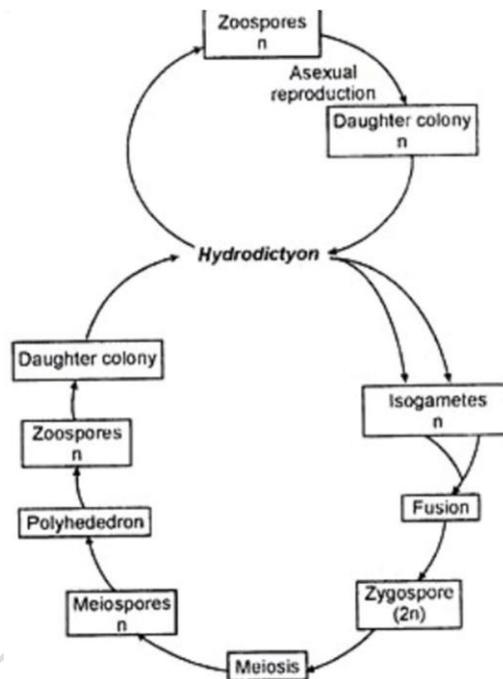


Fig. 3.12. Hydrodictyon, Graphic life cycle.

Genus: Cladophora

Division: Chlorophyta Class: Ulvophyceae Order: Cladophorales Family: Cladophoraceae
Genus: *Cladophora*.

Cladophora is a widely distributed genus of green algae, comprising about 160 species found in both freshwater and marine environments. The majority of species inhabit freshwater ecosystems, where they can be seen in running water, shallow ponds, and lakes. These algae may occur as attached forms, free-floating masses, or as epiphytes growing on other aquatic plants. Some species have unique habitats; for example, *Cladophora crispata* grows epizoically on mollusc shells, while *Cladophora holosatica* is known for forming sponge-like structures called *Cladophora balls (aegagropila)*, which are noted for their ability to inhibit insect larval growth.

Marine species of *Cladophora* are typically found in intertidal zones and often grow epiphytically on larger algae. In India, commonly observed species include *Cladophora glomerata*, *Cladophora crispata*, and *Cladophora bengalensis*.

The Plant Body Structure

The plant body of *Cladophora* consists of profusely branched, coarse, and stringy filaments that form a bush-like appearance. These filaments are attached to the substratum by long, septate rhizoidal branches. In species such as *Cladophora glomerata*, these rhizoidal branches also function as stolon-like outgrowths, from which new upright filaments arise at intervals. **Branching.**

Branching in *Cladophora* is true and predominantly lateral. However, occasional **dichotomous** and **trichotomous** branching can also be observed. Lateral branches typically emerge just below the septum of a cell and may be pushed further apart as the filament grows, resulting in a dichotomous appearance. In some instances, two branches may arise from opposite sides of the same cell. As these develop further by a process called evection, they give rise to a trichotomous branching pattern. In *Cladophora verticillata*, branches are long and simple but are mostly restricted to the basal region of the plant.

Cell Structure

The cells of *Cladophora* are cylindrical and typically 3 to 20 times longer than their breadth. The cell wall is thick and stratified, comprising three distinct layers.

- The innermost layer is made of cellulose,
- The middle layer consists of pectin, and
- The outermost layer is possibly composed of chitin.

The inner two layers may exhibit lamellated (layered) structures, while the outer layer is rough and coarse in texture. Electron microscopic studies have revealed that the inner cellulose and pectin layers are made up of spirally arranged, interwoven microfibrils, which are secreted from the peripheral cytoplasm.

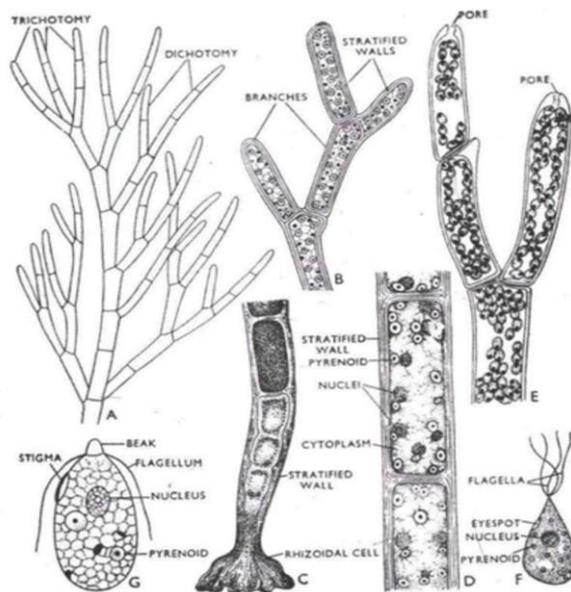


Fig. 3.13: *Cladophora* sp. A. Portion of a filament showing nature of branching. B. Filament cells magnified. C. Lower portion of the filament. D. Structural details of cells. E. Finer branches with zoospore primordia. F. Zoospore. G. Gamete.

Inside the cell, the cytoplasm is pushed to the periphery due to the presence of a large central vacuole. The cells are multinucleate, containing several nuclei. A notable feature is the chloroplast, which is typically single, parietal (lining the cell wall), and reticulate (net-like), and contains multiple pyrenoids. Occasionally, projections of the chloroplast may extend into the central vacuole. In some cases, the chloroplast may appear discoid and lack pyrenoids.

In freshly collected specimens, the structure of the chloroplast is often obscured by excessive starch accumulation. However, when the material is stored in tap water for a few days, the starch content reduces, making the chloroplast structure visible.

Reproduction

Cladophora reproduces by **vegetative**, **asexual**, and **sexual** methods.

1. Vegetative Reproduction

Vegetative reproduction occurs by the following methods.

(a) **Fragmentation:** The filaments may break into smaller pieces, known as fragments, each capable of growing into a new plant. This method is common in aegagropilous species.

(b) **Stolons:** In species like *C. glomerata*, the stolon-like rhizoidal portions may break off. Each segment can give rise to a new plant.

(c) **Rhizoidal System:** Observed in perennial species like *C. glomerata* and *C. ophiophila*. During unfavourable conditions, the upper vegetative parts die, while the rhizoidal parts

survive. These cells store food, develop thick, lime-encrusted cell walls, and remain dormant. When favourable conditions return, these rhizoidal cells regenerate into new filaments.

2. Asexual Reproduction

(a) **By Zoospore Formation:** Zoospores are produced during **favourable conditions** by **healthy plants**. The process typically **starts in the apical cells** and proceeds towards the lower parts.

Before zoospore formation, the **nuclei undergo meiotic division** (Schüssing, 1928; Foyn, 1934). The protoplast then cleaves into several portions, each enveloping a nucleus and transforming into a quadriflagellate (four-flagella-bearing), naked zoospore, which may be pear-shaped or spherical.

In *Cladophora glomerata*, **zoospore formation** occurs purely by **mitotic division** (in contrast to meiotic division observed in some other species). Each zoospore is.

Small, pyriform (pear-shaped), Uninucleate, and Quadriflagellate

In most species, the zoospores are haploid, but in *C. glomerata*, they are diploid. Each zoospore contains: A single chloroplast with several pyrenoids, A distinct eye spot. In some species, such as *C. crispata* and *C. sauteri*, biflagellate zoospores are also reported.

Zoospore Liberation and Germination

Zoospores are liberated through a small circular pore at the upper end of the cell, formed by gelatinization and bursting of a lens-shaped area in the cell wall. In marine species, liberation occurs specifically when the thalli are reflooded by the incoming tide.

After liberation

- The zoospores swim actively for a short time.
- They then attach to the substratum by their anterior end.
- Upon attachment, they secrete a wall, elongate, and become multinucleate.
- The developing filament divides transversely: The lower cell forms the rhizoidal part. The upper cell undergoes further divisions to form the photosynthetic, upright filament.

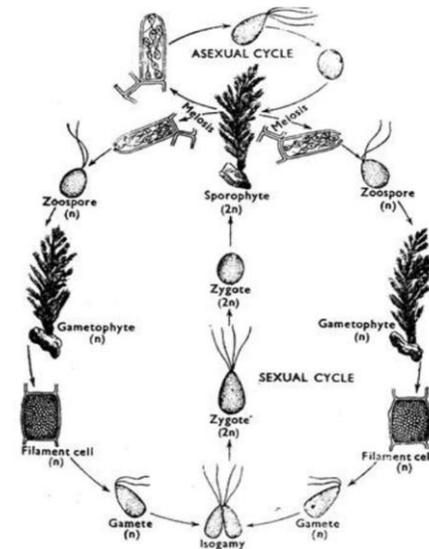


Fig 3.14: Life cycle of *Chladophora* sps.

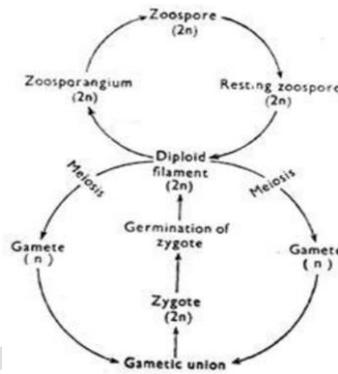


Fig. 3.15 Life cycle pattern of *Cladophora glomerata*.

Genus: *Oedogonium*

Kingdom: Plantae Division: Chlorophyta Class: Chlorophyceae Order: Oedogoniales Family: Oedogoniaceae Genus: *Oedogonium*.

Occurrence: *Oedogonium* is a filamentous green alga that reproduces by oogamous sexual reproduction and occurs in both macrandrous and nannandrous types. The name *Oedogonium* is derived from Greek words where "oedos" means swelling and "gonos" means reproductive bodies, referring to the swollen reproductive structures found in the organism. *Oedogonium* is exclusively freshwater in habitat, and out of approximately 400 species known worldwide, more than 200 species have been reported from India. It commonly occurs in stagnant freshwater bodies such as pools, ponds, and lakes.

The plant body of *Oedogonium* is filamentous and unbranched. It is attached to submerged surfaces like stones, wood, leaves of aquatic plants, or decaying plant matter through a

specialized basal cell called the holdfast. This holdfast helps anchor the filament in place. Though primarily aquatic, a few species like *Oedogonium terrestris* are found growing on moist soil, making them terrestrial.

Plant Body of *Oedogonium*

The plant body is a green, multicellular, filamentous thallus. It is unbranched, and the cells are arranged in a uniseriate row (i.e., in a single file, one after the other).

The filament is differentiated into three distinct types of cells.

Structure and Characteristics of *Oedogonium*

1. Basal Cell

Oedogonium has a distinct filamentous structure composed of three main types of cells: basal, apical, and middle cells. The basal cell is the lowermost part of the filament. It is elongated, gradually narrows, and then expands at the base into a disc-like, multilobed, or finger-shaped structure called a holdfast. This cell is colourless and non-photosynthetic, serving mainly to anchor the alga to a substrate such as rocks, plants, or submerged debris.

The apical cell is the topmost cell of the filament. It is typically rounded at the apex and green in colour due to the presence of chloroplasts. This cell is responsible for the elongation of the filament as it divides and adds new cells to the filament's length. (Fig-3.15)

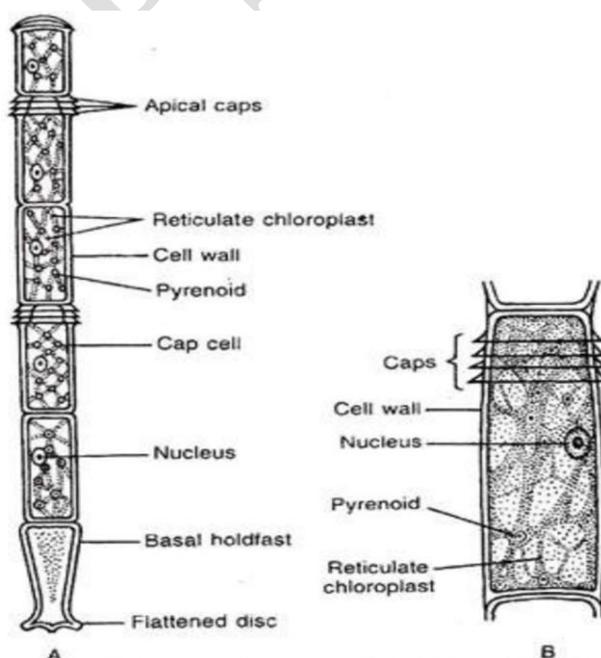


Fig 3.15: *Oedogonium* sp.: A. Single vegetative filament with holdfast and apical cell, B. Single vegetative cell.

The middle cells are found between the basal and apical cells. These cells are uniform in structure, rectangular in shape, and longer than they are wide. They contain reticulate or net-like chloroplasts, which carry out photosynthesis to sustain the alga. Some of the middle cells possess apical caps, which are ring-like structures at the upper end of the cell. A cap cell is a middle cell bearing one or more caps. Each cap represents a previous cell division event and serves as an indicator of the cell's division history.

Important Features of *Oedogonium*

Oedogonium is a common freshwater alga that grows attached to various submerged substrates such as sand particles, rocks, and aquatic plants. The plant body is unbranched and filamentous, clearly differentiated into an apex and a base. Its cells contain reticulate chloroplasts, which help in efficient photosynthesis. A distinct feature of *Oedogonium* is the presence of cap cells on young, dividing cells, which indicate past cell divisions. Vegetative cell division is highly organized and shows a unique pattern not found in many other algae.

Asexual reproduction in *Oedogonium* occurs through the formation of multiflagellate zoospores. These zoospores have several flagella arranged around a beak-like apical region, allowing for movement in water. Sexual reproduction is oogamous, characterized by the fusion of a large, non-motile ovum and a small, motile antherozoid. The oogonium is a specialized cell that produces a single ovum, while the antheridium forms two antherozoids per cell. These antherozoids are structurally similar to zoospores but are smaller in size.

Oedogonium exhibits two types of male reproductive structures based on where the antheridia form. In macrandrous species, the antheridia develop on a normal-sized filament. In nannandrous species, the antheridia form on a dwarf male filament called a nannandrium. The nannandrium originates from androspores, which are produced in androsporangia present on the normal filament. Androspores are smaller than zoospores but larger than antherozoids.

After fertilization, the resulting zygote undergoes meiosis, producing four zoospores. In dioecious species, where male and female filaments are separate, two of these zoospores develop into male plants and the other two into female plants, maintaining the sexual diversity of the species.

Cell Structure of *Oedogonium*

The cell structure of *Oedogonium* is well-organized and adapted for its aquatic environment.

The intercalary or middle vegetative cells are cylindrical and longer than they are broad, forming the main photosynthetic and structural parts of the filament.

Each cell is enclosed by a thick and rigid cell wall, which consists of three distinct layers. The outer layer is made of chitin, the middle layer is composed of pectin, and the innermost layer consists of cellulose. Beneath the cell wall lies the plasma membrane, which encloses the internal living part of the cell known as the protoplast. (Fig. 3.16)

The protoplast contains the cytoplasm, chloroplast, vacuole(s), and nucleus. The cytoplasm forms a thin lining situated between the cell membrane and the large central vacuole. The vacuole may be single and large or multiple and small, occupying the central part of the cell and filled with cell sap that helps maintain cell turgor and store nutrients.

A prominent feature of each vegetative cell is the presence of a single, large, reticulate (net-like) chloroplast. This chloroplast is embedded within the cytoplasm and often extends across the entire length of the cell, maximizing the surface area for photosynthesis.

Each cell is uninucleate, meaning it contains a single nucleus. The nucleus is usually located at the center of the cell, suspended in the cytoplasm, although in some cases, it may be slightly off-center (eccentrically located), depending on the stage of the cell's activity.

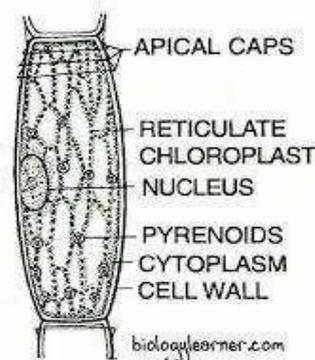


Fig 3.16 Cell structure of Oedogonium.

Cell Division in *Oedogonium*

The filament of *Oedogonium* grows by intercalary cell division, meaning cell division occurs in the middle cells of the filament, while apical and basal cells do not divide. This division is highly specialized and elaborate, resulting in the formation of cap cells, which are characteristic of *Oedogonium*.

Steps of Cell Division

- 1. Nuclear Movement:** The **nucleus**, which is initially located near the cell periphery, **shifts to the center**, then moves slightly **upward** within the cell (Fig. 3.17 A, B).
- 2. Formation of Ring-like Thickening:** A **ring-like thickening** forms near the **upper region of the cell wall**. This structure **increases in thickness** and is crucial for the later stages of division (Fig. 3.17 B).
- 3. Mitosis:** The **nucleus divides mitotically** into **two daughter nuclei** (Fig. 3.17 C).
- 4. Formation of the Floating Septum:** After nuclear division, a **row of microtubules** appears and forms a **floating layer** between the daughter nuclei. This structure will later form the **cross wall (septum)** between daughter cells (Fig. 3.17 C).
- 5. Splitting of the Mother Cell Wall:** The **ring-like thickening elongates**, causing the **mother cell wall to split** from the top. This leads to the formation of a **concave; cylindrical ring** that helps define the new daughter cell (Fig. 3.17D).
- 6. Cap Formation:** The **ruptured upper part of the mother wall** remains attached to the **new upper (daughter) cell** as an **apical cap**. The remaining part stays towards the basal side of the daughter cell (Fig. 3.17D).
- 7. Fixation of Septum:** The **floating septum** moves upward to the **top of the ruptured mother cell**, where it becomes fixed and eventually forms a **mature cross wall** separating the two cells (Fig. 3.17 E).
- 8. Development of New Wall:** A **new side wall** forms between the **cuticle and the plasma membrane** of the upper (daughter) cell. This results in the formation of **two separate cells** (Fig. 3.17 F). The **cell with the apical cap** is the **newly formed daughter cell**, indicating its recent origin from cell division.

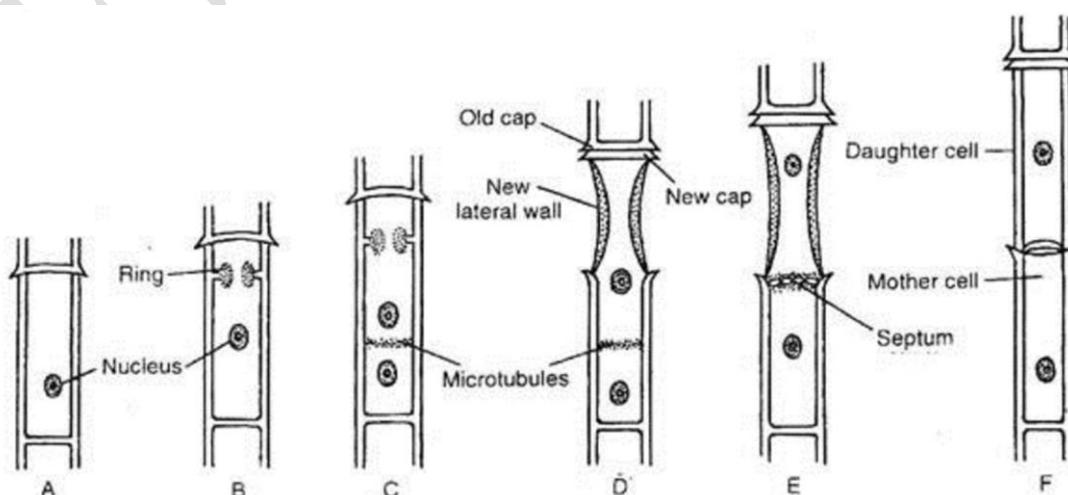


Fig 3.17 Oedogonium Spp. Successive stages of Cell division.

Reproduction in *Oedogonium*

Oedogonium exhibits all three types of reproduction:

1. Vegetative, 2. Asexual and 3. Sexual

1. Vegetative Reproduction: Vegetative reproduction in *Oedogonium* occurs by:

a) **Fragmentation:** It happens through: Accidental breakage of the filament, Death of intercalary cells, Formation of intercalary sporangia

- Each resulting fragment can grow into a **new filament** under suitable conditions.

b) **Akinete Formation:** In unfavourable conditions, the protoplast of a vegetative cell transforms into a thick-walled structure called an akinete.

- Features of akinetes: Reddish-brown, round or oval, contain reserve food and are dormant forms, often formed in chains

- In favourable conditions, akinetes germinate and produce new filaments.

2. Asexual Reproduction: Asexual reproduction occurs through **zoospore formation**.

Zoospores: Formed singly within a cap cell (a younger cell that behaves as the sporangium mother cell). The zoospore is: Mult flagellate (many flagella), Ovoid, pyriform (pear-shaped), or spherical, Uninucleate (one nucleus), Contains a single, reticulate chloroplast May possess an eyespot for phototactic movement, after liberation, zoospores swim for a short time, settle on a suitable substratum, and germinate to form a new filament.

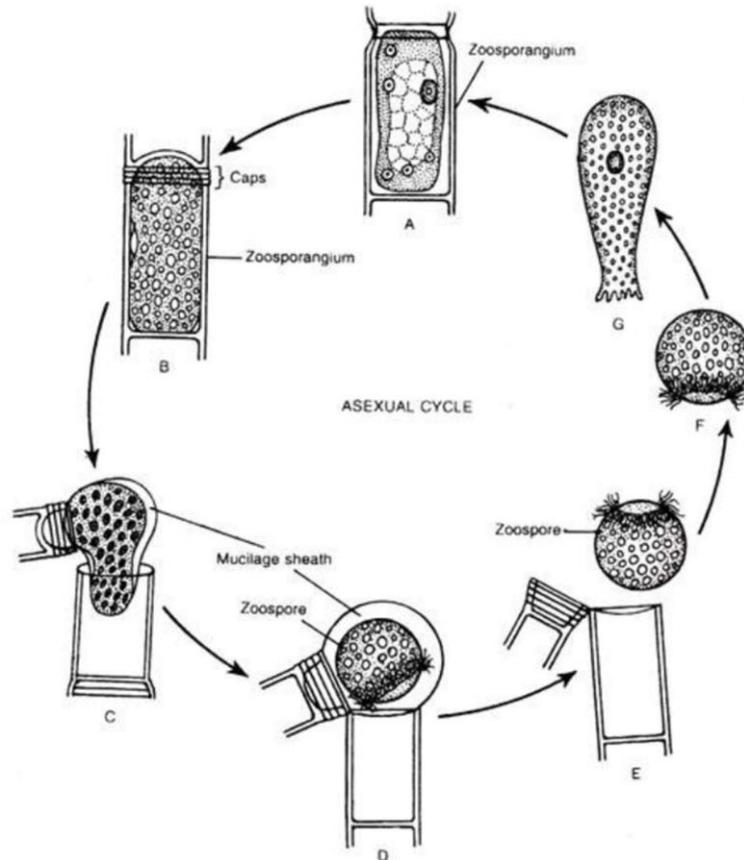


Fig 3.18: Oedogonium sp. Asexual reproduction: A-E. Successive stages of zoospore formation, F. Single zoospore, and G. Germination of Zoospore.

Zoospore Formation and Germination in *Oedogonium*

During favorable conditions, *Oedogonium* reproduces asexually by forming zoospores in the cap cells, which act as zoosporangia. The entire protoplast of the zoosporangium contracts and becomes round or oval. The nucleus migrates toward one end of the protoplast, where a semicircular, transparent region called the hyaline area develops near the nucleus. Below this hyaline area, a ring of blepharoplast granules forms, connected by fibrous strands as described by Ringo (1967). Each blepharoplast granule gives rise to a single flagellum, eventually forming a crown of flagella arranged around the hyaline area.

When the zoospore is fully developed, the wall of the zoosporangium ruptures near the cap region. The adjacent vegetative cell bends slightly, assisting in the release of the zoospore. The zoospore initially emerges enclosed within a mucilaginous vesicle. This vesicle dissolves within 3 to 10 minutes, after which the zoospore becomes free and actively swims in the surrounding water using its crown of flagella.

Germination of Zoospore

The zoospore of *Oedogonium* swims freely in water for about one hour or more, propelled by its crown of flagella. When it comes into contact with a suitable substratum, typically by its anterior end, it loses its flagella and begins the germination process. The lower hyaline region of the zoospore becomes enclosed by a cell wall, giving rise to the holdfast, which anchors the developing organism to the substrate. Following this, the zoospore undergoes a series of cell divisions in a single plane, leading to the formation of a new unbranched filament, thus developing into a mature *Oedogonium* thallus.

Sexual Reproduction in *Oedogonium*

Sexual reproduction in *Oedogonium* is oogamous, characterized by the fusion of two morphologically distinct gametes: a large, non-motile female gamete called the egg and a small, motile male gamete called the antherozoid.

The sex organs involved in this process are well-differentiated. The antheridia are the male reproductive structures that produce two motile antherozoids per cell. These antherozoids are capable of swimming in water to reach the female gamete. The oogonia are the female reproductive structures, each producing a single large, non-motile egg cell.

In some species, androsporangia are present. These structures produce motile androspores, which play a role in the formation of dwarf males, a special feature in the nanandrous species of *Oedogonium*. The androspores are released and germinate to form dwarf male filaments called nanandria, which bear the antheridia for gamete production.

Inducing Factors: Nitrogen deficiency and **alkaline pH** promote sexual reproduction.

Types of *Oedogonium* Based on Antheridial Filament

Oedogonium species are classified into two main types based on the structure and development of the antheridial filaments.

1. Macrandrous Species: In macrandrous species, the antheridia develop on normal-sized filaments. These species can be further divided into two types:

a. Monoecious (Homothallic) Macrandrous Species:

- Both the antheridia (male sex organs) and oogonia (female sex organs) develop on the same filament. **Examples:** *Oedogonium fragile*, *O. nodulosum*, *O. hirnii*

b. Dioecious (Heterothallic) Macrandrous Species:

- The antheridia and oogonia develop on separate filaments, with distinct male and female plants. **Examples:** *Oedogonium gracilius*, *O. cardiacum*, *O. aquaticum*.

2. Nannandrous Species: In nannandrous species, the antheridia develop on a tiny, reduced male filament called the **dwarf male** or **nannandrium**. These species are always **dioecious**, meaning they have separate male and female plants.

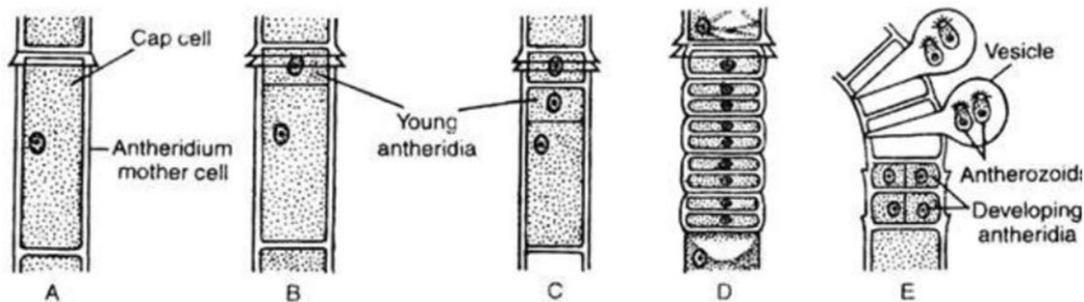


Fig 3.19 Oedogonium sp.: A-E. Successive stages of development of antherozoids.

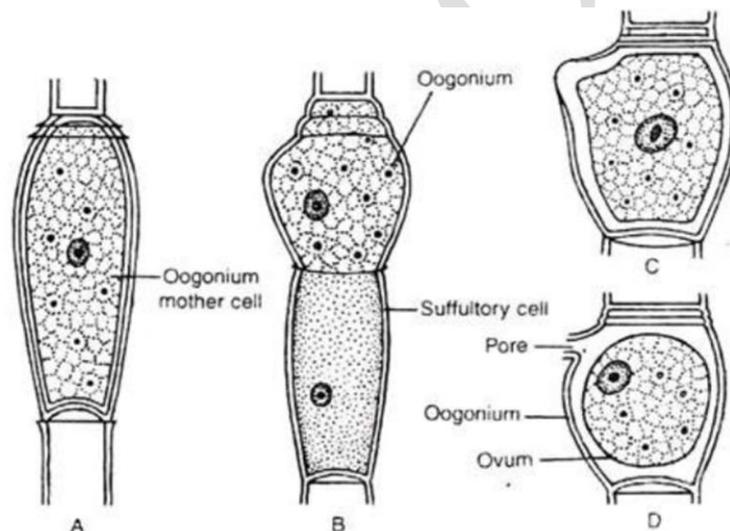


Fig 3.20 Oedogonium sp.: A-D. Successive stages of the development of the ovum.

Formation of Dwarf Males

- Androsporangia are formed in series on a normal vegetative filament.
- Each androsporangium produces a single motile androspore.
- After being released, the androspore swims and attaches to The **oogonial wall**, as seen in *Oedogonium ciliatum*, or A **supporting cell**, as seen in *Oedogonium concatenatum*.
- The androspore germinates at the point of attachment, forming a dwarf male filament.
- The apical cells of the dwarf male filament develop into antheridial cells, each producing

two motile antherozoids. This differentiation allows for sexual reproduction even in species where male and female structures do not form on the same filament.

Formation of Dwarf Males.

1. **Androsporangia** form in series on a normal filament.
2. **Each** androsporangium produces one androspore.
3. After release, the **androspore swims** and attaches to:

The **oogonial wall** (e.g., *O. ciliatum*), or A **supporting cell** (e.g., *O. concatenatum*).

4. It then germinates to form a **dwarf male filament**. The apical cells of this filament differentiate into **antheridial cells**, each producing **two antherozoids**.

Table 3.1: Differences Between Zoospore, Androspore, and Antherozoids.

Characteristic	Zoospore	Androspore	Antherozoid
1. Formed in	All species	Nannandrous species	All species
2. Morphology	Spherical, uninucleate, multiflagellate	Like zoospore	Like zoospore
3. Size	Largest	Intermediate	Smallest
4. Formed in (structure)	Zoosporangium	Androsporangium	Antheridium
5. Number per cell	One	One	Two
6. Further activity	Develops into new filament	Develops into dwarf male (nannandrium)	Fertilizes the egg in oogonium

Distribution of Sex Organ in Oedogonium: Based on the size of the male (antheridial) filament, the species of Oedogonium are divided into two groups: macrandrous and nannandrous type.

1. **Macrandrous Type:** In the macrandrous type, the antheridium develops in the filament of normal size.

It is of two Types

- i. Monoecious type (homothallic or bisexual). In this type (e.g., *O. fragile*, *O. nodulosum* and *O. hirnii*), antheridia and oogonia are borne on the same filament (Fig. 3.21).
- ii. Dioecious type (heterothallic or unisexual). In this type (e.g., *O. gracilius*, *O. cardiacum* and *O. aquaticum*) the antheridia and oogonia are borne on different filaments (Fig. 3.21).

2. Nannandrous Type

The nannandrous species are always dioecious (heterothallic), i.e., antheridia and oogonia are borne on different filaments. In this type, the antheridia develop on a very small filament termed a dwarf male or nannandrium. In nannandrous type, initially androsporangia are developed in series on normal normal-sized filament. The androspore forms singly within an androsporangium.

Liberating from the androsporangium, the androspores swim freely in water. The androspore germinates on the oogonial wall (*O. ciliatum*) or a supporting cell (*O. concatenatum*) and forms a dwarf male filament. Towards the apical region, the dwarf male filament cuts off small cells as the antheridial mother cells.

Each antheridium produces two antherozoids. The androspores, antherozoids and zoospores are morphologically alike but differ in their sizes (Table 4.1). The androspores are smaller than zoospores (produced asexually) but larger than antherozoids.

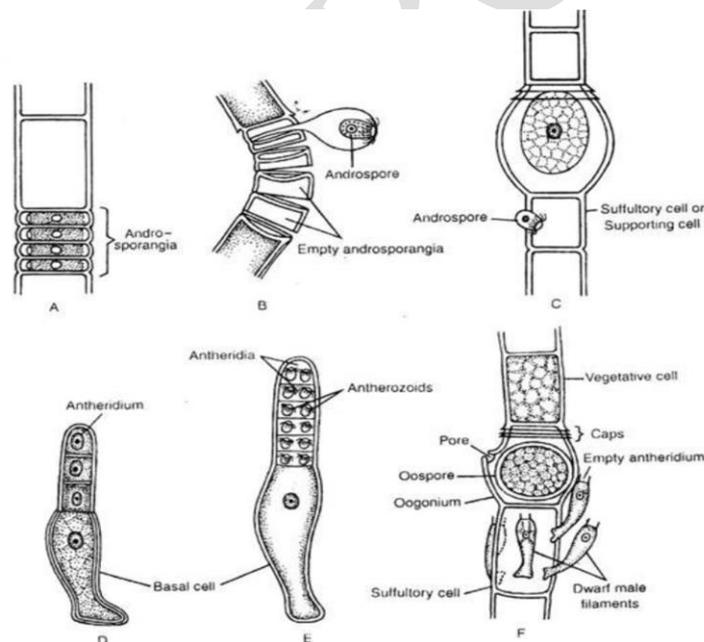


Fig 3.21: *Oedogonium* sp. Development of dwarf male: A-B. Development of androspore, C. Attachment of androspore on the suffultory cell, D-E. Development of dwarf male and formation of antherozoid, and F. Formation of oospore after fertilization.

They are of two types: i. Cynandrosporous Type: In this type (e.g., *O. concatenatum*) the androsporangia and oogonia are borne on the same filament (Fig. 3.23).

ii. Idioandrosporous Type: In this type (e.g., *O. setigerum*, *O. confertum* and *O. iyengarii*)

the androsporangia and oogonia are borne on different filaments.

Sexual Reproduction in Macrandrous Species.

The structure and development of antheridium and oogonium are similar in all the species belonging to either monoecious or dioecious types. They differ only in the position of sex organs. In monoecious type, both the sex organs develop on the same filament, but in dioecious type, they are on different filaments.

a. Antheridium: Any cap cell of the vegetative filament may function as an antheridial mother cell (Fig.4.5). It divides transversely into an upper, smaller antheridium and a lower, larger sister cell. The sister cell then undergoes repeated transverse division and forms an uniseriate row of about 2-40 rectangular uninucleate antheridia.

The nucleus of the antheridium undergoes mitotic division and forms 2 nuclei. Each nucleus becomes surrounded by some cytoplasm and metamorphoses into an antherozoid. Thus, two antherozoids are developed from each antheridium.

The antherozoids are unicellular, uninucleate, multiflagellate, and yellowish. Morphologically, it is similar to zoospore and androspore, but much smaller in size. The liberation of antherozoid is similar to zoospore formed during asexual process.

b. Oogonium

Any cap cell of the vegetative filament may function as oogonial mother cell (Fig. 3.76). It divides transversely into an upper oogonium and a lower supporting cell or suffultory. The lower cell may again undergoes similar divisions in repeated sequence to form two or more oogonia with a lower supporting cell.

With maturity the oogonium becomes globose, which contains single egg. A receptive spot is present at one side of the egg. Before fertilisation a transverse slit or pore develops on the oogonial wall through which the antherozoids take the entry.

Sexual Reproduction in Nannandrous Species.

The structure and development of androsporangium, antheridium and oogonium are similar in all the species either belonging to Gynandrosporous or Idioandrosporous type. They differ only in the position of androsporangium. In Gynandrosporous type the androsporangia and oogonia are borne on the same filament, whereas in Idioandrosporous type the

androsporangia and oogonia are borne on different filaments.

a. Androsporangium

The mode of development of androsporangia is alike with the antheridial development in macrandrous species. The androsporangia are larger than the antheridia of macrandrous type. The nucleus of androsporangium does not divide and the entire protoplast metamorphoses into a single androspore.

The androspores are unicellular, uninucleate and multiflagellate. The androspores are larger than the antherozoids. The androspores are liberated by breaking the wall of androsporangium.

During liberation, each androspore remains in a mucilage envelope for a few minutes and then becomes free to swim in water (Fig. 3.15B).

b. Germination of Androspore and Formation of Antherozoids:

After swimming for some time, it gets attached either to the oogonial wall or to the supporting cell (Fig. 3.22C). Then a wall develops around the asporum. The androspore elongates and cuts off a few flat cells at its apex to form the antheridia (Fig. 3.22). The nucleus of each antheridium divides mitotically to form two nuclei.

Each nucleus with some cytoplasm metamorphoses into a single antherozoid. Thus, two antherozoids are formed in each antheridium (Fig. 3.22E). The antherozoids are liberated similarly to those found in macrandrous species. The antherozoids swim in water for some time and, in contact with the receptive pore or slit, the antherozoid enters the oogonium and fertilizes the egg.

c. Oogonium: The structure and development of oogonium are the same as macrandrous species.

Fertilisation: Antherozoids are attracted by the mature oogonium through a chemical stimulus. Normally, only one antherozoid enters through the opening on the oogonial wall and fertilises the egg, resulting in the formation of a diploid zygote or oospore (Fig. 3.22A, B; 3.23 F).

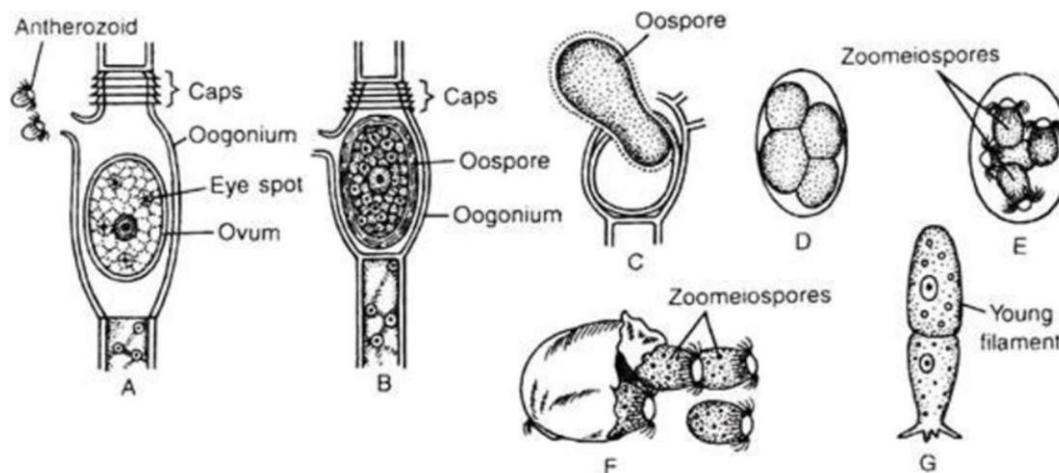


Fig 3.22: *Oedogonium* sp. A. A stage before fertilization, B. Oospore in oogonium, C. Liberation of oospore from oogonium. D-E. Stages of zoospore formation: F. Liberation of zoospore, and G. Young filament develops after germination of zoomeiospore.

Oospore: The zygote during further development retracts itself from the oogonial wall and secretes 2-3 layered outer wall. Later, the outermost one becomes ornamented. The zygote generally undergoes a long period of rest and becomes brown.

Germination of Oospore: The oospore germinates during favourable conditions. The nucleus undergoes meiosis and forms 4 haploid daughter nuclei. The nuclei accumulate some cytoplasm and form 4 daughter protoplasts. They liberate by rupturing the oospore wall. During liberation, they develop flagella and are called meiospores or zoomeiospores. Initially, they remain inside a delicate vesicle, which soon disintegrates, and the zoospores get free into the environment. After swimming for some time in water, they withdraw their flagella and germinate into new haploid *Oedogonium* filament-like zoospores in asexual reproduction. The nature of zoospore development varies in monoecious and dioecious species. In monoecious species, all the zoospores develop into similar *Oedogonium* filaments. In dioecious species, out of 4 zoospores, 2 develop into male and the other 2 develop into female *Oedogonium* filaments.

Indian Species: *Oedogonium cardiacum*, *O. aster*, *O. elegans*, *O. aerolatum* and *O. armigerum*.

Life Cycle of Oedogonium: Fig. 3.23 depicts the life cycle of *Oedogonium*.

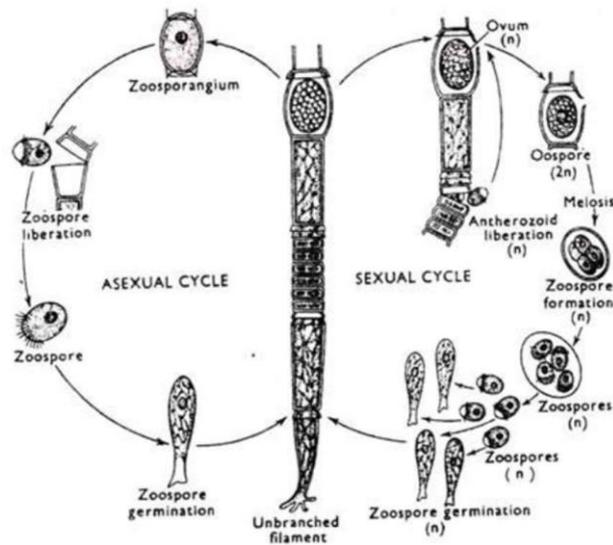


Fig. 3.23: Life cycle of macrandrous monoecious species of Oedogonium.

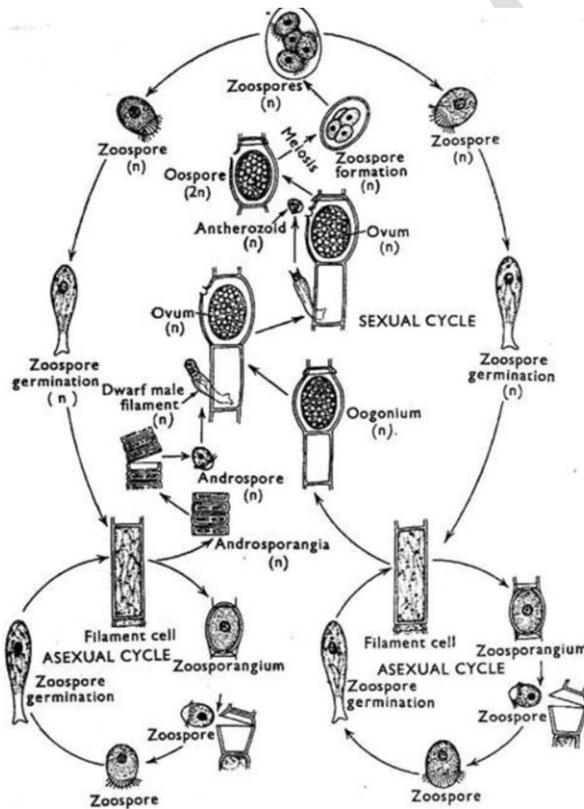


Fig 3.24: Life cycle of nanandrous (all are dioecious) -idioandrosporus species of Oedogonium.

Occurrence of Chara.

Genus: Chara

Kingdom: Plantae Division: Chlorophyta Class: Charophyceae Order: Charales Family: Characeae Genus: Chara.

Chara is represented by about 188 species, out of which 30 species are found in India. It is commonly known as “stonewort”. The plant body of Chara is encrusted with calcium and magnesium carbonate, especially on the plants growing in heavy water. Thus, the plants become strengthened and are called stoneworts. Generally, they grow in fresh water of ponds, lakes, tanks, etc., in a submerged condition. Some species, like *C. fragilis*, grow in hot springs, whereas *C. baltica* grows in brackish water.

Plant Body of Chara.

Chara is a macroscopic, multicellular, profusely branched thalloid plant body, generally attains a height of about 20-30 cm (rarely about 1 meter). It is differentiated into rhizoid and main axis (Fig. 3.25 A).

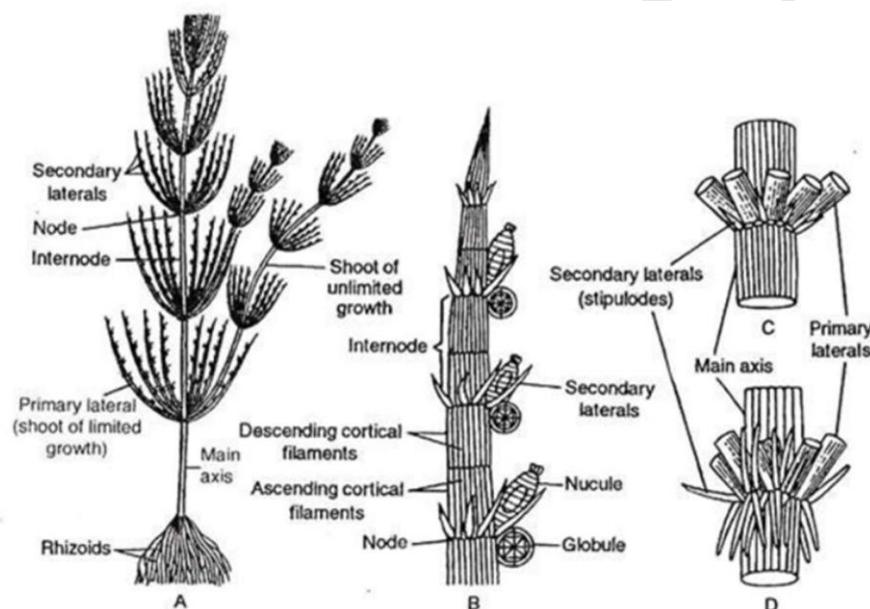


Fig 3.25: Chara sp. A. External morphology. B. Shoot (branchy of limited growth or primary lateral, C-D. Appendages on node (C. *Haplostephanous* and D. *Diplostephanous* type).

A. Rhizoid: The rhizoids are thread-like, white, multicellular, uniseriate, and branched. It is an elongated, branched structure having oblique septa. They are developed either from the base of the plant body or from peripheral cells of lower nodes of the main axis.

B. Main Axis: It is an erect, long, branched epigeal portion of the plant body, which is differentiated into internodes and nodes.

(i) **Internodes:** Generally, it consists of two types of cells: i. axial cell or internodal cell,

and ii. cortical cells. i Axial Cell: It consists of an elongated central cylindrical cell (Fig. 3.25).

ii. Cortical Cells

These are elongated but much smaller in diameter than axial cells and ensheathed or corticated as a layer on the outer surface of the axial cell (Fig. 3.25). They originate from the node. After originating from the node, 50% of the cortical cells grow upward as the ascending filaments and the rest 50% grow downward as the descending filaments (Fig. 3.25 B).

The ascending filaments cover the lower half, and the descending filaments cover the upper half of the axial cell. Cortication is not common in all species.

Depending on the presence or absence of cortex, the species of Chara are divided into two types: Corticate (e.g., *C. fragilis*, *C. zeylanica*, *C. hatei*, etc) and Ecorticate (e.g., *C. corallina*, *C. succinata*, *C. wallichii*, *C. braunii*, etc.).

(ii) **Node:** The node consists of two cells surrounded by 6-20 peripheral cells (Fig. 3.25 C, D). Three types of appendages are developed from each node.

These are

1. Branches of unlimited growth, 2. Branches of limited growth, and 3. Stipulodes.

1. Branches (Shoots) of Unlimited Growth:

They are also called axillary branches or long laterals (Fig. 3.25 A) and are developed from the older nodes. These branches are also differentiated into nodes and internodes like the main axis. Each node bears branchlets like the main axis.

2. Branches (Shoots) of Limited Growth

They are also called primary laterals, branchlets, or leaves (Fig. 3.25 B). About 6-16 branchlets develop in whorls around the node of the main axis or branch of unlimited growth. It is also divided into 5-15 nodes and internodes. Each node develops some unicellular, hair-like secondary laterals. Sex organs are developed on the lower nodes of each branchlet.

Stipulodes: These are unicellular outgrowths developed from lower nodes of branchlets i.e., branches of limited growth. The number of stipulodes at each node may be equal to the number of branchlets, which is called unistipulate (*C. nuda*, *C. brouni*, *C. corallina*) or if double, it is called bistipulate (*C. contraria*, *C. tomentosa*, *C. baltica*).

Depending on the arrangement of stipulodes species of *Chara* are divided into haplostephanous (i.e., stipules are arranged in a single row) e.g., *C. braunii*, and *diplostephanous* (i.e., stipules are arranged in two rows), e.g., *C. delicatula* (Fig. 3.25 C, D).

Cell Structure of Chara: The nodal cells are short, uninucleate, with dense and granular cytoplasm and many discoid chloroplasts without pyrenoids. Small vacuoles may be present in the cytoplasm. The internodal cells are long, with a large central vacuole, many nuclei, and many discoid chloroplasts in the cytoplasm. The cytoplasm is differentiated into outer ectoplasm and inner endoplasm. The endoplasm shows streaming movement.

Growth: Growth of *Chara* takes place by a dome-shaped apical cell. The cell undergoes repeated transverse divisions and forms a row of three cells (Fig. 3.26 A-B). The upper one remains as the apical cell, the middle biconcave one forms the nodal initial and the lower one forms the internodal initial.

The nodal cell undergoes repeated vertical divisions and ultimately forms two central cells surrounded by 6-20 peripheral cells. Branches of limited growth are developed from the peripheral cells arranged in a single row. The internodal initial does not divide further and elongates much more to form a long internode (Fig. 3.26).

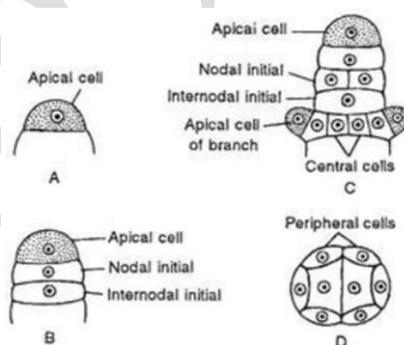


Fig. 3.26: Chara sp. A. Stages of growth, and D. T.S. of node.

Important Features of *Chara*:

1. The plant body shows very much of complexity in its structure.
2. They remain attached to the substratum by rhizoids.
3. The main axis is differentiated into nodes and internodes. Each node bears several branches of limited growth and sometimes single branches of unlimited growth.
4. The branches of limited growth are also differentiated into nodes and internodes. Each node bears both the sex organs (Nucule i.e., female, and globule i.e., male) and secondary

laterals. Nucleus is situated above the globule.

5. Reproduction is of two types: Vegetative and Sexual.
6. Vegetative reproduction takes place using specialised star-like, tuber-like and protonema-like structures.
7. Sexual reproduction is of oogamous type. The nucleole is oval-shaped and very much protected, which contains one egg and globule is round and develops many antherozoids. Zygote is produced after sexual reproduction. It shows very much elaborate post-fertilisation changes.
8. During germination, the zygote undergoes meiosis, and gradually it forms the plant body of Chara.

Reproduction in Chara: Chara reproduces by both vegetative and sexual means. Asexual reproduction is absent.

Vegetative Reproduction: Vegetative reproduction takes place by the formation of the following structures.

1. **Bulbils:** These are small, oval, or spherical bodies developed on the stem or root nodes. Bulbils are formed on the root of *C. aspera* and the stem of *C. baltica*. After detachment, they germinate and develop new plants (Fig. 3.27 A, B).
2. **Amorphous Bulbils:** These are small cells developed and aggregated at the node, called amorphous bulbils. They are found in *C. fragilis*, *C. baltica* etc. On being detached from the mother plant, they germinate and develop into new plants (Fig. 3.27 C).

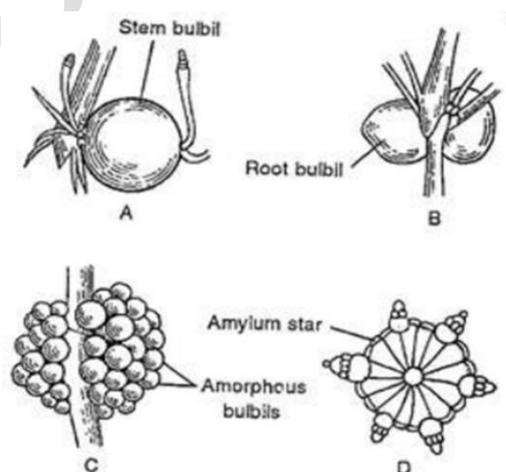


Fig. 3.27: Chara sp. A. Stem bulbil, B. Root bulbil, C. Amorphous bulbil, and D. Amylum star.

3. **Amylum Stars:** These are multicellular aggregations of cells, looking like stars and the

cells are densely filled with amyloamorphous starch; thus, they are called amyloamorphous stars. The amyloamorphous stars are developed at the nodal cells of the basal region e.g., *C. stelligera* (Fig. 3.27 D).

4. Secondary Protonema: These are thread-like structures developed from primary protonema or the basal cell of the rhizoid. New plants are also developed from the secondary protonema.

Sexual Reproduction: Sexual reproduction of *Chara* is an advanced oogamous type. The sex organs are macroscopic and large. The male sex organ is spherical and yellow to red, called a globule. The female sex organ is oval and green in colour, called the nucule or oogonium.

They develop on the nodes of the branch of limited growth (i.e., primary lateral), intermingled with secondary laterals. Nucule is always situated singly above the globule (Fig. 3.28).

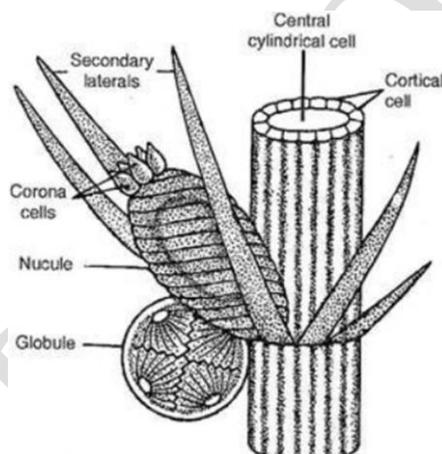


Fig 3.28: *Chara* sp.: A portion of the branch of limited growth showing attachment of nucule, globule and secondary laterals at the node.

Structure of Mature Globule

Mature globules are spherical in shape and yellow to red (Fig. 3.29C). Each globule consists of eight curved plates, situated towards the outer side, which are the shield cells.

From the inner side of each shield cell, a centrally placed rod-shaped structure is developed, called the manubrium. At the distal end of each manubrium, one or more globose cells develop and are called primary capitula. Each primary capitulum develops two or more secondary capitula.

Finally, each secondary capitulum develops 2-4 long antheridial filaments (Fig. 3.29 H, I).

Each antheridia filament has 25-250 cells, and each cell, i.e., antheridium (Fig. 3.29 J, K), forms a biflagellate, coiled and uninucleate antherozoid (Fig. 3.29 L). Thus, a globule can develop as many as 20,000 to 50,000 antherozoids.

Most of the species are homothallic or monoecious (i.e., male and female sex organs develop on the same plant), but some are heterothallic or dioecious (e.g., *C. wallichii*).

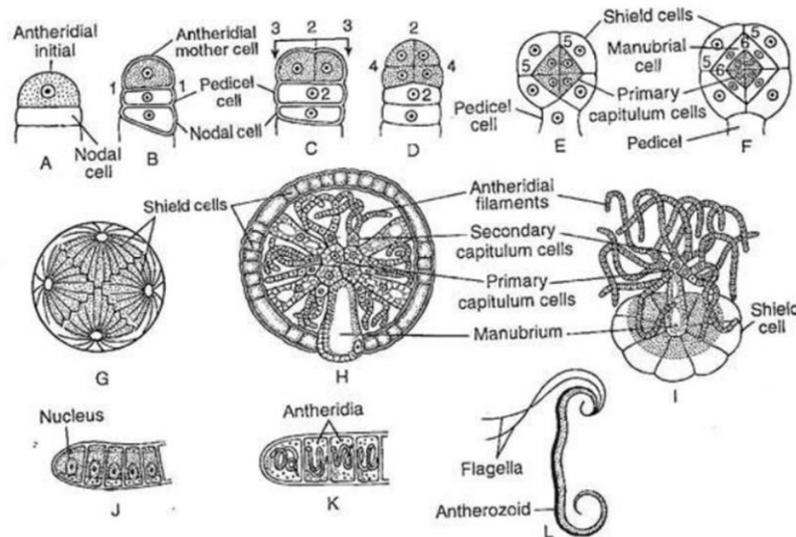


Fig. 3.29: Chara sp. Development of the globule. A-F. Stages in the development of globule, G. Mature globule, H. Globule in longitudinal section, I, A shield cells with manubrium, primary and secondary capitulum cells and spermatogenous filaments, J-K. Stages in spermatogenesis, L. An antherozoid.

Structure of Mature Nucule or Oogonium

The nucule of Chara is oval with a short stalk. Like a globule, it is also developed at the node of primary laterals just above the globule in homothallic species. It consists of a centrally placed one central cell, one stalk, and one large egg at the top (Fig. 3.30H). The entire structure is covered from the base by five spirally twisted tube cells except at the apex, where they form a crown made up of five corona cells (Fig. 3.28, 3.30H).

The jacket of the nucule shows similarity with the neck cells of the archegonium of the Bryophyte.

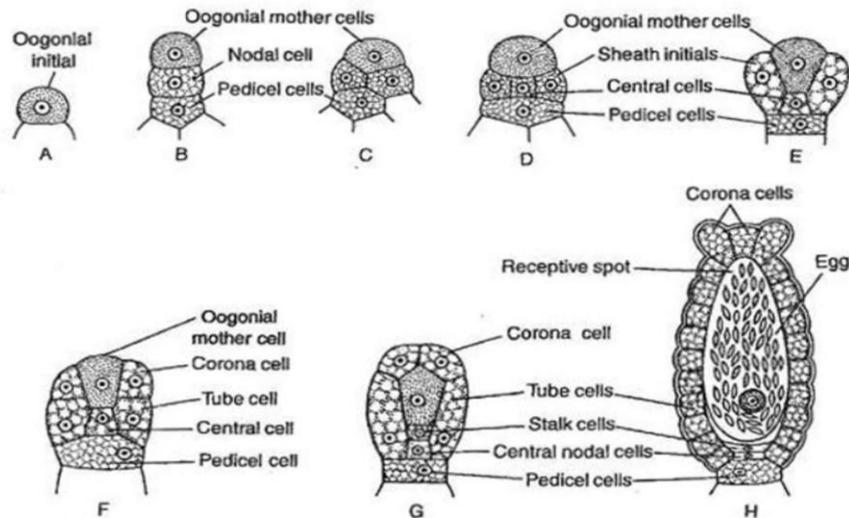


Fig 3.30: Chara sp. Development of nucule: A-G. Stages in the development of nucule, and H. L.S. of Mature Nucule.

Development of Sex Organ in Chara

Development of globule (Fig. 3.29). The globule develops at the node of branches of limited growth. Single peripheral cell of each node functions as the antheridial initial (Fig. 3.29A). The antheridial initial first undergoes transverse division (1-1) to form 2 cells, of which the lower one is the pedicel cell, which forms the stalk.

The upper one is the antheridial mother cell. The antheridial mother cell then undergoes two vertical divisions at right angles to each other (2-2, 3-3) followed by one transverse division (4-4), thus an octant (8-celled stage) is formed.

Each cell of the octant stage then undergoes periclinal division (5-5) to form outer 8 and inner 8 cells. Either the outer or the inner cells then undergo another periclinal division (6-6), thus forming 3 layers of 8 cells each (Fig. 3.29B-F).

The outer 8 cells form the 8 shield cells, the middle 8 cells form the manubrium and the inner 8 cells form primary capitula. The primary capitula further divide and form two or more secondary capitula (Fig.3.29H, I).

Each secondary capitulum further divides and forms 2-4 antheridial filaments consisting of 25 to 250 antheridial cells or antheridia, formed by repeated mitotic divisions. The protoplast of each antheridium metamorphoses into single biflagellate and coiled antherozoid (Fig. 3.29 K, L).

Development of nucule (Fig. 3.23). The oogonial initial is developed from the peripheral nodal cell of the primary laterals (Fig. 3.30A). The oogonial initial cell undergoes two transverse divisions, thus forming a 3-celled stage. The lowermost is the pedicel cell, the

middle one is the nodal cell, and the uppermost one represents the oogonial mother cell (Fig. 3.30B). The pedicel cell remains undivided and forms the stalk of the nucule.

The middle one undergoes several vertical divisions; thus, 5 sheath initials are formed which surround a central cell (Fig. 3.30C, D). The oogonial mother cell divides transversely and forms the lower stalk cell and the upper egg (Fig. 3.30G). The egg elongates further and forms an oval structure. The apical region of the egg develops the receptive spot. A large amount of oil and starch is deposited in the ovum.

The sheath initially elongates further and divides transversely into upper small cells, the corona cells, which form a crown-like structure at the top of the oogonium, and the lower five cells form the tube cells (Fig. 3.30F, G). The tube cells elongate and become spirally twisted in a clockwise direction outside the oogonium, giving protection to the egg (Fig. 3.28).

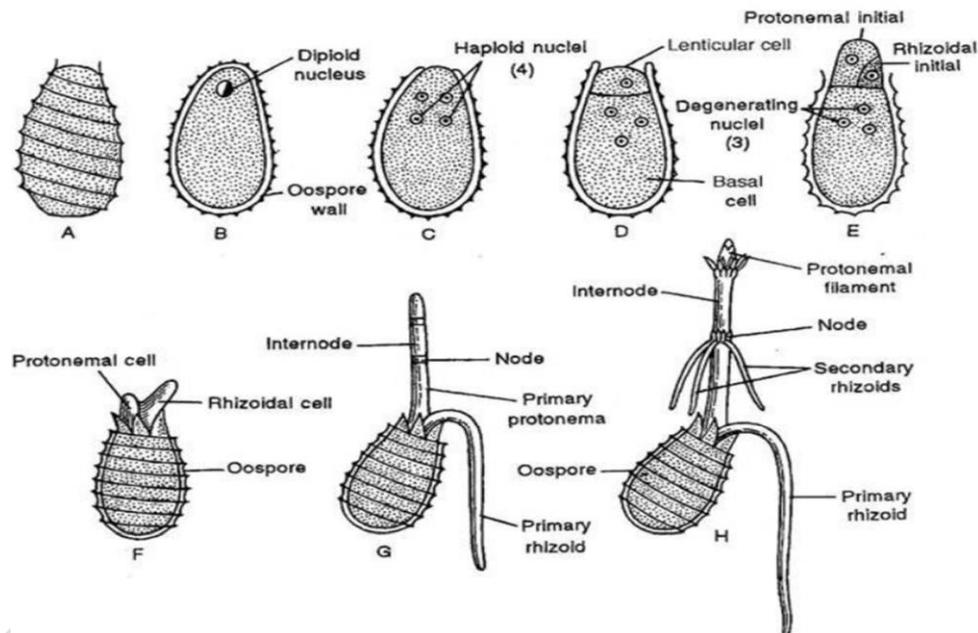


Fig. 3.31 Chara sp.: A-H. Successive stages in oospore germination.

Fertilisation: During fertilisation, the tube cells just below the corona get separated slightly and form five narrow slits or openings. The antherozoids get entry through these slits (Fig. 3.30H). Out of many aggregated antherozoids towards the slits, only one comes near the receptive spot of the egg. On contact with the egg, it fuses and forms an oospore (2n).

Oospore: It is hard, spherical to ellipsoidal, and of various colours like light yellow, brown, red, or black. It is surrounded by four-layered walls, of which the outer two are coloured and the inner two are colourless.

Germination: During germination, the nucleus of the oospore migrates towards the upper region (Fig. 3.31 B). The nucleus then undergoes meiotic division to form 4 haploid nuclei (Fig. 3.31 C). The oospore then divides into two unequal cells, of which the upper lenticular cell contains one nucleus, and the lower large basal cell contains three nuclei (Fig. 3.31 D). The nuclei of the basal cells gradually degenerate.

The lenticular cell projects out by rupturing the oospore wall and divides mitotically by an oblique longitudinal septum to form a larger protonemal initial and a small rhizoidal initial (Fig. 3.31 E). Both the initials grow in opposite directions. The protonemal initial is differentiated into nodes and internodes and forms the upper part of the plant body, whereas the rhizoidal initial forms rhizoids (Fig. 3.31 F, G, H). Secondary rhizoids may develop from the lower node of the protonemal filament (Fig. 3.31 G)

Life Cycle of Chara

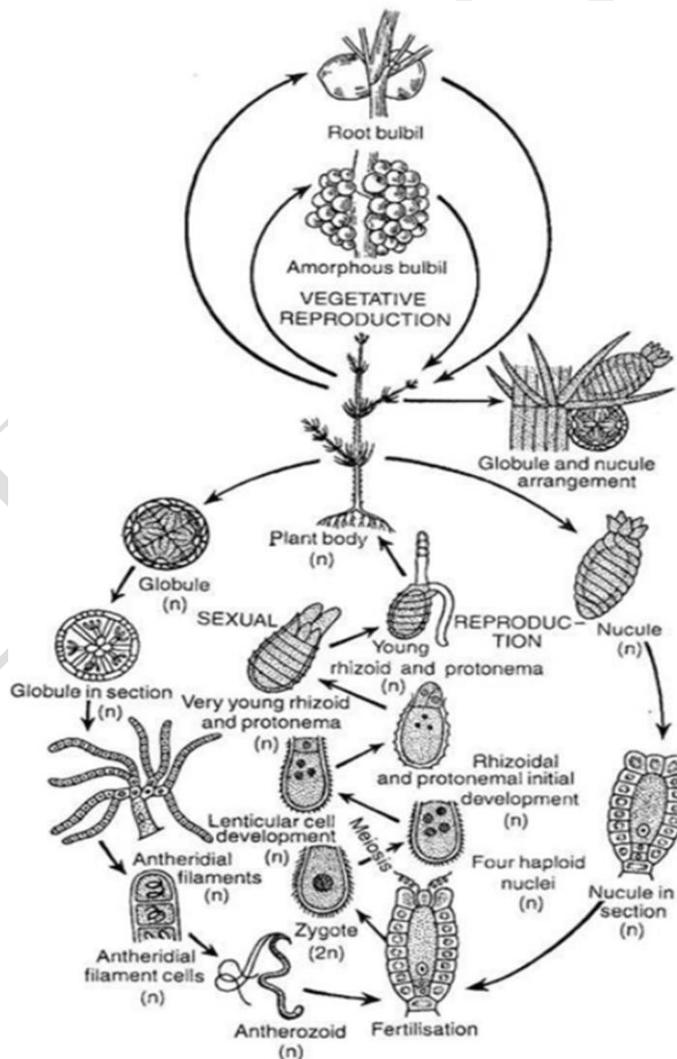


Fig. 3.32 Life cycle of Chara.

EXERCISE

I Short Answer Questions (5–6 sentence answers expected): Short Answer Questions (4).

1. What pigments are primarily responsible for the green color of Chlorophyceae?
2. Name any two genera of green algae that reproduce through fragmentation.
3. Which order of Chlorophyceae includes branched filaments with multinucleate cells?
4. What type of sexual reproduction is exhibited by *Spirogyra* and *Zygnema*?
5. What are the key characteristics of the division Chlorophyta to which Chlorophyceae belongs?
6. Briefly describe the classification of Chlorophyceae according to F.E. Fritsch (1944).
7. How did G.M. Smith and V.J. Chapman classify Chlorophyceae differently from Fritsch?
8. What are the main features of the order Volvocales under Chlorophyceae?
9. Describe the structure and reproductive features of the genus *Volvox*.
10. What type of habitat is preferred by *Pandorina*, and where is it commonly found?
11. Describe the structure and arrangement of cells in a *Pandorina* colony.
12. What is a coenobium, and how is it formed in *Pandorina*?
13. Explain the role of the gelatinous matrix in *Pandorina* colonies.
14. What is a motile coenobium and how is it represented in *Volvox*?
15. What are gonidia and what role do they play in *Volvox*?
16. How are vegetative cells of *Volvox* different from reproductive cells?
17. What is the plakea stage in *Volvox*, and how does inversion take place?
18. What is the difference between homothallic and heterothallic species of *Volvox*?
19. Explain the process of oogonium development in *Volvox*.
20. Describe the structure of a mature *Hydrodictyon* coenobium.
21. How does *Hydrodictyon* form daughter colonies through asexual reproduction?
22. Describe the structure and branching pattern of *Cladophora* filaments.
23. What are the major steps involved in zoospore formation and germination in *Cladophora*?
24. What are cap cells in *Oedogonium*, and how are they formed?
25. Differentiate between macrandrous and nannandrous species of *Oedogonium*.
26. Describe the structure of a vegetative cell in *Oedogonium*.
27. Write a note on zoospore formation in *Oedogonium*.
28. Why is *Chara* called stonewort?
29. Differentiate between corticate and ecorticate species of *Chara*.

30. Define stipulodes and mention their types in *Chara*.

II Essay Questions (2)

1. Describe the various types of thallus structures found in Chlorophyceae with suitable examples.
2. Explain the different types of reproduction in Chlorophyceae and give examples for each type.
3. Discuss the major classification systems of Chlorophyceae proposed by F.E. Fritsch, G.M. Smith, and V.J. Chapman, highlighting their similarities and differences.
4. Describe the various economic and ecological roles of Chlorophyceae in detail, including their applications in food, industry, agriculture, environment, and biotechnology.
5. Discuss in detail the structure, habitat, reproduction (asexual and sexual), and life cycle stages of *Pandorina*.
6. Describe the detailed structure of a *Volvox* colony, highlighting the cellular components and their functions.
7. Explain the process of asexual reproduction in *Volvox*, focusing on gonidial development and daughter colony formation.
8. Outline the stages of sexual reproduction in *Volvox*, including antheridium and oogonium formation, fertilization, and zygote development.
9. Write a comparative account of the reproductive strategies in *Pandorina* and *Volvox* with diagrams.
10. Illustrate and explain the life cycle of *Volvox*, including both sexual and asexual phases with structural changes.
11. Describe in detail the structure, types of reproduction (vegetative, asexual, and sexual), and life cycle of *Hydrodictyon*, highlighting the unique features of its reproduction and colony formation.
12. Explain the occurrence, thallus structure, and detailed reproduction strategies (vegetative, asexual, and sexual) of *Cladophora*, highlighting adaptations to both freshwater and marine environments.
13. Describe the plant body, cell structure, and types of cell division in *Oedogonium*.
14. Explain the methods of reproduction in *Oedogonium* with diagrams.
15. Describe sexual reproduction in nannandrous species of *Oedogonium*. How do dwarf males develop?
16. Describe the external morphology and anatomical structure of *Chara*

17. Describe the mode of reproduction in *Chara*
18. Explain the development and structure of sex organs in *Chara*.

EJBPS BOOK

UNIT IV: XANTHOPHYCEAE

1.1 Xanthophyceae (Yellow-Green Algae)

Occurrence and Habitat of Xanthophyceae (Yellow-Green Algae)

Xanthophyceae, commonly known as yellow-green algae, are primarily found in **freshwater environments**, although some species are also present in **marine, soil**, and even **polar regions**.

1. Freshwater Habitats

Phytoplankton and Periphyton: These algae occur as: *Phytoplankton*: Free-floating in lakes, ponds, rivers, and streams. *Periphyton*: Attached to submerged surfaces like rocks and plants. **Still Water Bodies:** Many unattached forms thrive in still water environments, often found: Among other algae and submerged vegetation. In habitats with **low pH** and **iron-rich** conditions.

Late Winter Mats: Filamentous species, such as *Tribonema*, commonly form floating mats in still waters, especially during the **late winter months**.

2. Other Habitats

Soil: Coccoid (spherical) forms of Xanthophyceae are frequently found in soil, contributing to the soil algal biota

Marine Environments: Although less common in the sea, some benthic (bottom-dwelling) species inhabit **brackish waters** and **coastal areas**.

Polar Regions (Antarctica): Both coccoid and filamentous forms have been discovered in **terrestrial habitats** in Antarctica.

3. Ecological Preferences

pH: Xanthophyceae prefer **acidic conditions** (low pH).

Iron Availability: They are often found in **iron-rich environments**.

Water Type: Shows higher diversity in **dystrophic** (high organic content, acidic) and **mesotrophic** (moderately nutrient-rich) waters.

1. Pigmentation: Xanthophyceae have **chlorophyll a**, **β -carotene**, and **xanthophylls** like *lutein* and *neoxanthin*. **Chlorophyll b is absent**, which distinguishes them from green algae. These pigments give them a **yellow-green appearance**.

2. Storage Products: The main food reserve is **chrysolaminarin**, also called **leucosin**, which is a type of carbohydrate. They may also contain **oil droplets** in small amounts. **Starch is completely absent**, unlike in many other algal groups.

3. Flagellation: Motile cells, such as **zoospores** or **gametes**, have **two unequal flagella** at their front end. The **longer flagellum** is of **tinsel type**, having fine hair-like structures. The **shorter flagellum** is of **whiplash type**, which is smooth. This unequal flagellum arrangement is known as **heterokont**, which is a key feature of this group.

4. Cell Wall Structure

In some genera, the **cell wall is made of two overlapping halves**, resembling diatoms. The wall may be composed of **cellulose** or may be **partially silicified**, depending on the species.

5. Reproduction: **Asexual reproduction** occurs through **zoospores**, **aplanospores**, and **statospores** (which are thick-walled resting spores). **Sexual reproduction is rare** and mostly **isogamous**, where similar gametes fuse. In one genus, a type of sexual reproduction called **cogamy** (a form of anisogamy or oogamy) is also found.

6. Habitats: Most Xanthophyceae species live in **freshwater**, especially in **soft and slightly acidic waters**. Some species are **aquatic** (e.g., *Tribonema*), while others are **terrestrial** (e.g., *Botrydium*). A few species are found in **marine or brackish water** environments.

7. Thallus Organization: The body structure of these algae varies widely. They may be **unicellular**, either motile or non-motile. They can also be **colonial** (groups of cells), filamentous (thread-like), or **siphonaceous** (tubular and multinucleate). This variety in structure is like that seen in green algae (Chlorophyceae).

Classification of Xanthophyceae

The class Xanthophyceae includes **six main orders**:

1. Heterochloridales,
2. Rhizochloridales,
3. Heterocapsales,
4. Heterotrichales,
5. Heterococcales and
7. Heterosiphonales

1. Heterochloridales: The plant body is **unicellular, naked, and flagellated**. Each cell contains **two or more discoid or band-shaped chromatophores** and **one or more contractile vacuoles**. Reproduction occurs by **simple cell division** and sometimes by **statospores**. This order has **9 genera and about 15 species**; 4 are marine, and the rest are

freshwater.

- **Important genus:** *Chloromeson*.

2. Rhizochloridales: The plant body is **amoeboid** and moves using **pseudopodia**. Several individuals may form connections via **cytoplasmic bridges**. They are mostly **naked** or **partially covered**, and may attach to a surface using a **stalk**. Reproduction is by **cell division**, **zoospores**, **aplanospores**, or **statozooids**. The cells may be **uninucleate** or **multinucleate**, with one-to-many chromatophores. There are **7 genera and around 10 species**, mainly freshwater.

Important genus: *Chlorachnion*.

3. Heterocapsales: The plant body is **palmelloid**, forming **gelatinous colonies** that are amorphous or dendroid (tree-like). The cells can **revert to a motile form** directly. Reproduction happens through **fragments**, **akinetes**, and **zoospores** (which may further divide). There are **8 genera and about 9 species**, all freshwater.

- **Important genus:** *Gloeochloris*.

4. Heterotrichales: The plant body is a **simple or branched filament**. Reproduction occurs via **fragmentation**, **akinetes**, **zoospores**, **aplanospores**, and **hypnozooids**. **Physiological isogamy** (fusion of similar gametes differing only physiologically) is found in *Tribonema*. The order includes **8 genera and around 35 species**, all freshwater.

- **Important genus:** *Tribonema*.

5. Heterococcales: These are non-filamentous forms that cannot revert to motile stages. Cells may be uninucleate or multinucleate and usually have two overlapping cell wall halves. The plant body is either coccoid (spherical) or colonial. Reproduction is by zoospores and aplanospores (autospore type). They do not divide vegetatively. This is the largest order, with 45 genera and about 270 species, all freshwaters. Important genus: *Botrydiopsis*.

6. Heterosiphonales: All members are siphonaceous, multinucleate, and unicellular in structure. Asexual reproduction occurs through zoospores, aplanospores, and hypnozooids. The thallus is coenocytic, meaning the cytoplasm contains multiple nuclei without internal cell walls.

EXERCISE

I Short Answer Questions (5–6 sentence answers expected).

1. What are the common habitats of Xanthophyceae?
2. What are the key pigments found in Xanthophyceae, and how do they differ from green algae?
3. What is heterokont flagellation, and how is it exhibited in Xanthophyceae?
4. Name and describe the significance of two important genera from the class Xanthophyceae.
5. Mention any two representative genera from different orders of Xanthophyceae and describe one characteristic feature or habitat of each.

II Essay Questions (2–3 pages)

1. Discuss the occurrence, ecological preferences, and structural diversity of Xanthophyceae.
2. Give a detailed account of the classification of Xanthophyceae, highlighting key features of each order.

Genus: *Vaucheria*

Occurrence of *Vaucheria*

Systematic Position: Class: Chlorophyceae **Order:** Siphonales **Family:** Vaucheriaceae

Genus: *Vaucheria*

Vaucheria is represented by 54 species, of which about 19 species are found in India. *Vaucheria* is found mostly in freshwater, but about six species are marine, and some are terrestrial, found on moist soil.

The terrestrial species like *V. sessilis* and *V. terrestris* form green mats on moist soil in shady places in greenhouses. *V. amphibia* is amphibious. *V. jonesii* was reported by Prescott (1938) in winter ice in the U.S.A. The common Indian species of *Vaucheria* are *V. amphibia*, *V. geminata*, *V. polysperma*, *V. sessilis*, and *V. uncinata*, etc.

Thallus: The thallus is made of long, cylindrical well branched filaments. The filament is aseptate, coenocytic structure. The thallus is attached to substratum through branched rhizoids or branched holdfasts called the haptera. The thallus of *V. mayyanadensis* is differentiated in a subterranean branched rhizoidal system and an erect aerial system. The filaments are rough, interwoven, and appear as a dark green felt-like structure.

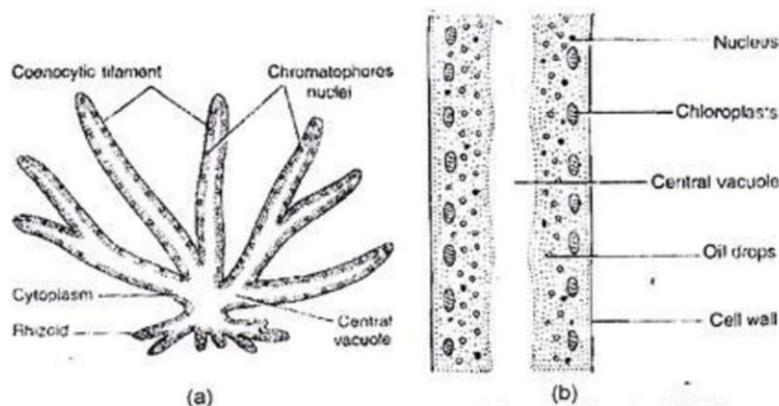


Fig. 4.1. (A, B). Vaucheria structure. (A) Entire thallus, (B) A part of thallus.

Some species like *V. debaryana* show calcium carbonate incrustations. The branching may be lateral or dichotomous. The filaments are non-septate, the protoplasm with many nuclei is continuous along the entire length of thallus, thus the coenocytic Vaucheria thallus makes siphonaceous structure (Fig. 4.1A, B). The septa formation occurs only during reproduction or in *Gongrosira* condition or for sealing of an injury.

The thallus structure is differentiated into the cell wall and protoplasm. The cell wall of the thallus is thin, weak, and non-elastic. The cell wall is made of two layers; the outer layer is pectic, and the inner layer is cellulosic. Inner to the cell wall, there is a thick layer of protoplasm. A very large central vacuole filled with cell sap runs from one end of the filament to another, forming a continuous canal or siphon.

In the peripheral part of protoplasm are present many small oval or disc-shaped chloroplasts which lack pyrenoids (Fig. 4.1 B). Christensen (1952) reported the presence of pyrenoids in chromatophores.

The chromatophores in *Vaucheria* contain pigments, chlorophyll a, chlorophyll e, carotenoids and an unknown xanthophyll. The pigments in *Vaucheria* are like those of Xanthophyceae as chlorophyll b the characteristic pigment of Chlorophyceae is absent.

Many small nuclei lie in the cytoplasm inner to the layer of chloroplasts. The arrangement of nuclei concerning chloroplasts is reversed at the time of zoospore formation. The cytoplasm also contains other membrane-bound cell organelles such as mitochondria, small vesicles, and food is stored in the form of oil. The growth of the filament is apical, the filament increases in length by apical growth of all the branches.

The thallus of *Vaucheria* is a branched, non-septate, and multinucleate structure that appears like a single large cell, but *Vaucheria* cannot be considered as a single cell. As in multicellular forms, mitotic divisions take place, increasing the number of nuclei. The apical growth takes place. Hence, the aseptate coenocytic structure of *Vaucheria* should be considered as an acellular coenocyte.

Reproduction in *Vaucheria*.

Reproduction in *Vaucheria* takes place by vegetative, asexual and sexual methods.

(i) **Vegetative Reproduction in *Vaucheria*:** The vegetative reproduction takes place by fragmentation. The thallus can break into small fragments due to mechanical injury or insect bites etc. A septum develops at the place of breaking to seal the injury. The broken fragment develops thick wall and later develops into *Vaucheria* thallus.

(ii) **Asexual Reproduction in *Vaucheria*:** The asexual reproduction takes place by the formation of zoospores, aplanospores, and akinetes.

(a) **By Zoospores:** The zoospore formation is the most common method of reproduction in aquatic species. In terrestrial species, it takes place when the plants are flooded. Zoospore formation takes place in favourable seasons or can be induced if aquatic species are transferred from light to darkness or from running water to still water.

Zoospores are formed singly within elongated club-shaped zoosporangium (Fig. 6.2A, B). The development of zoosporangium begins with a club-shaped swelling at the tip of a side branch. Many nuclei and chloroplasts along with the cytoplasm move into it. A colourless protoplasmic region becomes visible at the base of the cytoplasm, and it is separated from the rest of the cytoplasm of the thallus.

Each separated protoplast secretes a thin membrane, and the zoosporangium gets separated by a cross wall. Inside the zoosporangium, the vacuole decreases, and the contents of the sporangium become very dense and round off. The change takes place in the relative position of chloroplasts and nuclei, the nuclei become peripheral, and chloroplasts enter in inner layer of cytoplasm.

The entire protoplasm of the zoosporangium contracts to form oval zoospore. Opposite to each nucleus, two flagella are produced, making the zoospore a multi-flagellate structure. A terminal aperture develops in the zoosporangium by gelatinization of the wall. The zoospore

is liberated through an aperture in the morning hours (Fig. 24.C, D).

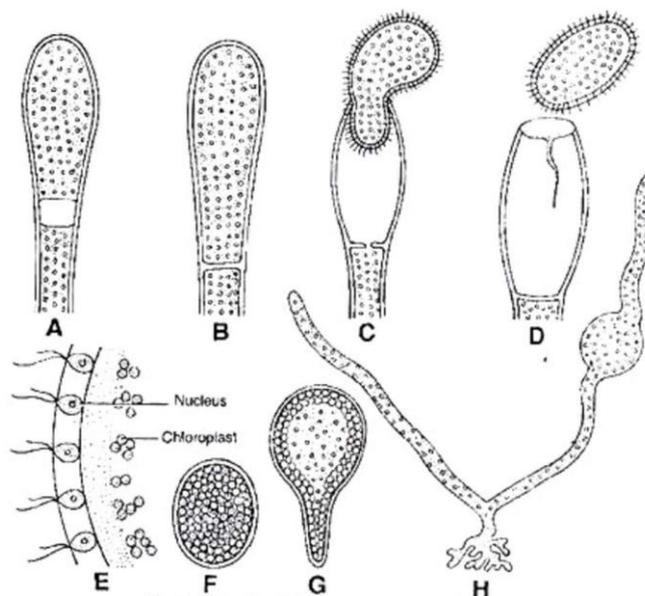


Fig. 4.2. (A-H). Vaucheria. Asexual reproduction.

Each zoospore is a large, yellow-green, oval structure. It has a central vacuole, which has cell sap and may be traversed by cytoplasmic strands. The protoplasm outer to vacuole has many nuclei towards the walls and chromatophores towards the vacuoles. Two flagella arise opposite each nucleus. This part of the cytoplasm can be regarded as equivalent to one zoospore.

Fritsch (1948) regarded this kind of zoospore as a compound zoospore or synzoospore, as a few biflagellate zoospores have failed to separate from one another.

According to Greenwood, Manton, and Clarke (1957), the flagella of a pair are heterokontic and whiplash type. The shorter flagellum of each pair is directed towards the anterior end of the zoospore. The flagellar bases are united in pairs and are firmly attached to the tips of the nuclei.

According to Greenwood et. al (1957), there is large anterior vacuole and small ones in the posterior region of the zoospores. Mitochondria are present in the peripheral layer of cytoplasm. Fat bodies and plastids are present in the cytoplasm. Chlorophyll has also been reported from the zoospores.

The zoospores swim in water for 5-15 minutes and germinate without undergoing any

significant period of rest. The zoospores get attached to the substratum, withdraw flagella and secrete thin walls (Fig. 4.2 E, F). The chromatophores move outwards and nuclei inwards as in the vegetative condition.

The two tube-like outgrowths develop in opposite directions. One of the two outgrowths elongates, branches to form a colourless lobed holdfast, and the other outgrowth forms a yellow-green tubular coenocytic filament (Fig.4.2 G, H).

(b) By Aplanospores: Aplanospores are commonly observed in species. *V. geminata*, *V. uncinata* and in marine species *V. pitoboloides*. The aplanospores are generally formed by terrestrial species. Aquatic species form aplanospores under unfavorable condition of drought. The aplanospores are non-motile asexual spores formed in special structures called aplanosporangia (Fig. 4.3 A-C). The aplanospores are produced singly in cells at the terminal end of the short lateral or terminal branch. The protoplasm of an aplanosporangium gets metamorphosed into a single multinucleate aplanospore which is thin-walled. In *V. geminata* aplanospores are oval and are liberated from an apical pore formed by gelatinization.

In *V. uncinata* aplanospores are spherical and are liberated by rupture of the sporangial wall. The formation and structure of aplanospores and zoospores is similar except that the zoospores lack flagella. The aplanospores soon after liberation germinate into new thalli (Fig. 4.3D).

(c) By Akinetes: Akinetes are thick-walled structures formed during unfavorable conditions like drought and low temperature. The akinetes have been commonly observed in *V. geminata*,

V. megaspora and *V. uncinata*.

The akinetes are formed on the terminal part of lateral branches where protoplasm migrates to the tips, followed by cross-wall formation (Fig. 4.4). These multinucleate, thick-walled segments are called akinetes or hypnosporos.

The akinetes, by successive divisions, may form numerous thin-walled bodies called cysts. When many akinetes remain attached to the parent thallus, the thallus gives the appearance of another alga, *Gongrosira*.

Hence this stage of *Vaucheria* is called the *Gongrosira* stage. During favourable conditions,

the akinetes and cysts develop into new thalli. Randhawa (1939) has reported that in *V. uncinata* the submerged parts of the thallus develop sex organs whereas the exposed parts of the thallus form brick-shaped akinetes.

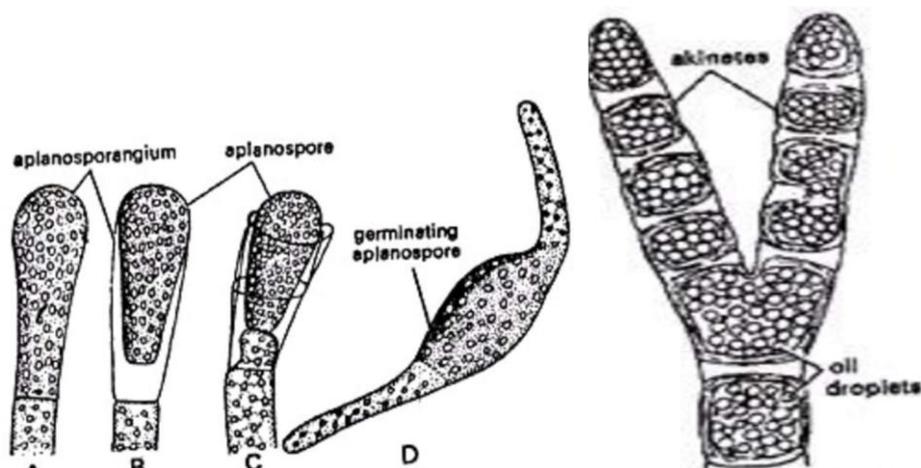


Fig. 4.4 (A-D) Vaucheria Akinetes Fig. 4.3 (A-D) Vaucheria. Aplanopore formation, liberation, and germination.

(iii) Sexual Reproduction in Vaucheria: In Vaucheria sexual reproduction is of an advanced oogamous type. The male and female sex organs are antheridia and oogonia, respectively. Majority of the freshwater species are monoecious or homothallic, while some species like *V. dichotoma*, *V. litorea* and *V. mayyanadensis* are dioecious or heterothallic. There are different types of arrangement of antheridia and oogonia in homothallic species. The position, structure, and shape of antheridia are of taxonomic importance in Vaucheria.

The common patterns of arrangement of sex organs are as follows:

- (a) Antheridia and oogonia develop close to each other on the filament at intervals (Fig. 4.5 A- C).
- (b) The antheridia and oogonia are borne on special side branches with a terminal antheridium and several lateral oogonia (Fig.4.5D).

In *V. hamata* the reproductive branches bear a median terminal antheridium and two oogonia, one on either side of the antheridium.

In *V. geminata* and *V. terrestris*, the sex organs are produced at the ends of the lateral branches with a terminal antheridium and a group of oogonia (Fig. 4.5D). The sex organs are unilateral when they are arranged on one side of the filament or bilateral when they are on both sides of the filament.

(c) Antheridia and oogonia are borne on adjacent branches (Fig.4.5E).

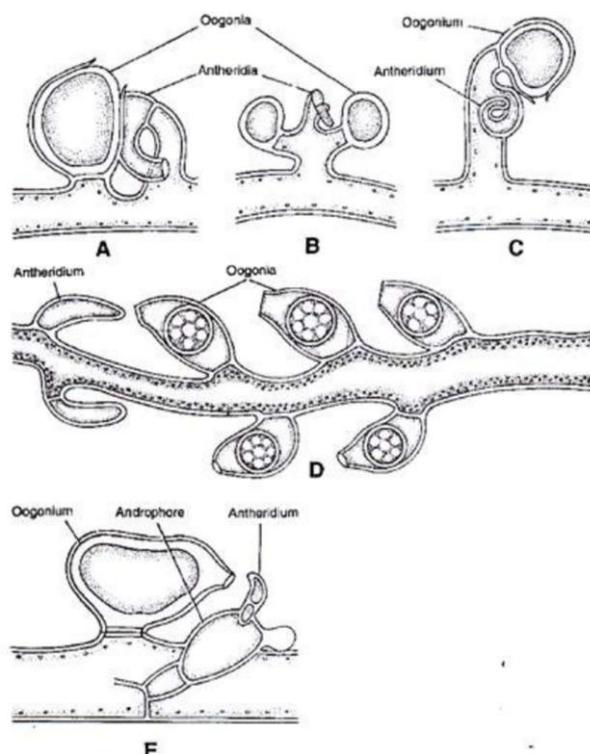


Fig 4.5 (A-E). Vauchería. Arrangement of antheridia and oogonia.

Structure and Development of Antheridium

The mature antheridia may be cylindrical, tubular, straight, or strongly curved. The antheridium is separated from the main filament by a septum. The antheridia can be sessile (without stalk) arising directly from the main branch e.g., *V. civersa*. The antheridia may be placed high on the branch the antheridia are situated on androphore *V. synandra*.

The young antheridium is usually green in colour. It contains cytoplasm, nuclei and chloroplasts. The mature antheridia are yellow and contain many spindle-shaped antherozoids. The antherozoids are liberated through a terminal pore, e.g., *V. aversa*, or through many pores e.g., *V. debaryana*.

In monoecious species, the antheridium arises as a small bulging or lateral outgrowth along with or before the oogonium development (Fig. 4.6A). Many nuclei, along with cytoplasm, enter it, and it gets cut off from the lower part, forming a septum.

The antheridium grows and becomes highly curved structured, its upper part is main antheridium and the lower part is the stalk. The nuclei of antheridium get surrounded by

cytoplasm and develop into biflagellate, yellow coloured antherozoids. The antherozoids are liberated from the tip of antheridium through the apical pore shortly before daybreak (Fig. 4.6D-1).

Structure and Development of Oogonium

The oogonium development starts with the accumulation of colourless multinucleate mass of cytoplasm near the base of the antheridial branch. This accumulated cytoplasm has been termed as “**wanderplasm**”. The wanderplasm enters the outgrowth or bulging of the main filament. This outgrowth is called as oogonial initial.

A large amount of cytoplasm and nuclei enter oogonia, making it a large globular structure called an oogonium (Fig. 4.6 B-E). As the oogonium matures, it gets separated from the main branch by the development of a septum at its base. The mature oogonium is an uninucleate structure. The nucleus of an oogonium with protoplasm develops into a single egg.

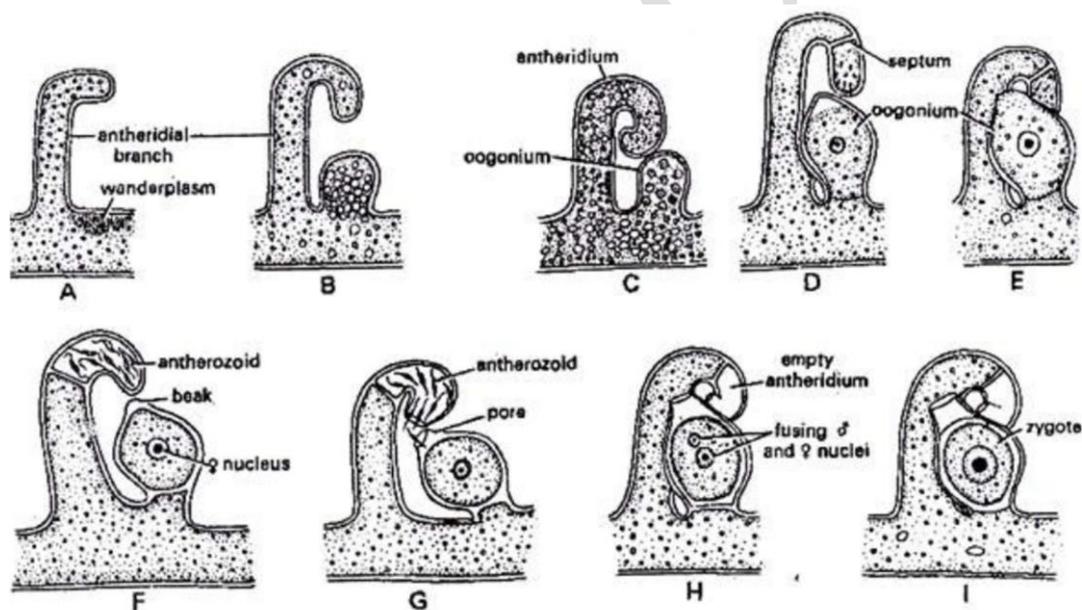


Fig 4.6 Vaucheria. Sexual reproduction in *V. sessilis*.

There are three hypotheses regarding the fate of extra nuclei of oogonium of Vaucheria.

- (a) According to Oltmanns (1895) accept a single nucleus which forms female nucleus, all other nuclei migrate back into the filament. This was supported by Heidinger (1908) and Couch (1932).
- (b) According to Davis (1904), the single nucleus forms the egg, and all other nuclei degenerate.

(c) According to Brehens (1890), all nuclei fuse to form a single nucleus.

The mature oogonia are globose, obovoid, hemispherical, or pyriform in shape. The oogonia may be sessile or stalked structures. The protoplast of an oogonium is separated from the main filament by septum formation.

The entire protoplasm with a single nucleus makes a central spherical mass called an oosphere or ovum. In mature oogonium, a distinct vertical or oblique beak develops in the apical part. Opposite to the beak develops a colourless receptive spot. A pore develops just opposite to the receptive spot (Fig. 4.6 F).

Fertilization

The oogonium secretes a gelatinous drop through a pore near the beak. Many liberated antherozoids stick to the drop. Many antherozoids push into the oogonium. The antherozoids strike violently, fall back, and push forward again and fall back. Only one antherozoid enters the oogonium.

After its entry, the membrane develops at the pore to stop the further entry of antherozoids. The male nucleus increases in size and fuses with the egg nucleus to make a diploid zygote. The zygote secretes a thick 3-7 layered wall and is now called an oospore (Fig. 4.5 G-I). The chromatophores degenerate and lie in the centre of the cell.

Germination of oospore

The oospore undergoes a period of rest before germination. During the favourable season, the oogonial wall disintegrates and the oospore is liberated. The oospore germinates directly into new filaments.

Although the exact stage at which the reduction division takes place in *Vaucheria* is not clear, it is believed that reduction division occurs in the first nuclear division in the germinating oospore (Fig. 4.6 A-D). The oospore germinates to make a haploid thallus of *Vaucheria*.

Life Cycle of *Vaucheria*

According to Williams, Hanatsche, and Gross, the life cycle of *Vaucheria* is haplontic, the oospore being the only diploid structure in the life cycle (Figs. 4.8, 4.9). *Vaucheria* thallus is haploid. It is aseptate, branched, tubular, and coenocytic structure.

Vegetative reproduction takes place by fragmentation. Asexual reproduction takes place by zoospores in aquatic species and by aplanospores in terrestrial species.

The zoospore is a large multi multi-flagellate structure and is supposed to be compound Zoospore or Synzoospore.

The sexual reproduction is an advanced oogoinous type; the male and female sex organs are antheridia and oogonia. Most of the species are homothallic; some are heterothallic.

After fertilization, a diploid zygote is formed, which converts into an oospore and undergoes a period of rest. The reduction division takes place in the oospore during germination, and a haploid thallus is formed (Fig. 4.8,4.9).

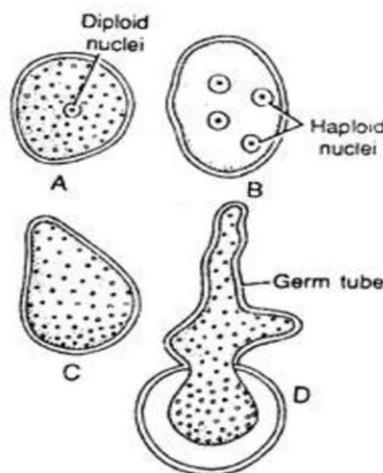


Fig 4.7: Vaucheria Germination of oospore.

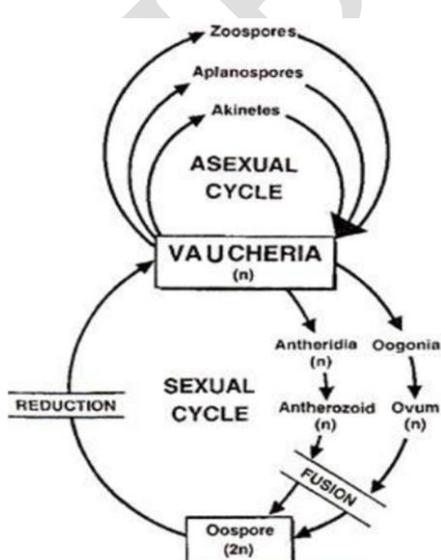


Fig 6.8 Graphic life cycle of Vaucheria sp.

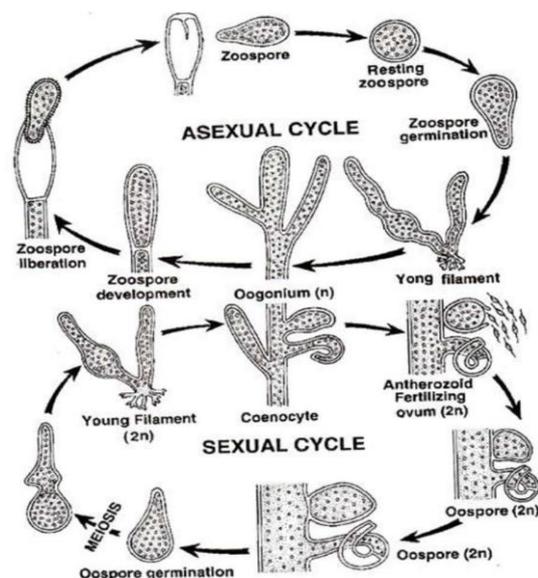


Fig 6.9: Life cycle of Vaucheria sp.

EXERCISE

I. Short Answer Questions (5–6 sentence answers expected)

1. Describe the habitat and occurrence of *Vaucheria*.
2. Explain the structure and nature of *Vaucheria* thallus.
3. How are zoospores formed in *Vaucheria*?
4. Differentiate between aplanospores and akinetes in *Vaucheria*.

Essay Questions (2–3 pages)

1. Discuss the structure and reproduction of *Vaucheria*, emphasizing its coenocytic nature and reproductive adaptations.
2. Describe the life cycle of *Vaucheria* and highlight its significance in understanding algal evolution.

EJBPS BOOK

UNIT V: BACILLARIOPHYCEAE

The members of the class *Bacillariophyceae* are commonly known as diatoms. They are microscopic, photosynthetic algae found in both freshwater and marine environments. Diatoms may exist as unicellular organisms or may form colonies in various shapes such as chains, ribbons, or stellate (star-like) groups.

One of the most distinctive features of diatoms is their siliceous cell wall, known as a frustule, which is composed of two overlapping halves, much like a petri dish. These frustules are highly sculptured and intricately ornamented, often with radial or bilateral symmetry, making them easily distinguishable from other algal groups. The presence of silica (SiO₂) in their cell walls also leads to the formation of fossil deposits known as diatomaceous earth, which has multiple industrial applications.

The class Bacillariophyceae is a large and diverse group, comprising about 190 genera and approximately 5,500 recognized species, though ongoing research and molecular studies suggest that the actual diversity may be much higher. Most diatoms are planktonic, drifting in the water column, while others are benthic, attached to submerged surfaces such as rocks, plants, or sediments.

Diatoms are primary producers, playing a critical role in aquatic food chains. They contribute significantly to global oxygen production and are key players in carbon fixation and silica cycling in aquatic ecosystems. Their sensitivity to environmental changes also makes them important bioindicators for monitoring water quality and ecological conditions.

Key Characteristics of Bacillariophyceae (Diatoms)

The class *Bacillariophyceae*, commonly known as diatoms, is characterized by the following distinctive features.

- 1. Thallus Structure:** The organisms may be unicellular or form colonies (in chains, ribbons, or clusters).
- 2. Ploidy of Vegetative Cells:** The vegetative cells are diploid (2n), unlike many other algal groups where they are typically haploid.
- 3. Frustule or Cell Wall Structure:** The cell is enclosed in a unique, silicified wall called a frustule, composed of two overlapping halves or valves – the epitheca (larger) and hypotheca (smaller).

- 4. Silicification:** The cell wall is impregnated with silica, giving it rigidity and intricate ornamentation. This siliceous wall persists after the cell dies and contributes to fossil deposits.
- 5. Chromatophores (Pigments):** The plastids contain chlorophyll-c along with fucoxanthin, diatoxanthin, and diadinoxanthin, imparting a characteristic golden-brown or brownish colour to the cells. Each cell may contain one to many chromatophores.
- 6. Reserve Food Material:** The main food reserves are oil droplets, and a carbohydrate called chrysolaminarin.
- 7. Size Reduction During Multiplication:** A unique feature is the gradual reduction in cell size during vegetative reproduction due to the way the new valve fits inside the older one. To restore original size, auxospore formation occurs – auxospores are larger than the cells that produce them.

Occurrence

Habitat and Distribution of Bacillariophyceae (Diatoms)

- **Cosmopolitan Distribution:** Diatoms are ubiquitous and occur in all types of aquatic habitats both freshwater and marine environments. They are also found in damp terrestrial surfaces and thrive under planktonic, benthic, and epiphytic conditions.
- **Common Habitats:** Diatoms often form yellowish-brown scums on the surface of mud, ponds, and ditches, especially in stagnant or nutrient-rich water. They are important primary producers in aquatic ecosystems, forming the base of the food chain and playing a vital role in global carbon fixation.

Representative Forms

- **Freshwater Diatoms:** Common freshwater genera include: *Asterionella*, *Navicula*, *Nitzschia*, *Melosira*, *Synedra*.
- **Epiphytic Diatoms (Freshwater):** These grow attached to other algae such as *Cladophora*, *Oedogonium*, and *Pithophora*. Common epiphytic genera include: *Cocconeis*, *Gomphonema*, and *Eunotia*.
- **Marine Epiphytic Diatoms:** These are found growing on marine seaweeds. Examples include: *Triceratium* and *Hyalodiscus*.

Fossil Diatoms

- Diatoms have an extensive fossil record, with fossil forms dating back to the Silurian period.

- Around 70 fossil genera have been reported, with most being centric diatoms.
- One of the oldest fossil diatoms is *Pyxidicula*, believed to be from the Jurassic period.
- In India, significant fossil deposits have been discovered in Ladakh and Kashmir regions, particularly Laradura, Kashmir (*Shukla, 1962*).
- These fossilized deposits are collectively known as Kieselguhr (also called diatomaceous earth), which has industrial applications in filtration, insulation, and polishing materials.

The Plant Body

Structure of Diatoms (Bacillariophyceae)

1. Thallus Structure

- **General Form:** Diatoms are typically **unicellular**, but some may form **colonies** or **filamentous aggregations**. Shapes vary, **boat-like**, **disc-like**, **triangular**, etc. Example shapes are shown in **Fig. 5.1**

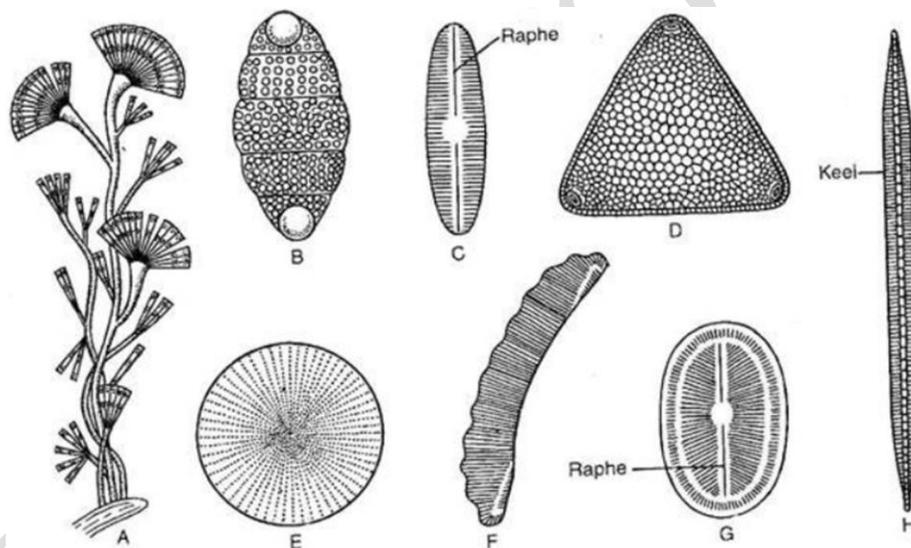


Fig 5.1: Different forms of Diatom: A. *Licmophora flabellata*. B. *Biddulphia pulchella*, D. *Triceratium planoconcaum*, E. *Cascinodiscus excentricus*, F. *Eunotia* sp., G. *Cocconeis placentula*, and H. *Bacillaria paradoxa*

- **Types Based on Symmetry:** The classification of unicellular diatoms is primarily based on their **symmetry**.
 - Pennate Diatoms (Order: Pennales):** Exhibit bilateral (isobilateral) symmetry Example: *Pinnularia*
 - Centric Diatoms (Order: Centrales):** Exhibit radial symmetry. Example: *Cyclotella*
- **Additional Classification Features:** In centric diatoms, the presence or absence of

bristles or horns is used in classification.

In pennate diatoms, the number and morphology of raphes (longitudinal slits on the valve) are taxonomically important.

- **Colonial Forms:** Uniseriate Filaments: e.g., *Melosira* (common freshwater diatom)
Fan-shaped Colonies: e.g., *Licmophora*, with mucilage stalks branching to form groups.
Bristle-linked Colonies: e.g., *Chaetoceros*. Stellate Colonies: e.g., *Asterionella*, with cells joined at their basal ends.

2. Cell Wall (Frustule)

Composition and Structure: The wall is siliceous, made of hydrated amorphous silica and an organic component (unknown composition). Composed of two overlapping halves: Epitheca (upper, larger half)

Hypotheca (lower, smaller half): These fit together like a petri dish, creating an overlapping zone called the girdle.

Key Terms: Valves: The flat surfaces of the epitheca and hypotheca. Connecting Band: Incurved margin around each theca. Girdle View: Side view of the diatom (often rectangular). Valve View: Top view (shape may vary by species). Prevalver: Line connecting the middle of two valves.

Formation of Silica Wall: Occurs intracellularly in a vesicle lined by a three-layered membrane called the silicalemma. The cytoplasmic membrane is involved in silica deposition. **Striae:** Fine lines or patterns formed during silica deposition, which help differentiate species. **Radial symmetry** in centric diatoms Bilateral symmetry in pennate diatoms.

Special Cases: In some marine centric diatoms, coarse markings are observed.

In *Navicula pelliculosa*, the silica wall is further impregnated with an organic material.

3. Valve Morphology and Ornamentation

According to **Hendey (1959)**, the surface sculpturing of diatom valves is crucial for taxonomy. Four main patterns are.

Punctae: Fine perforations arranged in regular rows.

Areolae: Larger cavity-like depressions, coarser than punctae. Often contain **sieve membranes**.

1. **Canaliculi:** **Tubular canals** running through the valve surface.
2. **Costae:** **Thickened ridges** on the valve surface, appearing like rings.

Diatom Cell Wall, Protoplast, and Locomotion

1. Types of Diatom Cell Wall Based on Ribs

Based on the **structure of ribs**, diatom walls are classified into two types:

Laminar Wall: Composed of a **single silicified layer**.

Locular Wall: Composed of **two parallel wall layers** with **numerous small cavities (loculi)** in between.

2. Valve Markings and Symmetry

Markings (Striae): In **pennate diatoms** (e.g., *Pinnularia*), the striae are arranged **longitudinally**, one on either side of the valve.

In **centric diatoms** (e.g., *Cyclotella*), striae are arranged concentrically around a central point. **Valve Views in Diatoms:** In pennate diatoms like *Pinnularia*, the Apical axis connects the two ends (poles or terminal nodules) of the valve. The transapical axis runs perpendicular to the apical axis. These axes help describe the shape and symmetry of the valve.

3. Raphe System and Nodules

Raphe: A **longitudinal slit** along the central axis of the valve in **pennate diatoms** (e.g., *Navicula*). Serves a role in **locomotion**. Interrupted in the center by the **central nodule**, an internal thickening of silica.

Nodules: **Central nodule:** Located in the middle of the valve. **Polar nodules:** Found at both ends (poles) of the valve.

False Raphe (Pseudoraphe): Found in genera such as *Synedra* and *Fragilaria*, where the axial area appears like a raphe but lacks a slit.

Raphe Variations: *Navicula* and *Pinnularia* have two raphes, one on each valve. *Achnanthes* has a single raphe. Centric diatoms typically lack a raphe.

4. Transapical Ribs and Pore Structure: In *Navicula*, Displays bilateral symmetry. The raphe lies along a central longitudinal rib (apical rib). Transapical ribs lie laterally, and the rows of pores between them are separated by siliceous bridges, connecting adjacent ribs. **Areolae** and other sculpturing features assist in taxonomic identification.

5. Protoplast (Cell Content)

Enclosed within the frustule is a dense cytoplasm, typically with a large central vacuole. The cells are uninucleate: In centric diatoms, the nucleus is peripheral. In pennate diatoms, it is suspended in the vacuole via fine cytoplasmic strands.

Nuclear Division: Spindle forms inside the nucleus (intranuclear spindle). Chromosomes arrange in an equatorial ring rather than a plate. The spindle is shaped like an elongated cylinder with flattened ends. **Chromatophores (Plastids):** Discoid in centric diatoms. Plate-like and lobed in pennate diatoms. Each chromatophore is surrounded by four membranes. Internal thylakoid lamellae are grouped in threes. Naked pyrenoids (without starch sheaths) are seen in some species like *Nitzschia*.

Reserve Food Materials: Oil droplets and chrysolaminarin (a β -1,3-glucan).

Organelles Observed via Electron Microscopy: Endoplasmic reticulum, Golgi bodies, Mitochondria.

6. **Locomotion:** Centric diatoms are generally non-motile. Pennate diatoms show gliding movement, which may be: Jerky and intermittent, or Creeping and steady.

This movement is typically associated with the raphe system, possibly involving the secretion of mucilage.

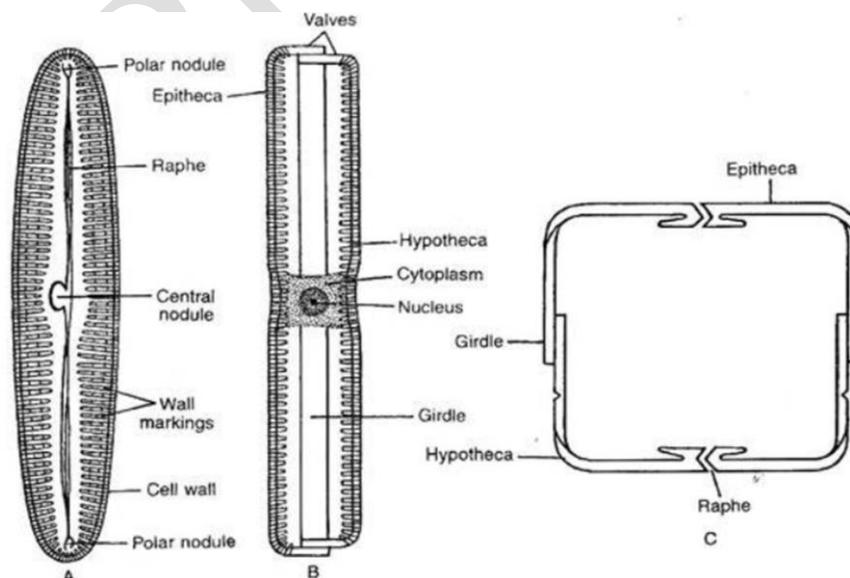


Fig. 5 .2 Cell structure of *Pinnularia viridis* (Pennales): A. Frustule in valve view, B. Frustule in girdle view, and C. Frustule in transverse section.

Reproduction in Diatoms (Bacillariophyceae)

Diatoms reproduce by both **vegetative** and **sexual** methods. A unique feature of their reproduction is the **gradual reduction in size** during successive vegetative divisions, which is later restored by **auxospore formation** during sexual reproduction.

1. Vegetative Reproduction

- **Method:** Occurs by **mitotic cell division**.

- **Process:**

1. The **frustule** (siliceous cell wall) increases in volume.
2. The two **thecae (epitheca and hypotheca)** of the parent cell slightly separate.
3. The **nucleus divides mitotically**, followed by **cytokinesis** (cytoplasmic division).
4. Each daughter protoplast forms a **new hypotheca** on the side opposite to the inherited theca.
 - The **parent epitheca** becomes the epitheca of one daughter cell.
 - The **parent hypotheca** becomes the epitheca of the **smaller daughter cell**.
5. Therefore, each daughter cell forms its **own hypotheca**, resulting in two daughter cells of unequal sizes.

- **Outcome**

One daughter cell is **equal in size** to the parent. The other is **smaller** than the parent.

This leads to **progressive size reduction** in each generation.

- **Biological Law:** This phenomenon is explained by **MacDonald Pfitzer's Law**, which describes the **diminishing size of diatom progeny** over successive generations through vegetative reproduction. The law has been confirmed in many species.

2. Sexual Reproduction

- **Earlier Understanding:** Until 1907, auxospore formation was mistakenly considered asexual, but it is now recognized as a sexual process.
- **Gamete Types:** The fusion may be isogamous, anisogamous, oogamous, or even automictic (self-fusion).
- **Differences Between Centric and Pennate Diatoms:** The mechanism of sexual reproduction varies:
 - In **centric diatoms**, the process is usually oogamous, involving a large non-motile egg and small motile or non-motile sperm.
 - In pennate diatoms, the process is typically isogamous or anisogamous, where two similar

or slightly dissimilar gametes fuse.

- **Auxospore Formation:** Following gamete fusion, a zygote is formed. The zygote develops into an auxospore, which grows to restore the original maximum size of the diatom.

The auxospore later forms a new frustule and resumes the vegetative cycle.

Auxospore Formation in Pennate Diatoms

Auxospore formation is a crucial sexual process in diatoms, particularly in pennate forms, used to restore the original cell size lost during repeated vegetative divisions. In pennate diatoms, sexual reproduction is typically isogamous or anisogamous, and the auxospore develops from the zygote formed after gamete fusion. There are three main types of auxospore formation observed.

1. Formation of a Single Auxospore by Two Conjugating Cells

Process: Two cells align and become enclosed in a mucilaginous envelope. In each cell, the nucleus undergoes meiosis, forming four nuclei. Three nuclei degenerate, and the remaining nucleus becomes functional. The functional protoplast acts as a gamete and emerges from the parent cell. Gamete fusion occurs within the mucilage. A zygote is formed, which later elongates and develops into an auxospore.

- **Example:** *Cocconeis placentula* (Fig. 5.3)

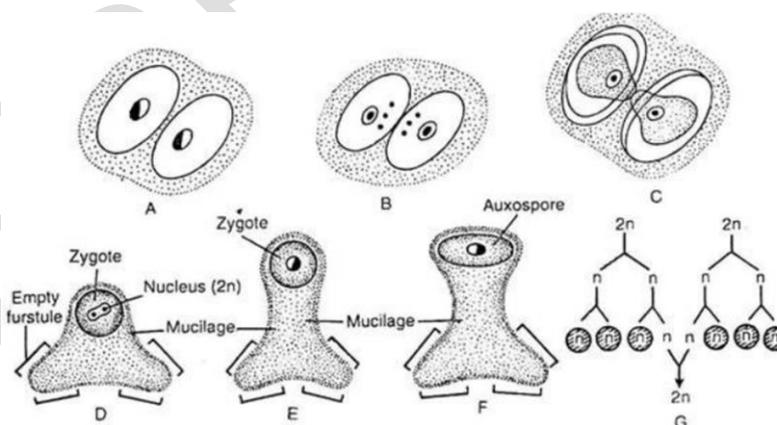


Fig 5.3 A-F. Production of one auxospore by two conjugating cells of *Cocconeis placentula*, and G. Nuclear behaviour during reproduction.

2. Formation of Two Auxospores by Two Conjugating Cells

Process: Two compatible cells come close and lie side by side in a common gelatinous sheath. In each cell, the nucleus undergoes meiosis, producing four nuclei, two of which degenerate.

Each cell thus forms two gametes. Fusion occurs between gametes from different cells, resulting in two zygotes. These zygotes form in the mid-frustule region of the parent cells. Both zygotes elongate and develop into two auxospores.

Gamete Types: Gametes may be **equal or unequal**, depending on the nature of protoplast division. **Example:** *Cymbella lanceolata*

3. Auxospore Formation by Parthenogenesis

- **Rare and exceptional case.**

Process: Occurs **without actual gamete fusion** (i.e., no conjugation). Two paired cells undergo **two mitotic divisions**, producing multiple nuclei. All but one **degenerate**, leaving a **single functional diploid nucleus**.

The surviving protoplast, now diploid, is liberated from the cell.

This **diploid protoplast functions as an auxospore**, bypassing gametic fusion.

Outcome: **Two auxospores** are formed from the two parent cells. **Example:** *Cocconeis placentula*.

Auxospore Formation in Centric Diatoms

(i) Formation of auxospore by autogamy. Autogamous kind of auxospore formation has been observed in *Cyclotella meneghiniana*. During auxospore formation epitheca and hypotheca separate and the nucleus divides meiotically to form four nuclei. Two degenerate and the remaining two nuclei fuse and form again a diploid nucleus. That is why this process is known as autogamy. The protoplast with a diploid nucleus is liberated and functions as auxospore which enlarges and secretes an overlapping wall.

(ii) Formation of auxospores by zoogamy. The protoplast of a frustule divides and redivides and ultimately forms 4 to 128 small, haploid, uninucleate daughter protoplasts. The first division is meiotic division, which is followed by the mitotic divisions.

(iii) Statospores. The formation of thick-walled cysts, endospores or statospores within the frustules have also been reported. The detailed process is, however, unknown.

Economic importance

The economic importance of diatoms is varied, right from their use as food and in industries. They act as primary producers in the food chain of aquatic animals such as fishes and whales (marine ecosystem), and that is why they are popularly called "grasses of sea". But at places their abundant growth and larger accumulation create trouble in sea transport. These huge accumulations are known as diatomaceous earth. Diatomaceous earth formed by fossil

diatoms has great industrial value. Such deposits are frequently reported from America (San Francisco, California), Spain, Russia, Maryland etc. The use of diatomaceous earth (also called kieselguhr) is varied, such as.

- (i) used in polishing material.
- (ii) used as filters in sugar refineries and brewing industries.
- (iii) used in the manufacture of dynamite.
- (iv) as insulators in pipes, blast furnaces, boilers, etc.
- (v) in the manufacture of glass, porcelain, paints and varnishes.
- (vi) in making tooth paste and face powders.
- (vii) for making light and heat resistant bricks.

The biological significance of diatoms lies in testing efficacy of high power of microscope by examining the thickness of their cell walls, accumulation of oil in the liver of fishes resulting from their condensation and oil production during photosynthesis and energy of the fuel petroleum arose from the fossil forms.

Classification of Bacillariophyceae

Fritsch (1935) followed Hustedt (1930) and Karsten (1928) in dividing the class Bacillariophyceae.

1. Centrales

Valves with centric structure, no raphe or pseudoraphe, markings not along two lines, no movement. Chromatophores numerous, auxospores apparently formed without conjugations. It is further divided into.

- (a) Discoideae. Cells shortly cylindrical, valves circular, hyaline, areolated or with radiating striations, e.g. Cyclotella, Melosira, Stephanodiscus.
- (b) Solenoideae. Cells elongate, cylindrical or subcylindrical, girdle complex with numerous intercalary bands, e.g., Rhizosolenia.
- (c) Biddulphioideae. Cells are box-shaped, valves with two or more poles, mostly provided with horns or bosses, e.g. Biddulphia, Triceratium.
- (d) Rutilarioideae. Valves naviculoid, e.g., Rutilaria.

2. Pennales

Valves are isobilateral, medianly zygomorphic, boat or needle-shaped, raphe present, movement in several forms. Chromatophores are commonly large and few. Auxospores are

normally formed by conjugation.

It is further divided as follows

- (1) Araphideae. Only pseudoraphe present. (e) Fragilarioideae. Valves mostly straight, e.g. *Asterionella*, *Fragilaria*, *Synendra*.
- (II) Raphidioideae. Showing the beginning of raphe, no central nodule. Eunotioideae. Raphe on one or on both valves, e.g., *Eunotia*.
- (III) Monoraphideae. Fully developed raphe on only one valve.
- (g) Achnantheroideae. Frustules crooked or suddenly bent, e.g., *Cocconies*.
- (IV) Biraphideae. Both valves have with fully developed raphe.
- (h) Naviculoideae. Raphe occupying the apical axis, e.g., *Cymbella*, *Navicula*, *Pinnularia*.
- (i) Epithemioideae. Raphe not occupying the apical axis, e.g. *Denticula*. (Nitzschioidae. Both valves with a canal raphe, e.g. *Nitzschia*.
- (k) Surirelloideae. Valves with two lateral wings occupied by the canal raphe, e.g. *Surirella*.

Phylogeny

The occurrence of fossil forms of centric diatoms from Jurassic and pennate diatoms from early Tertiary indicates that centric diatoms are more primitive. This fact is also substantiated by the marine habit of centric diatoms and freshwater habit of pennate diatoms. However, the nature of pigments such as fucoxanthin and chlorophyll a and c shows their link with Phaeophyceae, but the characteristic food reserve of diatoms recalls kinship with Xanthophyceae and Chrysophyceae.

EXERCISE

I. Short Answer Questions (5–6 sentence answers expected):

1. What are the common freshwater forms of diatoms?
2. What is Kieselguhr, and how is it formed?
3. Name any three industrial uses of diatomaceous earth.
4. What is the role of diatoms in the aquatic food chain?
5. Distinguish between Centric and Pennate based on structure.
6. Why are diatoms referred to as "grasses of the sea"?

II Essay Questions

1. Discuss the economic importance of diatoms with special reference to diatomaceous earth.

2. Describe the classification of Bacillariophyceae as per Fritsch (1935), including the key characteristics of Centrales and Pennales.
3. Explain the biological significance and phylogenetic position of diatoms in relation to other algal groups.

EJBPS BOOK

UNIT VI: PHAEOPHYCEAE (BROWN ALGAE)

1.1 General Account

- Pigments: Fucoxanthin, chlorophyll *a* and *c*
- Reserve food: Laminarin, mannitol
- Thallus structure: parenchymatous, complex
- Marine habitat

Description of Phaeophyceae (Brown Algae).

It is a large group of algae consisting of 240 genera and over 1,500 species, out of which 32 genera and 93 species are reported from India. They are commonly known as brown algae, due to the presence of a golden-brown xanthophyll pigment, fucoxanthin (C₄₀H₅₄O₆), in the chromatophores.

About 99.7% members are marine and a few grow in freshwater. The freshwater members are *Pleurocladia*, *Heribaudiella*, *Pseudobodanella*, *Lithoderma* and *Sphacelaria*. Members like *Pleurocladia lacustris* grow both in freshwater and marine habitats.

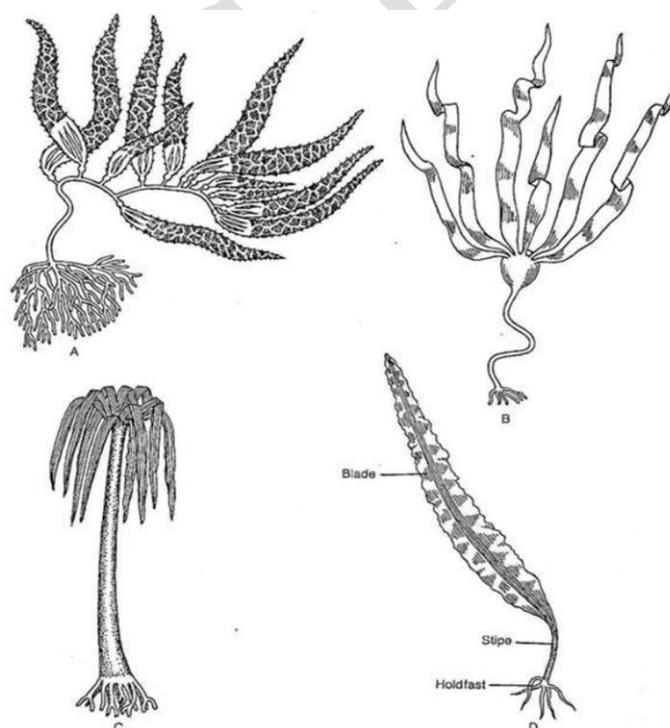


Fig 6.1 Some marine members of Phaeophyceae: A. *Macrocystis pyrifera* (largest alga), B. *Nereocystis luelkeana* (bladder- kelp), C. *Postelsia palmaeformis* (sea-palm), and D. *Laminaria saccharina* (Devil's apron).

Important Characteristics of Phaeophyceae (Brown Algae):

The important characteristics of the class Phaeophyceae are given below:

1. The plant body is immobile, multicellular, and highly differentiated both externally and internally. [Unicellular, colonial (motile and non-motile), and unbranched filamentous forms are completely absent.
2. They range from a simple microscopic heterotrichous filament (*Ectocarpus*) to the largest alga (*Macrocystis pyrifera*), which attains a length of 60-90 meters. (The largest forms are known as kelps or rockweeds. *Lessonia davicans* reaches a length of 4 meters and looks like a miniature tree. *Nereocystis luelkeana*, the bladder kelp, attains a length of 25-30 meters. *Postelsia palmae formis* appears like a palm tree and is commonly known as Sea Palm (Fig. 6.1).
3. Commonly the plant body is differentiated into hold fast, a short or elongated stipe and an expanded blade. The blade performs photosynthesis and bears reproductive structures. Many species remain afloat by having air bladders.
4. The photosynthetic pigments include chlorophyll a, chlorophyll c, β -carotene and xanthophylls like lutein, fucoxanthin, flavoxanthin and violaxanthin. The fucoxanthin is however, present sufficiently, which partially masks the chlorophyll and carotenoid, thereby giving the characteristic brown colouration.
5. The growth of the plant body may be apical (*Fucales*, *Dictyotales*), intercalary (*Laminariales*) or trichothallic (*Ectocarpales*).
6. The cell wall is differentiated into outer and inner layers. The outer mucilaginous layer has fucinic and alginic acid, but the inner layer is mainly cellulosic. [The alginic acid is used to manufacture artificial silk and adhesive, obtained commercially from *Sargassum*, *Laminaria*, etc].
7. The cells usually have many small vesicles and white granules. The granules are called fucosan vesicles.
8. Pyrenoides are usually absent, but if present, they are of single stalk type.
9. Motile structures (zoospores and gametes) have two laterally inserted unequal flagella, of which the larger one is tinsel or pantonema- tic and the smaller one is whiplash or acronematic type.
10. The reserve foods are commonly laminarin and mannitol. Sucrose and glycerol are also present in some members.
11. They reproduce by all three means: vegetative, asexual, and sexual.

- a. Vegetative reproduction takes place by fragmentation. Special reproductive branches, the propagules, are developed in some members of Sphacelariales; those develop to new plants after detachment.
 - b. Asexual reproduction takes place by zoospores except Tilopteridales, Dictyotales and Fucales. The zoospores produced in unilocular sporangia are haploid, while in pleurilocular sporangia they are diploid.
 - c. Sexual reproduction ranges from isogamy (*Ectocarpales* and *Sphacelariales*) to oogamy (Fucales, Dictyotales, and Laminariales) through anisogamy (Cutleriales and Tilopteridales).
12. In most of the members, fertilisation is external. Zygote does not undergo meiotic division, and on germination, it develops a diploid thallus.
13. The members show various types of alternation of generations i.e., isomorphic (*Ectocarpus*), heteromorphic (*Laminaria*) or diplontic (*Sargassum*).

The members of Phaeophyceae show two types of life cycle:

1. Diplontic life cycle e.g., *Sargassum*.
2. Diplohaplontic life cycle.

It is of two types

- i. Isomorphic type e.g., *Ectocarpus*.
- ii. Heteromorphic type e.g., *Laminaria*.

Classification of Phaeophyceae (Brown Algae).

Fritsch (1935, 45) classified the Class. Phaeophyceae into nine orders. This was also followed by Mishra (1966).

Class. Phaeophyceae Order.

1. Ectocarpales e.g., *Ectocarpus*, *Haiiothrix*.
2. Tilopteridales e.g., *Ptilopteris*.
3. Cutleriales e.g., *Cutlria*.
4. Sporochnales e.g. *Sporochnus*.
5. Desmarestiales e.g., *Desmarestia*.
6. Laminariales e.g., *Laminaria*.
7. Sphacelariales e.g., *Sphacelaria*.
8. Dictyotales e.g., *Dictyota*.

9. Fucales e.g., Sargassum.

1. Order. Ectocarpales

Important Characteristics

- i. The plant body is filamentous, branched and heterotrichous, a few are pseudoparenchymatous.
- ii. In filamentous form the cells are arranged uniseriately.
- iii. The plant body elongates by intercalary growth.
- iv. Each cell contains chloroplasts with pyrenoids.
- v. Reproduction takes place both asexually and sexually. Asexual reproduction takes place by zoospores formed in pleurilocular sporangia. Sexual reproduction takes place by both isogamy and anisogamy, though anisogamy is rare. Oogamy is absent.
- vi. They perform either isomorphic or heteromorphic alternation of generations.

Family. Ectocarpaceae Important Characteristics:

- i. The thalloid plant body is filamentous, branched and heterotrichous.
- ii. Sexual reproduction is isogamous.
- iii. Alternation of generation is isomorphic.

2. Order. Fucales

Important Characteristics

- i. The plant body is a sporophytic parenchymatous thallus, grows by single apical cell.
- ii. The plant body bears two types of sporangia, the microsporangia and macrosporangia.
- iii. Microsporangia behave as antheridia and develop antherozoids, whereas macrosporangia behave as oogonia and develop single egg within each.
- iv. Sexual reproduction is oogamous type.
- v. The sporangia are borne within special cavities, the conceptacles.
- vi. Absence of alternation of generations.

Family. Sargassaceae Important Characteristics:

- i. Plant body is thalloid, much branched and radially or bilaterally symmetrical.
- ii. Branching is monopodial.
- iii. Growth takes place by three-sided apical cell.
- iv. Some branches are modified into leaves, which bear axillary air-bladders.
- v. Sex organs are developed in conceptacles, embedded in cylindrical or flattened

receptacles.

3. Order. Laminariales

Important Characteristics

- i. Members are commonly called “kelps”, because of very large size and complexity in structure. Some of the members reach up to 50-60 meters.
- ii. They are exclusively marine and commonly grow in sub-littoral and littoral zones of rocky coasts of temperate and polar regions.
- iii. Plant bodies are mostly parenchymatous, and growth takes place by intercalary, medullary and superficial meristems.
- iv. Dominant plant body is very large and sporophytic (2n) in nature. They are usually differentiated into root-like holdfast or hapteron, stalk-like stipe and leafy blades. But the gametophytic plant body is very small and microscopic.
- v. Reproduction takes place by both asexual and sexual means.
- vi. Asexual reproduction generally takes place by zoospores developed in unilocular sporangia.
- vii. Sexual reproduction is of oogamous type. Sex organs i.e. antheridia and oogonia are developed on gametophytic plant.
- viii. Plants of this group exhibit heteromorphic alternation of generations.

Family. Laminariaceae

Important characteristics

- i. The sporophytic plant body is differentiated into holdfast, stipe and blade with high degree of morphological and anatomical differentiation.
- ii. Sporangia are developed in distinct groups on both surfaces of the blade.
- iii. The gametophytic plants are much reduced and dioecious.
- iv. Plants of this group possess heteromorphic, diplohaplontic alternation of generations.

Types of Common Brown Algae: Some of the common brown algae are

1. **Laminaria:** It is a widespread kelp or large-sized brown alga popularly called the devil's apron. The size is 1-3 metres. The plant body is a sporophyte. It is differentiated into basal holdfast, a nearly cylindrical stipe, and a flattened blade or lamina. Alternation of generations is heteromorphic. Laminaria is a source of food, manure, algin, and iodine.

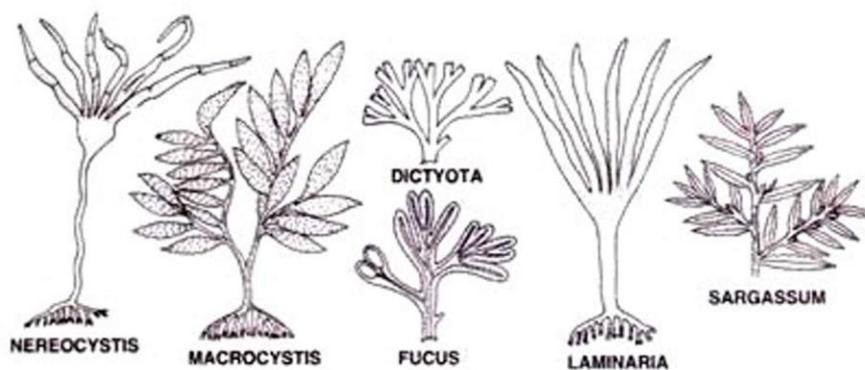


Fig 6.1: Some of Brown Algae.

2. **Dictyota:** It is a ribbon shaped dichotomously branched marine brown alga that grows in shallow waters. Frond is flat, dichotomously branched. The surface of the frond bears hair and unilocular sporangia. Unilocular sporangia produce haploid tetra spores.

Each tetraspore produces haploid gametophytic thallus that is similar in morphology to sporophytic thallus. Sex organs are borne in clusters or sori. Male sex organs or antheridia produce uniflagellate sperms. Fertilization produces diploid zygote which germinates to produce diploid plant body.

3. **Fucus:** It is a leathery flat branched perennial brown alga of small size which has been a source of fodder, manure and algin. Frond is flat and branched both dichotomously and monopodially. A pair of pneumocysts or air bladders occurs in the region of branching. At places the branches contain flask-shaped cavities called conceptacles. Meiosis occurs during gamete formation.

4. **Sargassum:** Sargassum is popularly called gulf weed which is used both as fodder and manure. Sarganine is an antibacterial and antifungal extract obtained from it. Both free floating and attached forms occur. Floating forms are common in part of North Atlantic ocean called Sargasso sea where these are menace to shipping. In attached forms, the plant has three parts— holdfast, main axis and laterals.

Main axis bears long laterals on which are borne short laterals or leaves. Pneumocysts or air bladders occur at places in the axils of leaves. In free floating forms, pneumocysts provide buoyancy for floating while in attached forms they provide buoyancy for keeping the plants upright. Sex organs are borne in two different types of conceptacles.

5. **Ectocarpus:** It is a filamentous marine brown alga which has both upright and prostrate regions. Such a growth is called heterotrichous. Upright branches show evectation (pushing of parent branch) to give an appearance of dichotomy. Fixation to solid substratum occurs through prostrate portion and rhizoids. Reproduction occurs by fragmentation. The plants can also multiply asexually through the formation of diploid biflagellate zoospores in plurilocular (= neutral) sporangia.

The sporophytic plant body also bears unilocular sporangia in which sporic meiosis occurs and haploid biflagellate Meio zoospores are formed. The latter germinate to produce gametophytic thalli. The gametophytes liberate biflagellate gametes from their plurilocular gametangia. The gametes fuse to form diploid zygote that germinates to produce diploid plant.

Economic Importance of Brown Algae

Some of the major economic importance of brown algae are listed below

1. **Food:** A few brown algae are used as food in some countries, e.g. Laminaria, Alaria, Macrocystis, Sargassum. The edible brown algae are also used as fodder.
2. **Fouling of Ships:** Some brown algae get attached to hulls of ships, e.g. Ectocarpus. Others floating in masses (e.g., Sargassum) have a nuisance value for ships.
3. **Iodine:** Fucus and Laminaria are rich source of iodine. Potash is abundant in Macrocystis and Nereocystis.
4. **Medicines:** Sodium laminarin sulphate is a blood anticoagulant. Laminaria and Ascophyllum have antibiotic properties, while Durvillea has worm expelling or vermifuge properties.
5. **Alginic Acid:** It is a phycocolloid which is obtained commercially from Laminaria, Macrocystis, Nereocystis, Fucus, Sargassum, etc. Alginic acid and its salts are used in obtaining emulsions (ice-creams, ointments, toothpastes, cosmetics, creams, shampoos, etc.), sizing textiles, flame-proof plastics, security glass, formation of pills and surgical threads.

EXERCISE

I. Short Answer Questions (5–6 sentence answers expected)

Short Answer Questions (5–6 lines)

1. What are the main pigments and reserve food materials found in Phaeophyceae?
2. Describe the general structure and organization of the thallus in brown algae.
3. How does sexual reproduction occur in Fucales?

4. What is the economic importance of brown algae like Laminaria and Sargassum?

Essay Questions (2–3 pages)

1. Write an account on the structure, classification, and reproduction of brown algae (Phaeophyceae).
2. Discuss the life cycles found in brown algae with examples of isomorphic, heteromorphic, and diplontic types.

Genus: Fucus

Systematic Position Class: Phaeophyceae Order: Fucales Family: Fucaceae Genus: Fucus

This is a common marine alga containing a few species that are widely distributed in the seacoasts of temperate and Arctic regions. Most species are found attached to rocks between low and high tide marks and are commonly known as rockweeds. The plant body of Fucus consists of a leathery, parenchymatous, dichotomously branched ribbon-like frond, a stem-like stipe, and a basal disc-like holdfast or hapteron by which it is attached to the substratum. The plants may be attached to completely or partly submerged rocks. The thallus gets its buoyancy in water from air vesicles or bladder-like structures. The swollen tips of the thalli, the receptacles, which lack a midrib, are covered with small, scattered pimple-like projections with small openings that lead into cavities, known as conceptacles. The thallus is diploid, may be monoecious or dioecious, and is characterized by anatomical complexity.

Anatomically, the thallus is divided into three parts

- a) Outer or peripheral or limiting layer: composed of small cells containing abundant plastids and performing the function of assimilation.
- b) Cortex: elongated mucilaginous parenchymatous cells, several layers, storage system.
- c) Medulla: central tissue is composed of hypha-like elongated cells, and conduction of food material.
- d) Rudimentary sieve plates are present in Fucus.
- e) Growth in length of the thallus takes place through an apical cell, which lies in the depression at the tip of each branch

REPRODUCTION

In *Fucus*, the only method of asexual reproduction is fragmentation. Sexual reproduction in *Fucus* is heterogamous, involving two types of gametes: large non-motile eggs and small motile antherozoids. These gametes are produced in specialized structures known as oogonia

(female) and antheridia (male), which are found inside cavities called conceptacles. These conceptacles may be borne on the same thallus in monoecious species or on different thalli in dioecious species. Inside each conceptacle, many multicellular hairs called paraphyses are present, interspersed with oogonia and antheridia.

The oogonium develops from a single cell on a short stalk and undergoes division to form eight egg cells enclosed in a wall of two to three layers. When mature, all eight eggs are released into the surrounding water. In contrast, antheridia are smaller and more numerous, produced in groups on short, much-branched hairs. The antheridial wall also consists of two to three layers, and each antheridium produces numerous pear-shaped antherozoids with two unequal laterally inserted flagella.

After release into water, the eggs become surrounded by many antherozoids, which swim around them, causing them to rotate. Eventually, one antherozoid fertilizes the egg, resulting in a diploid oospore. This oospore forms a thin wall and immediately undergoes cell division without a resting period. The resulting two cells differentiate, with the lower cell developing into the holdfast and the upper into the thallus, forming a new *Fucus* plant.

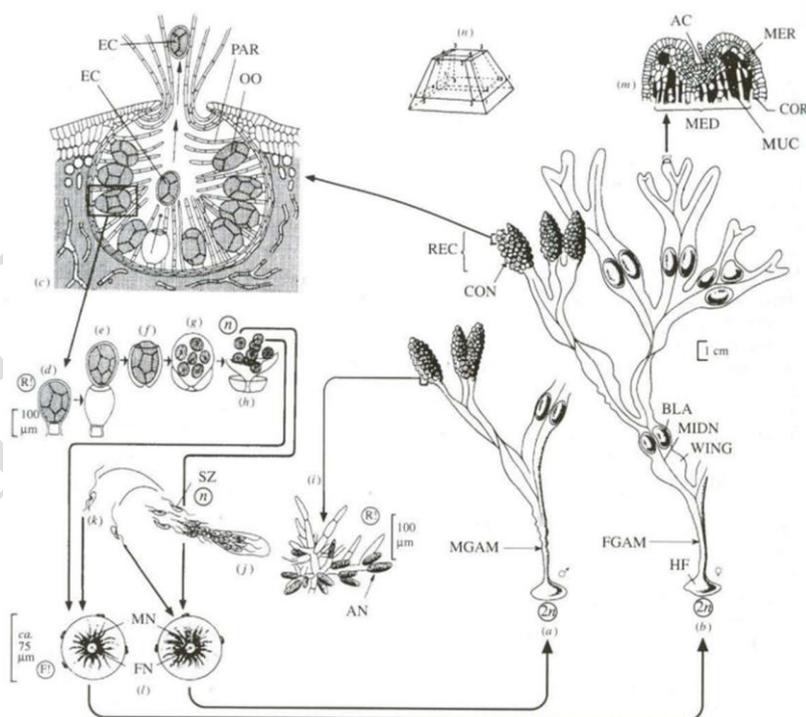


Fig. 6.2: Life cycle of *Fucus vesiculosus*. (a) Male gametophyte; (b) Female gametophyte; (c) Female conceptacle with oogonia; (d-h) Development of the oogonia and release of the egg cells; (i) Filaments bearing antheridia, which develop

from the walls of male conceptacles; (j) Release of spermatozoids from an antheridium; (k) Spermatozoids; (l) Fertilization of egg cells. AN = antheridium; CON = conceptacle; EC = egg cell; F! = fertilization; FGAM = female gametophyte; FN = female nucleus; MGAM = male gametophyte; MN = male nucleus; MUC = mucilage; OO = oogonium; R! = reduction division (meiosis); REC = receptacle; SZ = spermatozoid; n = haploid; 2n = diploid. For further explanation of abbreviations, see van den Hoek et al. (1995).

In *Fucus*, meiosis occurs during the formation of gametes, meaning that the diploid phase dominates the life cycle, while the haploid phase is reduced to the gametes alone. This is a unique feature among algae. The diploid plant does not form sporangia or spores but directly produces gametangia and gametes. As a result, *Fucus* exhibits no true morphological alternation of generations; there is only an alternation of chromosome numbers from diploid to haploid and back to diploid.

Some researchers suggest that the structures known as antheridia and oogonia in *Fucus* might be better interpreted as microsporangia and macrosporangia, respectively. According to this interpretation, meiosis in the microsporangium produces four haploid microspores, each of which gives rise to a male gametophyte that forms antherozoids. Similarly, meiosis in the macrosporangium yields four haploid macrospores, each producing a female gametophyte from which an egg cell arises. If this alternative view is accepted, then *Fucus* would be considered to show a heteromorphic alternation of generations, and the order Fucales would belong to the class Heterogeneratae.

Uses and Adverse Effects

- *Fucus vesiculosus* is marketed as a dietary supplement.
- Mucilage, algin, mannitol, fucitol, beta-carotene, zeaxanthin, volatile oils, iodine, bromine, potassium, and other minerals are among the primary chemical ingredients.
- *Fucus vesiculosus* consumption can produce platelet inhibition, which can increase the anticoagulant effect of warfarin (Coumadin). It is best to avoid it prior to surgery.
- The iodine in *Fucus vesiculosus* may cause allergic reactions in certain persons.
- It may slow down blood clotting and may lead to an increase in the risk of bruising or bleeding in people having bleeding disorders.
- It may lead to infertility in the case of women.
- It has iodine which can cause allergic reactions in the case of sensitive people.

- It has the tendency to affect blood sugar levels and can make the blood sugar level too low.

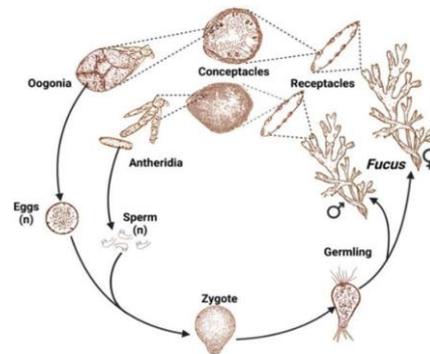


Fig: 6.3 Life Cycle of Fucus.

Genus: *Ectocarpus*

Occurrence of *Ectocarpus*

Division: Cryptogams Subdivision: Algae

Class: Phaeophyceae (Brown algae)

Order: Ectocarpales Family: Ectocarpaceae Genus: *Ectocarpus*

Different species of the genus *Ectocarpus* (Cr. ekos external and kapos fruit) is found throughout the world, out of which 16 species are found in India. They grow in marine habitat, either free-floating, epiphytes (on other sea plants) or lithophytes (on rocks). They are commonly available in both tropical and temperate seas. In India they are commonly found in the western coast.

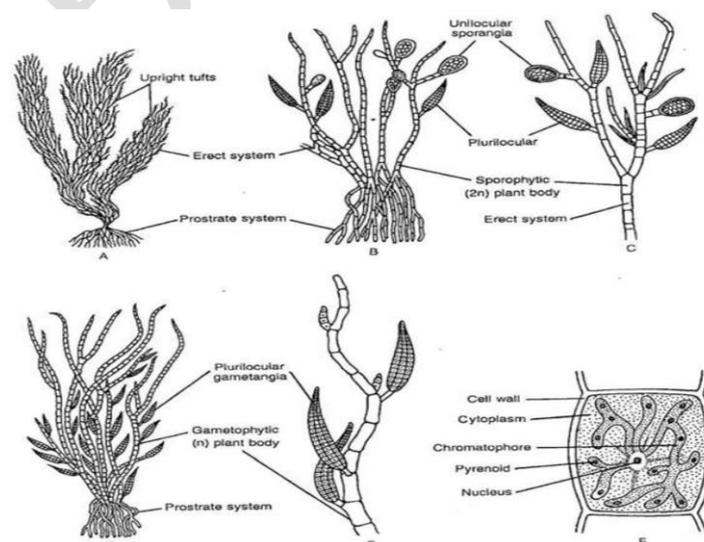


Fig. 6.4: *Ectocarpus* sp. A. Habit, B. Sporophytic (2n) plant body with both erect and prostrate system bearing unilocular and plurilocular sporangia, C. Portion of erect

filament of sporophytic (2n) plant, D. Gametophytic plant with both erect and prostrate systems bearing plurilocular gametangia, E. Portion of erect filament of gametophytic (n) plant and F. Cell structure.

Species like *E. spongiosus* and *E. conigerare* are free-floating, *E. breviararticulatus* and *E. coniferus* grow on larger algae like Laminaria and Fucus as epiphytes. *E. dermonematis* is endophytic and *E. fasciculatus* is an epizoic species, grows on the fins of fishes.

Galls are formed in Laminaria and Cystoseria due to the presence of *E. deformans* and *E. valianthei*, respectively, as endophytes. They are the most primitive of all the members of the class Phaeophyceae. The prostrate system is profusely branched and attached to the substratum. Some species like *E. filiferetc*, develop multicellular hairs from the prostrate system.

The erect system develops from the prostrate system which remains free-floating. It is much branched and well-developed. Both the main axis and branches are uniseriate (monosiphonous), but the lower part may become multiseriate (polysiphonous) due to longitudinal division e.g., *E. geminifructus*.

The prostrate system serves the function of anchorage with the substratum or on other plants and the erect system is photosynthetic and bears reproductive organs. The apical part of each filament generally terminates into hairs.

Two types of plant bodies are differentiated genetically; one is haploid and other one is diploid. Both haploid and diploid plants are morphologically identical (Fig. 6.4 OB, D).

Plant Body of Ectocarpus

The plant body is filamentous and heterotrichous, which is differentiated into prostrate and erect systems (Fig. 6.4 A, B). The prostrate system is profusely branched and attached with the substratum. Some species like *E. filiferetc*, develop multicellular hairs from the prostrate system.

The erect system develops from the prostrate system, which remains free-floating. It is much branched and well-developed. Both the main axis and branches are uniseriate (monosiphonous), but the lower part may become multiseriate (polysiphonous) due to longitudinal division, e.g., *E. geminifructus*.

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Two types of plant bodies are differentiated genetically; one is haploid, and the other is diploid. Both haploid and diploid plants are morphologically identical (Fig. 6.4 OB, D).

Cell Structure of Ectocarpus

The cells are rectangular or cylindrical (Fig. 6.4 OF). The cell wall is differentiated into outer pectic and inner cellulosic layers. The characteristic gelatinous substance present in the cell wall is composed of algin and fucoidan. Inner to the inner wall, a cell membrane is present which encircles the protoplast.

The protoplast contains one central nucleus and many chromatophores. The number and shape of chromatophore varies with species. They may be ribbon-shaped, band-shaped, discoid etc. and are associated with pyrenoids.

The photosynthetic pigments are chlorophyll a, chlorophyll c, β -carotene and fucoxanthin. The fucoxanthin masks the chlorophyll and gives the characteristic brown colouration.

The cytoplasm contains many vacuoles, which are called physodes. The physodes contain polyphenols, probably function as lysosomes. Morphologically, haploid and diploid vegetative filaments are almost alike, but the cells of haploid filaments are comparatively shorter in length than the diploid filaments.

Growth: The nature of growth varies with the region of plant body and with species. The erect system shows intercalary, diffuse or trichothallic growth, whereas it is apical in prostrate system.

Features of Ectocarpus:

1. It is a marine brown alga, distributed throughout the temperate and tropical seas of the world.
2. Plant body is filamentous, much branched and heterotrichous, having basal rhizoids and well-developed branched erect system.
3. Both sporophytic and gametophytic plants are alike (isomorphic).
4. The sporophytic plant bears both plurilocular and unilocular sporangia. The plurilocular

sporangium produces zoospores ($2n$) through mitosis. They germinate to produce new diploid sporophytic plant. On the other hand, unilocular sporangium produces zoomeiospore through meiosis, followed by several mitotic divisions. Zoomeiospores on germination develop gametophytic plants.

5. The gametophytic plants bear plurilocular gametangia (look similar to plurilocular sporangia) produce gametes.
6. Sexual reproduction may be isogamous, anisogamous or oogamous type. Physiological anisogamy is very common.
7. Direct germination of zygote results in the formation of a diploid sporophytic plant.

Reproduction in Ectocarpus

Ectocarpus reproduces both asexually and sexually

Asexual Reproduction: It takes place by zoospores. The zoospores are biflagellate having one whiplash and other tinsel-type of flagellum. The diploid plant ($2n$) develops two types of sporangia. These are unilocular sporangia and plurilocular or neutral sporangia (Fig. 3.11 OB, C). The unilocular sporangia develop haploid zoospores i.e., zoomeiospores, but the plurilocular sporangia develop diploid zoospores.

1. Unilocular Sporangia: The unilocular sporangia develop from the apical cell of short lateral branches (Fig. 6.5 A). The apical cell enlarges and functions as sporangial initial. The diploid nucleus of the initial first undergoes meiosis followed by several mitotic divisions, thus 32-64 haploid nuclei are formed. These nuclei accumulate some cytoplasm and develop individual units (Fig. 6.5 B-D).

Each unit metamorphoses into a pyriform, uninucleate, biflagellate zoospore also called zoomeiospore (Fig. 6.5 E). The flagella are unequal and laterally inserted. Out of two flagella, posterior one is short and whiplash type (i.e., acronematic) and the anterior one is larger and tinsel type (i.e., pantonematic).

During liberation the apex of the sporangium wall gets dissolved and the haploid zoospores are liberated in a gelatinous mass. After some time, they get free from the gelatinous mass and swim freely in water. They remain motile for about 30 minutes.

On contact with suitable substratum, the zoospore withdraws its flagella and forms a new cell wall around it (Fig. 6.5 F). Within short time a germ tube is formed, which divides many

times and form prostrate filament (Fig. 6.5 G, H). Some cells of the prostrate filament become active and form erect filaments.

Thus, the plants developed on germination of haploid zoospores (i.e., zoomeiospores) are gametophytic.

2. Plurilocular Sporangia: These are elongated, multicellular body developed on diploid (2n) i.e., sporophytic plant body (Fig. 6.6).

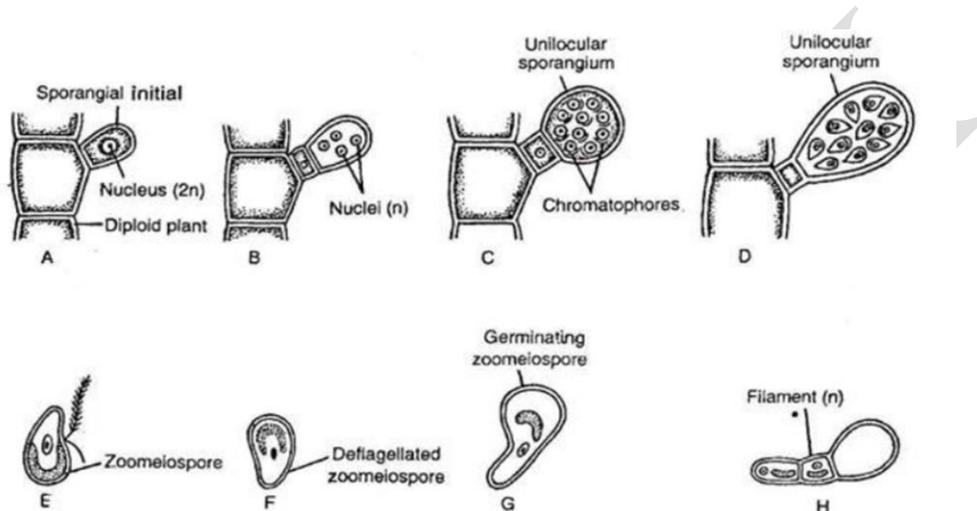


Fig 6.5: Ectocarpus sp. A-D. Development of unilocular sporangium. E. Zoomeiospore, F-H. Germination of Zoomeiospore.

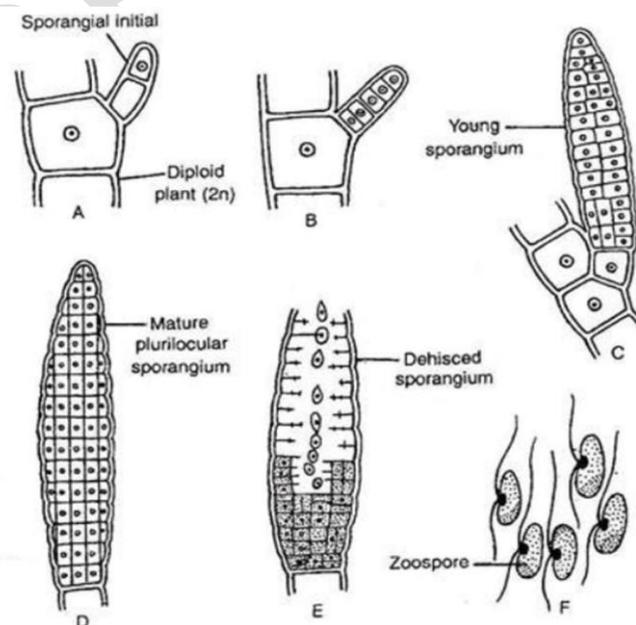


Fig. 6.6: Ectocarpus sp.: A-D. Development of multilocular sporangium, E. Liberation of zoospores from sporangium, and F. Zoospores.

They develop initially like the unilocular sporangia, at the tip of short lateral branches. The apical cell enlarges and functions as a sporangial initial. This sporangial initial becomes enlarged and undergoes repeated mitotic division; thus, 6-12 cells are formed. The cells are arranged in a vertical row (Fig. 6.6 A, B).

The cells then undergo several vertical divisions; thus, a multi-chambered structure is formed i.e., the plurilocular sporangium (Fig. 6.6 C, D). There is no reduction division during the formation of zoospores in a plurilocular sporangium. So, each small cubical cells of plurilocular sporangium contains single diploid nucleus. Each unit then metamorphoses into a single, uninucleate ($2n$) and biflagellate zoospore.

The zoospores formed from plurilocular sporangia are alike with the zoospores i.e., zoomeiospores developed in unilocular sporangia but are diploid. The zoospores of plurilocular sporangia liberate through apical (Fig. 6.6 E) or lateral aperture and on germination they produce the sporophytic ($2n$) plant.

Sexual Reproduction

The sexual reproduction is both isogamous and anisogamous type. Oogamy is absent. Anisogamy is very common. Anisogamy may be of two types: morphological anisogamy (*E. secundus*) and physiological anisogamy (*E. siliculosus*). The gametes are produced inside the plurilocular gametangia, developed on haploid plants.

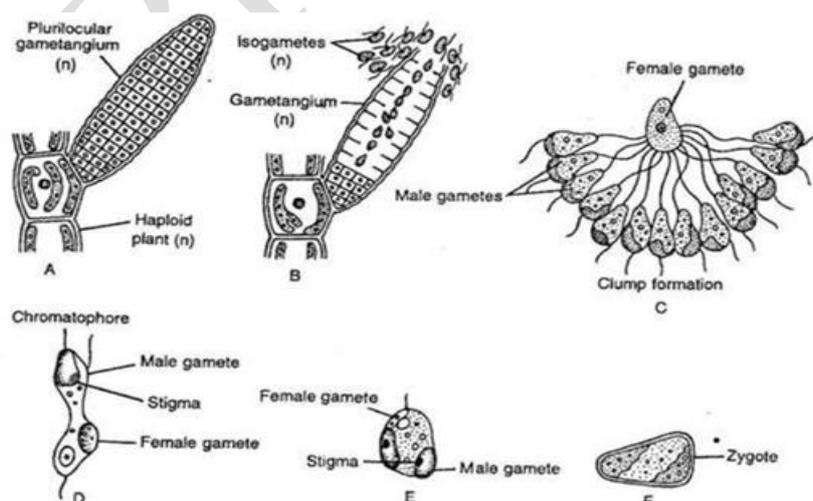


Fig 6.7. Liberation of gametes from gametangium, C. Male gametes around a female gamete before fertilisation (clump formation), D-E. Fusion of male and female gametes and F. Zygotes.

Plurilocular Gametangia

They are large, elongated, sessile or short stalked, multicellular structures (Fig.6.7 3.113A). Morphologically, both plurilocular gametangia and plurilocular sporangia are alike. The plurilocular gametangia produce haploid gametes; on the other hand, plurilocular sporangia produce diploid zoospores.

Though both are morphologically more or less alike, the gametes are slightly smaller in size than the zoospores. The development of plurilocular gametangia is alike with the development of plurilocular sporangia. The gametes are liberated from the gametangia following the same procedure as that of zoospore liberation from the plurilocular sporangia (Fig.6.7).

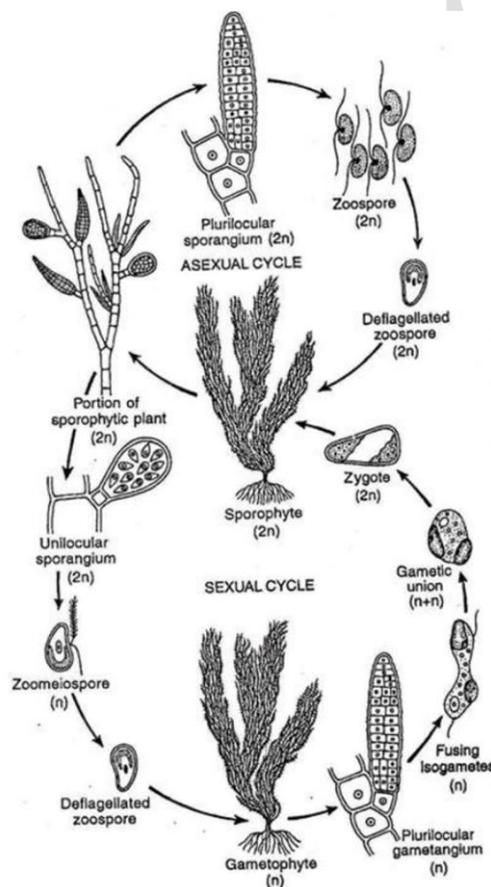


Fig. 6.8: Life cycle of Ectocarpus sp.

Fertilisation

Majority of the species show physiological anisogamy (Fritsch, 1945), but morphological anisogamy is observed in *E. secundus*. In physiological anisogamy both the uniting gametes are morphologically similar but in morphological anisogamy female gamete is larger

than the male gametes.

During fertilisation, many male gametes encircle the female gamete and get entangled by the anterior large flagellum. This stage is called clump formation (Fig. 6.7C). Out of many, only one male gamete fuses with the female gamete (Fig. 6.7 D, E) and the remaining gametes go astray and gradually get destroyed. The uniting gametes then form zygote (Fig. 6.7F), through plasmogamy and karyo- gamy.

Germination of Zygote: The zygote undergoes germination without any reduction division and rest. On germination it develops into a sporophytic ($2n$) plant. The sporophytic plant again develops unilocular and plurilocular sporangia.

Common Indian species

Ectocarpus arabicus, *E. filife*, *E. enhali*, *E. coniger*, *E. zeylanicus*, *E. rhodochortonoides* etc.

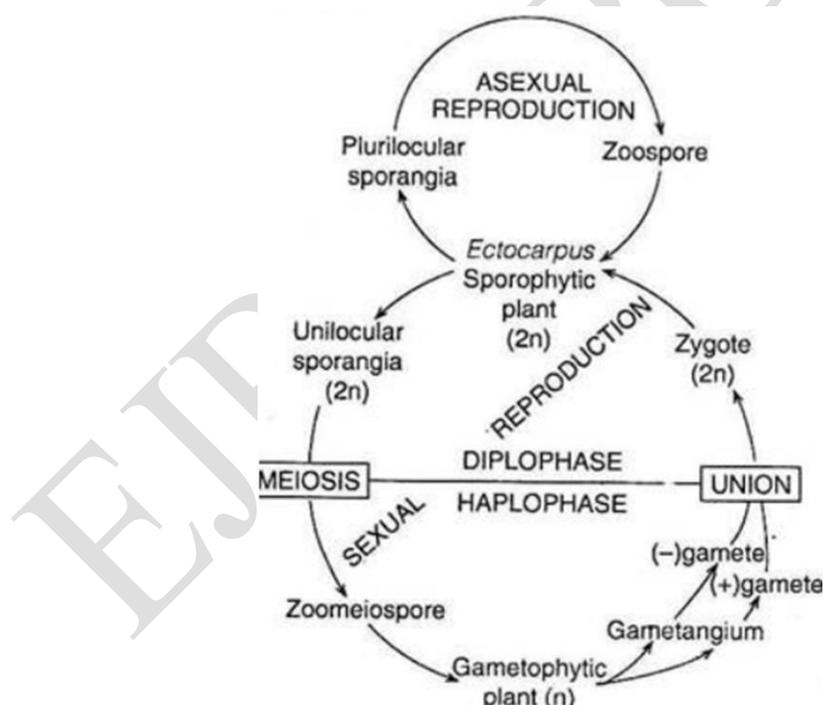


Fig 6.9: Graphic life cycle of Ectocarpus sp.

Genus: Laminaria

Occurrence of Laminaria

Class: Phaeophyceae (Brown algae)

Order: Laminariales **Family:** Laminariaceae **Genus:** *Laminaria*

Laminaria (Gr. a thin plate or leaf), with some 40 species, are exclusively grown on marine habitats in comparatively shallow water, mainly along the rocky shores, just below the tidal region. They are distributed widely on the Atlantic and Pacific coasts, especially where the water is cool. They are popularly called as “devil’s apron”.

Some common members are *L. digitata*, *L. saccharina*, *L. japonica*, *L. flavicans* and *L. flexicaulis*.

Plant Body of Laminaria

The plant body of Laminaria is diploid and attains a length of 2 to 12 metre or more in length. The sporophytic plant body is differentiated into holdfast, stipe and blade (*lamina*) (Fig. 3.123). It is an organ of attachment in variable forms. It may be like a solid disc or a cluster of profusely branched cylindrical root-like organs, also called haptera.

Stipe: It is an unbranched and cylindrical or slightly flattened stalk-like structure, developed on the holdfast and bears terminal blade (s).

Blade (Lamina): Blade may be simple (*L. saccharina*) or a cluster of vertically divided segments (*L. cloustoni*, *L. digitata*) (Fig. 6.10 A, B). Blades are flat, long, ribbon-shaped with wavy or smooth margins and tough and leathery in texture. Growth is intercalary and the meristematic zone is situated between the stipe and the blade.

Most of the members are perennial (*L. ephemera*, etc.) and live about 5 years or more, but in annual member (*L. ephemera*), a new sporophyte develops each spring.

Internal Structure of Laminaria

1. Stipe: In transverse section, the stipe shows the following regions:

- (i) Meristoderm,
- (ii) Cortex, and
- (iii) Medulla.

i) Meristoderm: It is the outermost region, consisting of one or two layers of small cubical cells containing chromatophores. It remains surrounded by a layer of mucilage and serves the function of assimilation.

ii) Cortex: It lies just below the meristoderm (between the meristoderm and central medulla). The cortex is usually differentiated into the outer and inner cortex. The outer cortex

is much wider and composed of elongated cells with pointed ends and the inner cortex is composed of longer cells with square ends. Mucilage canals or tracts are present in the cortex. The cortical cells serve the function of both storage and mechanical support.

iii) Medulla: It is the innermost layer, composed of loosely arranged cells and the spaces between them are filled with mucilage. Cross-connections are developed due to fusion of papillose outgrowths of the longitudinal walls. Due to regular cross-connections in the inner layer of cortex and in the medulla, the layers appear as an entangled network.

The medulla is characterised by the presence of elongated hyphal structures, the ‘trumpet hyphae’, formed due to swelling at the septa, which is larger at one side than the other (Fig. 6.10B). The transverse wall is perforated and shows a close resemblance to the sieve plates of sieve tubes. In older hyphae, the pores are sometimes blocked by callus pads.

2. Blade (Lamina): Like stipe, the blade also shows the following three main regions in transverse section:

(i) Meristoderm, (ii) Cortex (outer and inner), and (iii) Medulla (Fig. 3.124A). Only the elements of the medulla are drawn out due to the greater surface area.

Features of Laminaria

1. Sporophytic plant body is gigantic in size.
2. Plant body is differentiated into three regions: holdfast, stipe, and blade.
3. Internal structure of the plant body is very complex.
4. Presence of meristematic tissue between the stipe and blade causes annual replacement of the blade.
5. Sori containing sporangia and paraphyses are developed on the blade.
6. Reduction division in zoosporangia causes the development of haploid zoospores (meiozoospores).
7. Gametophytes are heterothallic.
8. Sexual reproduction is oogamous.
9. Fertilisation is external.
10. Alternation of generations is heteromorphic, where predominant sporophyte alternates with the much-reduced gametophyte.

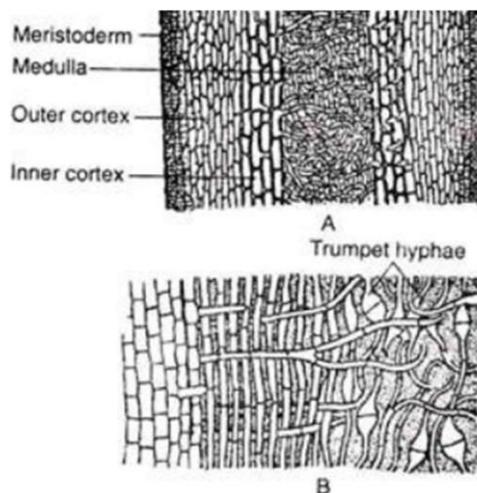


Fig. 6.10 Laminaria: A. T.S. of lamina showing internal structures, B. Portion of medulla in section showing the arrangement of trumpet hyphae.

Reproduction in Laminaria

The plant reproduces by all the three means: vegetative, asexual and sexual.

1. Vegetative Reproduction:

The vegetative reproduction takes place by stolons (*L. sinclarii*, *L. longipes* etc.). The stolons develop horizontally from the holdfast, grow upwardly into plantlets.

2. Asexual Reproduction:

It takes place by haploid zoospores developed within the club-shaped unilocular sporangia, borne inside the sori (Fig. 6.10 A) These haploid zoospores are also called meiozoospores or gonozoospores. Sori develop extensively on both the surface of the blade and nearly cover the entire area. Numerous sterile hyphae, the paraphyses are present intermingled with the sporangia.

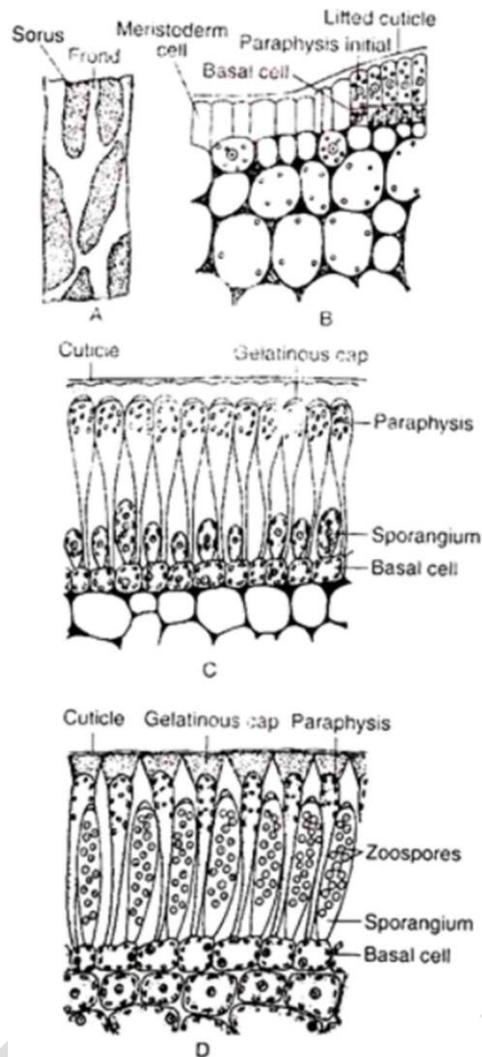


Fig. 6.11: Laminaria: A. Portion of lamina showing sori. B-D. Development of zoospores in sporangium.

Development

Sporangia develop from the superficial cells (meristoderm) of the blade. Initially these cells elongate and divide transversely into upper paraphysis initial and lower basal cell (Fig. 6.11). The paraphysis initial elongates and forms an elongated thread with a club-shaped upper region. During this time, the basal cell broadens and thus the paraphyses occupy a limited part towards its basal region. The upper region of the paraphysis contains numerous chromatophores and fucosan vesicles. Each one at its apex develops a cup-like gelatinous thickening (Fig. 6.11C).

By the side of the paraphysis, the basal cells enlarge and differentiate into sporangia by a transverse wall (Fig. 6.11D). During growth, the sporangia make their way and remain between the paraphyses. The nucleus of the sporangium undergoes the first meiotic division,

following successive mitotic divisions, thereby 32, sometimes 64, haploid nuclei are developed.

Each nucleus with some cytoplasm and chromatophore gets differentiated into a unit, which later gets differentiated into a zoospore. Zoospores are without eye spot (Henry and Cole, 1982), with two lateral flagella (biflagellate) of unequal length (the longer one tinsel and the shorter one whiplash).

Dehiscence of the sporangia takes place by the lateral pressure of paraphyses on the sporangium. After liberation, the zoospores swim actively for some time. Out of 32 or 64 zoospores, 50% develop into male gametophytes and the remaining 50% into female gametophytes.

After swimming for some time, the meiozoospores settle down to germinate. After withdrawing flagella, it becomes rounded and secretes a wall. On germination, it develops a small protuberance, which increases in length, and its apex becomes bulbous and appears almost like a dumbbell.

The bulbous region develops into a filamentous gametophyte, consisting of elongated cells. The male and female gametophytes develop male and female sex organs, respectively.

3. Sexual Reproduction

It is of oogamous type. Sperms and egg produce inside the antheridium (male sex organ) and oogonium (female sex organ), respectively. The male plants become many celled before they develop antheridia (Fig. 6.12 A), but the female plants develop oogonia at 2-3 celled stage.

Antheridia develop at the tip of lateral branches of many-celled male plants. Protoplast of each one-celled antheridium metamorphoses into a single pyriform or ellipsoidal antherozoid with two flagella (biflagellate) placed laterally (Fig. 6.12B). Sperms are liberated through the apical region of the antheridium. The male plant degenerates after the gametes are released.

Oogonia develop on 2-3 celled female plants (Fig. 6.12C). Oogonia are longer and thicker than the other cells of the female plant. The oogonial protoplast rounds off and becomes differentiated into an egg. At maturity, the egg is not extruded out but remains attached at the apex of the oogonial wall.

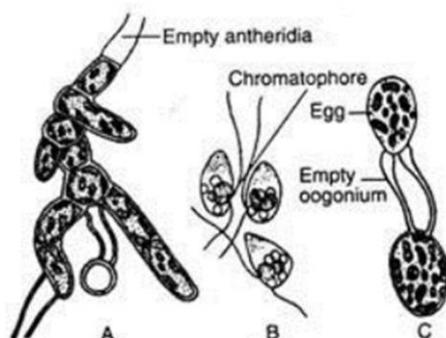


Fig. 6.12: Laminaria. A. Male gametophyte, B. Antherozoids, and C. Female gametophyte.

Fertilisation: After being liberated from the antheridium, the antherozoid swims in water. On reaching the oogonium, it unites with the egg and forms a zygote.

Germination of Zygote: Soon after the formation of the zygote, it develops into a sporophytic plant. Initially, the zygote undergoes successive transverse divisions and develops into a vertical row of 4-10 cells. Except the lowermost one, all other cells of the filament further divide by both vertical and transverse divisions, thus forming an expanded, thin and flat blade (Fig. 6.13 B).

The lowermost cell elongates to form the first rhizoid, but later several rhizoids are developed (Fig. 6.13 C). Further division takes place in the lower part of the blade, thus forming a meristematic region. With further development, the lower and upper parts of the meristem get differentiated into the stipe and blade, respectively. Parthenogenetically, an egg may develop into a plant, as of a sporophytic plant, which is irregular in shape.

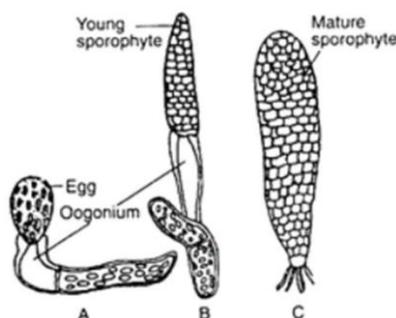


Fig. 6.13: Laminaria. A-C. Stages in the development of the sporophyte.

Alternation of Generations

Laminaria exhibits a heteromorphic alternation, showing a prominent and well-developed

sporophyte and a very small gametophyte. Asexual reproduction takes place in the sporophytic plant. The zoospores are developed inside the zoosporangium through meiosis and are thus called as zoomeiospores. Half of the zoomeiospores develop multicellular male thalli, where antherozoids are produced inside the antheridium.

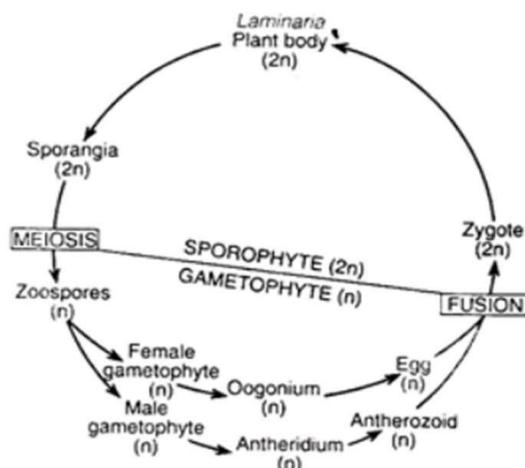


Fig. 6.14: Laminaria. Graphic life cycle.

The other half develop into female thalli; those develop egg inside oogonium. The entire process of sexual reproduction is unique of its kind. The egg does not remain within the oogonium, but it remains attached with the oogonial wall, indicating a transitional stage between the primitive and advanced nature.

There is spontaneous germination of zygote without rest, while it still remains attached with the female gametophyte. This is found to be an important feature in the life cycle of Laminaria (Fig. 6.14 and 6.15).

Economic Importance of Laminaria

The economic importance of Laminaria is given

The burnt ash (Europe) as well as the large brown seaweeds (America) are referred to as “kelp”. The ash contains a large amount of iodine (15 kg/ton).

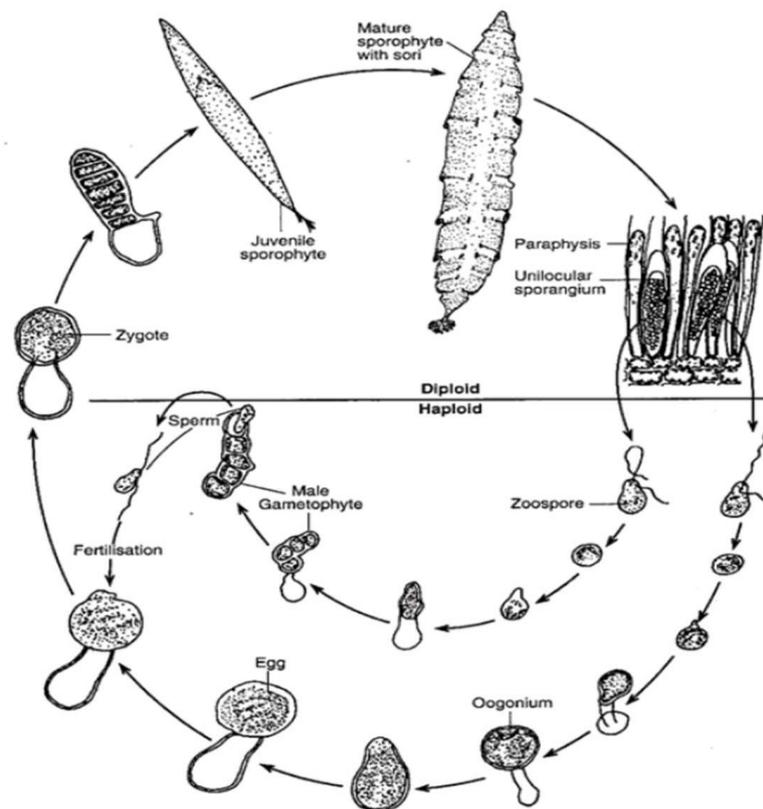


Fig. 6.15: Laminaria: Diagrammatic life cycle.

The industrial use of kelps is for the alginate, which has several uses.

- (i) In making ice-cream, Manufacturers add alginate before freezing their product, which prevents the water from forming coarse ice-crystals in ice-cream, thus it results in a smoother product (Smith, 1955).
- (ii) Goiter is treated by giving kelp pills or kelp ash.
- (iii) Stipes of Laminaria are used in surgery for opening fistulae (natural opening), because of their swelling properties.
- (iv) Brown seaweeds have also been used as green manure for the soil and as food for animals and human beings.
- (v) “Kombu” is a food made from members of Laminariales in Japan.
- (vi) In Mainland China, Laminaria is known as “haidai” (sea belt), which has been widely used as a food and medicine for over 1,500 years.

Genus: Sargassum

Class: Phaeophyceae Order: Fucales Family: Sargassaceae Genus: Sargassum

The genus Sargassum (Spanish sargazo, seaweed) is represented by about 150 species, out of

which 16 species are found in India. It is found in temperate, subtropical and tropical regions of both northern and southern hemispheres. It is very common in Africa, South America, Australia etc.

In West Africa, a part of the Atlantic Ocean becomes densely occupied by *Sargassum* and the region is called the 'Sargasso Sea'. *Sargassum filipendula*, a free-floating large kelp found in the Sargasso Sea, was discovered by Columbus in 1492, as the ships were held fast by the seaweeds. In India, it is found in Porbandar, Bombay, Okha, Lakshadweep Island, etc.

Plant Body of *Sargassum*

The plant body is diploid ($2n$), erect and branched thallus (Fig. 3.116). The thallus is differentiated into a basal holdfast and an expanded, leafy, cylindrical main axis.

The holdfast is discoid and serves the function of anchorage with the substratum. The main axis is generally of 10 to 50 cm in length. It is erect, flattened or cylindrical structure. The main axis bears many primary laterals arranged spirally in a phyllotaxy of $2/5$.

Due to its unlimited growth, the primary laterals are also called long shoots. The main axis and primary laterals (long shoots) bear flat, expanded structures, called secondary laterals or leaves. The leaves are flat, simple structures with distinct midribs and dentate, serrate or entire margins, with an acute apex.

Sometimes, the leaves growing towards sunlight show many dots on both the surfaces. These dots are the ostioles, i.e., openings of the sterile conceptacles. The sterile conceptacles are also called cryptoblasts or cryptostomata.

On the main axis as well as on the primary laterals, the secondary laterals i.e., the leaves are replaced by many spherical, hollow bodies, called air bladders. The air bladders help to float them in water (Fig. 6.16).

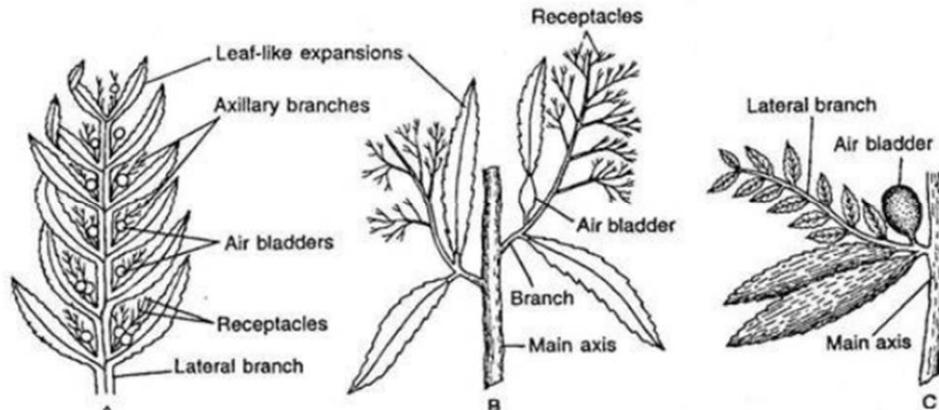


Fig. 6.16: Sargassum sp. A. Portion of a branch with leaf-like expansions, airbladders and receptacles, B. Portion of the main axis showing arrangement of branches, leaf-like expansions and receptacles, and C. Lower part of main axis with lateral branch and air bladder.

Internal Structure of Sargassum

Axis

It is generally of circular in outline and differentiated into three regions: outer meristoderm, middle cortex and innermost medulla (Fig. 3.117A).

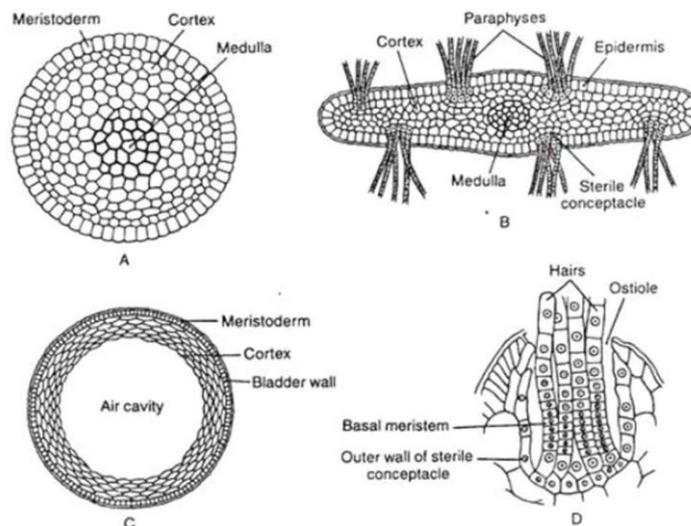


Fig 6.17: Sargassum sp. Internal structures A. TS of main axis B. TS of leaf. C. TS. through the air bladder, and VS of sterile conceptacles.

The meristoderm is made up of single layer of closely packed cells. The cells are meristematic in nature. The cells contain chromatophores and perform photosynthesis. This layer can store food material.

The cortex is situated next to the meristoderm and occupies major part of the axis. It consists of compactly arranged parenchyma cells of polygonal shape, rarely with intercellular spaces. The cells are smaller in size than meristoderm. Like the outer layer this layer also stores food material.

Leaf

It is flat and differentiated into outer meristoderm, middle cortex and inner medulla like the axis (Fig. 6.17B). The medulla is round and present in the middle region. On both surfaces of the leaf there are many sterile conceptacles, the cryptostomata or cryptoblasts (Fig. 6.17D).

These are flask-shaped with many sterile unbranched filaments, the paraphyses developed from the base. The paraphyses protrude out through the opening present on the outer side, the ostiole. The cells of the wall have many chromatophores.

Air Bladder

Internally it is almost alike with the axis but without medulla (Fig. 6.17C). The central region is occupied by a large hollow cavity filled with air and gases. Outer to the cavity, cortex is present; which consists of a few layers and thinner cells than axis and finally it ends with a single layered outer meristoderm. Thus the thallus shows division of labour along with differentiation of tissues. It serves the function of anchorage, photosynthesis, storage, conduction and support.

Features of Sargassum

1. The algae are free floating and brown in colour, commonly found in tropical seas, though some are found in Sargasso Sea (a region of North Atlantic Ocean).
2. The plant body is diploid and differentiated into root, stem and leaf-like structures.
3. The main axis i.e., stem is vertically elongated and differentiated into nodes and internodes.
4. It bears long shoots of unlimited growth (primary laterals), leaves (secondary laterals), air bladders and receptacles.
5. Both stem and leaves are differentiated into epidermis, cortex and medulla.
6. Apical growth takes place by a three-sided apical cell.
7. Reproduction takes place by vegetative and sexual means. Asexual reproduction is absent.
8. Vegetative reproduction takes place by fragmentation.

9. Sexual reproduction is oogamous.
10. Oogonia and antheridia are borne in unisexual conceptacles, those remain embedded in receptacles.
11. Oogonium produces one egg and the antheridium produces 64 biflagellate sperms.
12. Fertilization is internal, as the egg is not come out from the oogonium.
13. Zygote germinates directly and produces a new sporophytic (2n) plant.

Reproduction in Sargassum

It reproduces by both vegetative and sexual means. Asexual reproduction is absent.

1. Vegetative Reproduction

It takes place by fragmentation. Due to death and decay of the older part, the younger region gets separated. The separated region grows and finally develops into a new individual like the mother. The free-floating members like *S. hystrix* and *S. natans*, multiply only by this method.

2. Sexual Reproduction

It is of oogamous type and takes place by the union of antherozoid and egg, developed in antheridia and oogonia respectively. The sex organs develop in separate flask-shaped bodies the conceptacles, developed on branched receptacles. The conceptacles with antheridia or oogonia are called male or female conceptacles.

Development of conceptacle. The fertile and sterile conceptacle are almost similar. The difference lies in the activity of basal cells of the linear wall of conceptacle. In sterile conceptacle it only develops sterile hairs, the paraphyses, but in fertile conceptacle it develops either antheridia or oogonia and also paraphyses in some regions.

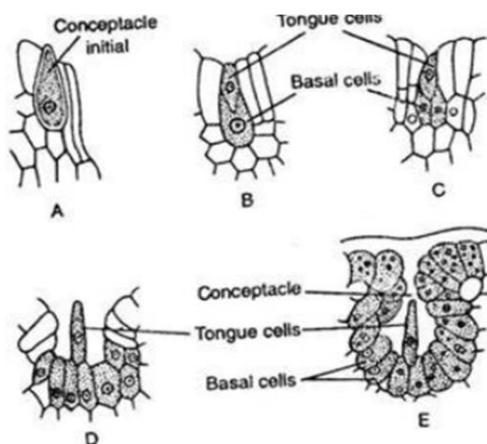


Fig. 6.18 Sargassum sp. A-E Development of conceptabl.

During development (Fig. 6.18) single superficial cell on the receptacular branch becomes enlarged and functions as conceptacle initial (Fig. 6.18A). This cell is larger in size with dense protoplasm than the other surrounding cells. The conceptacle initial becomes flask-shaped.

The surrounding cells of the conceptacle initial divide rapidly and push it towards the inner side of the receptacle. The conceptacle initial then undergoes mitotic division and by oblique septation it forms upper elongated tongue cell and lower broad basal cell (Fig. 6.18B).

The tongue cell elongates and gradually disappears. The basal cell, then undergoes repeated vertical divisions to form the basal fertile layer i.e., the inner layer of the conceptacle. The reproductive organs are developed from this inner layer.

Development of Antheridium

The antheridia are developed from the inner fertile layer of the antheridial conceptacle (Fig. 6.19). The lower basal cells of the conceptacle are the antheridial initials forming papilla like outgrowths (Fig. 6.19A). Each one divides by a transverse wall into two cells. The lower one remains as conceptacle Wall, whereas the upper one (Fig. 6.19A) again divides transversely and forms a lower stalk cell and an upper antheridial cell (Fig. 6.19B).

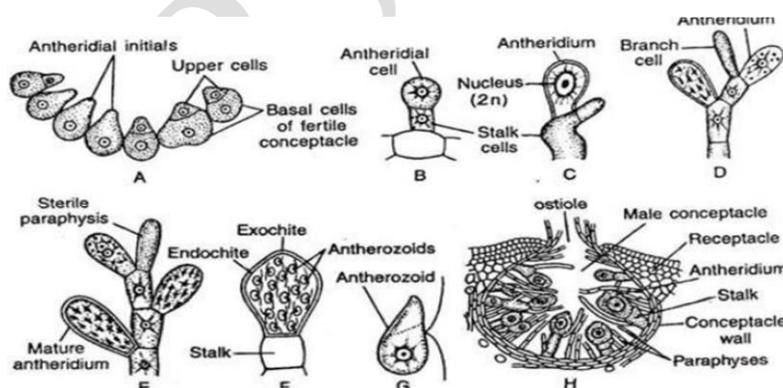


Fig 6.19: Sargassum sp. Development of antheridium: A. Cells of basal fertile layer of conceptacle, B-E. Development of antheridium, F. Mature antheridium, G. Single antherozoid, and H. VS. of male conceptacle showing antheridium along with paraphyses.

The antheridial cell develops into an antheridium (Fig. 6.19C). Due to rapid growth of the stalk cell, the antheridium becomes pushed at one side (Fig. 6.19D). The stalk cell again undergoes transverse division and forms the upper antheridial cell and the lower stalk cell.

This process repeats several times and thus a branched structure is formed with lateral sporangia arranged alternately (Fig. 6.19D, E). The apical cell of the stalk remains sterile and behaves as paraphysis. Many thread like filaments also develop from the basal cells of the conceptacle which are also called paraphyses (Fig. 6.19H).

The diploid nucleus of the antheridial initial undergoes meiosis followed by repeated mitotic divisions forming 32-64 haploid nuclei. The nuclei then accumulate some cytoplasm and form many uninucleate bodies. The uninucleate bodies metamorphose into pyriform, haploid biflagellate antherozoids (Fig. 6.19C).

The mature antheridium (Fig. 6.19F) is oval and covered by two walls, outer firm exochite and inner gelatinous endochite. At maturity the antheridium is detached from the stalk and comes out from the conceptacle through ostiole. After coming out, the wall of sporangium gets gelatinised and the antherozoids are liberated.

Development of Oogonium

Like antheridium, oogonium also develops from the basal fertile layer of the conceptacle (Fig. 6.20). Some of the cells of this layer function as an oogonial initials (Fig. 6.20A). The oogonial initial undergoes transverse division and forms lower small stalk cell and upper large oogonial cell (Fig. 6.20B).

The oogonial cell becomes enlarged and forms a spherical structure. The diploid (2n) nucleus undergoes first meiotic (Fig. 6.20C), then mitotic divisions and 8 nuclei are formed. Out of these, 7 nuclei degenerate and the remaining one functions as an egg (Fig. 6.20D) which remains in the centres.

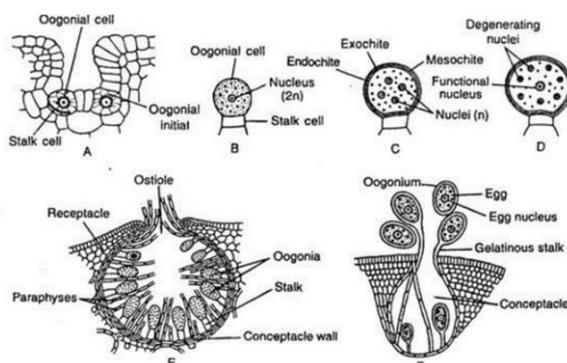


Fig. 6.20: Sargassum sp. Development of oogonium A-D. Development of oogonium, E. Vertical section of female conceptacle showing oogonia and paraphyses inside, and F.

Release of Oogonium from conceptacle.

The wall of the oogonium consists of three layers, the outer exochite, the middle mesochite and inner endochite (Fig. 6.20C). The mature oogonia come out of the conceptacle through the ostiole, but still they remain attached with the conceptacle base by a long gelatinous stalk formed by the exochite.

Some of the basal cells of the inner layer of conceptacle instead of forming oogonia remain sterile and form sterile, long, hair-like structures, the paraphyses (Fig. 6.20E). Thus conceptacle contains oogonia intermingled with paraphyses.

Fertilisation

Fertilisation takes place when the eggs remain outside but still attached to the conceptacle by gelatinous stalks (Fig. 6.20F). Many antherozoids get attached to the egg by their anterior flagella, and their posterior ones help in swimming (Fig. 6.21A).

Later on, only one penetrates the oogonial wall. The remaining antherozoids get separated and gradually degenerate. Initially, after fertilisation, both the nuclei remain side by side (Fig. 6.21 B), but later they fuse and form the zygote (Fig. 6.21C).

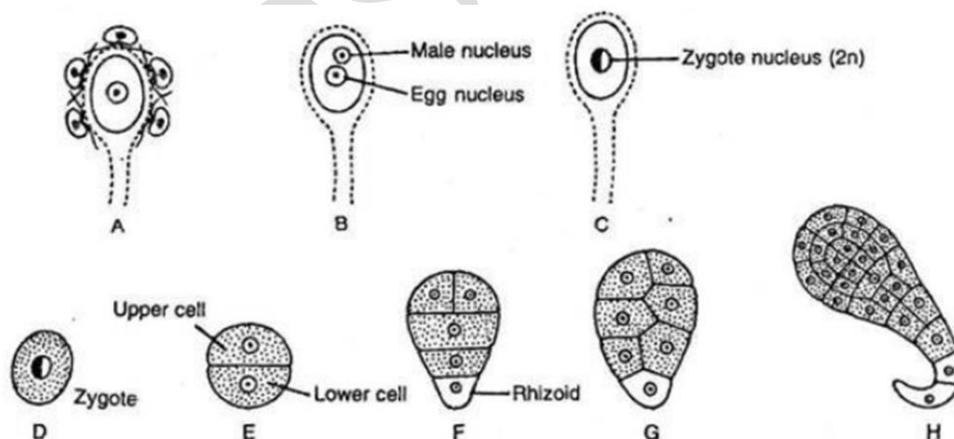


Fig. 6.21: Sargassum sp.: A-C. Stages of fertilization, D. Zygote, E-H. Development of the Zygote.

Germination of Zygote

Just after fertilization, the zygote undergoes germination (Fig. 6.21D-H), while the oogonium remains attached to the conceptacle. After some time, it comes out of the gelatinous wall. After liberation, the zygote gets attached to any solid substratum.

The zygote then divides transversely and forms the lower and upper cells. The lower cell develops into a rhizoid, and the upper cell undergoes repeated periclinal and anticlinal divisions, thus forming a thalloid sporophyte ($2n$) of *Sargassum*.

Life Cycle Pattern of *Sargassum*

Sargassum shows diplontic life cycle without any alternation of generations (Fig. 6.22). The plant body is diploid except for the antherozoids and eggs. The antherozoids and eggs i.e., the gametes, represent only the haploid (n) stage. After the fusion zygote is formed. The zygote is diploid ($2n$), and on germination, it develops a sporophytic ($2n$) plant of *Sargassum*. Thus, it shows a typical example of a diplontic life cycle.

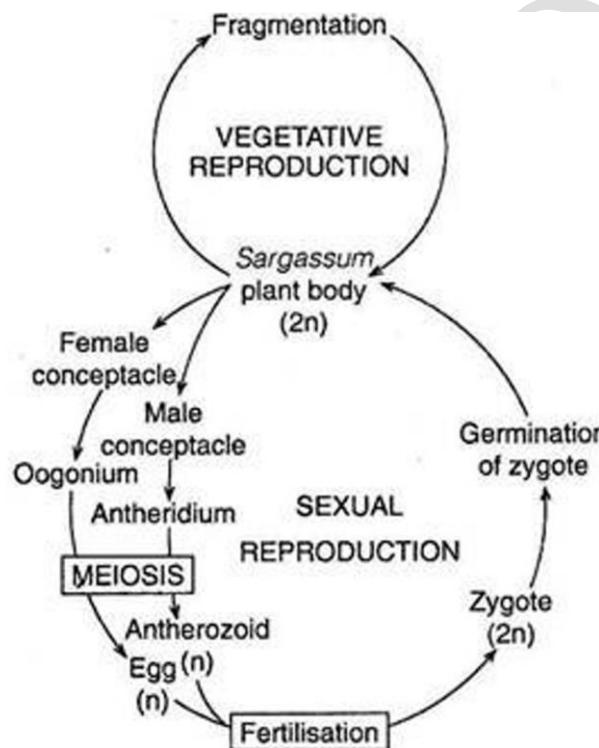


Fig. 6. 22: Graphic life cycle of *Sargassum* sp.

Common Indian species.

Sargassum ilicifolium, *S. tenerrium*, *S. wightii*, *S. duplicatum*, *S. myriocystum*, *S. christifolium*, *S. carpophyllum*, *S. cinereum* and *S. plagiophyllum*.

EXERCISE

Short Answer Questions (5–6 sentence answers expected)

1. Describe the general structure of the thallus in *Fucus*.
2. What are conceptacles and where are they located in *Fucus*?

3. How does fertilization occur in *Fucus*?
4. What are the main chemical compounds found in *Fucus vesiculosus*?
5. Mention two adverse effects of consuming *Fucus vesiculosus*.
6. Where is *Ectocarpus* commonly found, and what types of habitats does it prefer?
7. Describe the external morphology of the *Ectocarpus* plant body.
8. What are the main features of the cell structure in *Ectocarpus*?
9. What are the two types of sporangia found in *Ectocarpus*, and how do they differ?
10. How does sexual reproduction occur in *Ectocarpus*?
11. What is meant by isomorphic alternation of generations in *Ectocarpus*?
12. Describe the morphology of the *Laminaria* plant body.
13. What is the structure and function of the medulla in *Laminaria*?
14. Explain the nature of asexual reproduction in *Laminaria*.
15. What is the role of paraphyses in *Laminaria* reproduction?
16. Write a note on gametophytes and sexual reproduction in *Laminaria*.
17. What kind of alternation of generations is found in *Laminaria*?
18. What is the role of air bladders in *Sargassum*?
19. Write a note on the conceptacles of *Sargassum*.
20. Describe the internal structure of the axis in *Sargassum*.
21. Explain the process of vegetative reproduction in *Sargassum*.
22. What type of life cycle does *Sargassum* exhibit?

Essay Questions

1. Describe the internal structure and anatomy of *Fucus* thallus.
2. Explain the process of sexual reproduction in *Fucus* with labelled diagrams.
3. Discuss the life cycle of *Fucus* and explain why it is considered diplontic.
4. Write an account on the economic uses and side effects of *Fucus vesiculosus*.
5. Why is there no true alternation of generations in *Fucus*? Discuss with reference to gametophyte and sporophyte phase
6. Describe the life cycle of *Ectocarpus* with diagrams, highlighting alternation of generations.
7. Explain the structure and development of unilocular and plurilocular sporangia in *Ectocarpus*.
8. Give a detailed account of sexual reproduction in *Ectocarpus*.
9. Discuss the morphology, anatomy, and growth pattern of *Ectocarpus*.

10. Describe the life cycle of Laminaria with labelled diagrams.
11. Discuss the internal structure of Laminaria with reference to the stipe and blade.
12. Give a detailed account of sexual reproduction in Laminaria.
13. Explain the economic importance and reproductive adaptations of Laminaria.
14. Describe the external and internal structure of Sargassum with suitable diagrams.
15. Explain the sexual reproduction in Sargassum with reference to development of sex organs and fertilisation.
16. Discuss the process of zygote development and life cycle pattern of Sargassum.
17. Write an account on the occurrence and ecological importance of Sargassum

Rhodophyceae (Red Algae)

UNIT VII: RHODOPHYCEAE (RED ALGAE)

Rhodophyceae is a prominent and distinct class of algae, commonly known as **red algae**, comprising nearly **25,000 species** classified under around **400 genera**. This group is primarily marine and is ecologically and economically important.

Distinctive Features of Rhodophyceae

- 1. Pigmentation:** The characteristic **red colour** of the thallus is due to the dominance of **phycoerythrin** (a red phycobilin pigment), which absorbs blue-green light. **Phycocyanin** is also present, along with **chlorophyll** and minor amounts of **chlorophyll d**. These pigments allow red algae to photosynthesize efficiently in deeper marine waters where light penetration is minimal.
- 2. Storage Products:** The primary **reserve food** is **Floridean starch**, stored in the cytoplasm, not in plastids. Additionally, **floridosides** (a type of galactoside) serve as reserve materials.
- 3. Cell Wall Composition:** The **cell wall** is composed of **cellulose** and **mucilaginous polysaccharides** such as **agar**, **carrageenan**, and **polysulphate esters**. These substances are commercially valuable for use in food, pharmaceuticals, and microbiology.
- 4. Thallus Structure:** The thallus may be **unicellular**, **filamentous**, **branched**, or **parenchymatous** in structure. Some red algae exhibit a **heterotrichous habit** (both prostrate and erect systems).
- 5. Lack of Motile Stages:** **Motile stages are completely absent** throughout the life cycle. Even the **male gametes (spermatia)** are **non-motile**, relying on water currents for fertilization.
- 6. Sexual Reproduction:** Reproduction is **oogamous**, involving non-motile **spermatia** and a female reproductive structure called the **carpogonium**. The **carpogonium** typically has a **trichogyne**, a hair-like extension for receiving spermatia.
- 7. Post-Fertilization Changes:** **Highly elaborate post-fertilization development** is a unique feature of red algae. Structures such as **gonimoblasts** develop, leading to the formation of **carpospores**. In advanced forms, a **triphasic life cycle** is seen: **gametophyte** → **carposporophyte** → **tetrasporophyte**.
- 8. Life Cycle:** Many red algae exhibit a **triphasic alternation of generations**, which includes **Gametophyte** (haploid), **Carposporophyte** (diploid, parasitic on the gametophyte), **Tetrasporophyte** (free-living diploid form producing tetraspores).

Tetraspores are formed by meiosis and help in the dispersal and continuation of the life cycle.

Habitat: Most red algae are **marine**, especially abundant in **warm, tropical seas**. A few are **freshwater** species (e.g., *Batrachospermum*). They are commonly found **attached to rocks**, shells, or other substrates in the **intertidal to deep sea zones**.

9. Economic Importance: **Agar** (from *Gelidium*, *Gracilaria*) and **carrageenan** (from *Chondrus crispus*) are extracted from red algae. These compounds are widely used in **food industry, microbial culture media, cosmetics, and medicine**. Some species like *Porphyra* (Nori) are consumed as **edible seaweed**, especially in East Asia.

10. Examples of Rhodophyceae: *Polysiphonia*, *Gelidium*, *Gracilaria*, *Chondrus*, *Porphyra*, *Batrachospermum*, *Ceramium*, *Corallina*.

11. Ecological Role: Red algae contribute to **reef building** (e.g., *Corallina* with calcium carbonate deposits). They play a role in **marine food chains** and **oxygen production**. Their **mucilage** helps in **water retention** and **protection from desiccation** in intertidal zones.

Occurrence of Red Algae (Rhodophyceae)

Red algae are predominantly marine in habitat, thriving extensively in saltwater environments, especially in warm tropical and subtropical seas. However, a few notable exceptions like species of *Batrachospermum* and *Lemanea* are found in freshwater ecosystems, such as streams and rivers.

Despite their global distribution, red algae are most abundant in warmer oceanic regions. Light availability, particularly the quality and depth of light penetration, significantly influences the ecological distribution of these algae in the sublittoral zones (areas below the low tide mark). In aquatic environments, only blue and red wavelengths penetrate deeper waters, but beyond 10 meters, blue-green light is the primary spectrum that remains. The phycoerythrin pigment present in red algae efficiently absorbs this light, enabling these algae to perform photosynthesis even at depths of 60 meters or more. This adaptation helps them flourish where other photosynthetic organisms may struggle.

Red algae also demonstrate a phenomenon known as **complementary chromatic adaptation**, where pigment composition varies depending on the light conditions of their habitat.

Their occurrence can vary greatly

Species like *Rhodochorton rothii* and *Bostrychia* are found in upper intertidal zones, even at or above the high tide level. Some red algae are parasitic: *Ceratocolax* and *Choreonema* act as total or partial parasites. *Choreocolax* lives completely parasitically on *Polysiphonia*. *Polysiphonia fastigiata* is a semi-parasite on the brown alga *Ascophyllum*.

Certain red algae like *Corallina* and *Lithothamnion* undergo calcification by depositing calcium carbonate in their cell walls. These calcareous red algae play a vital role in reef formation and in stabilizing marine structures, contributing significantly to marine biodiversity and sediment formation.

Range of Structure (Somatic Organization) in Rhodophyceae

The red algae (Rhodophyceae) show a wide range of vegetative structures, based on which they are classified into two sub-classes. The first sub-class, Bangioideae, includes the simpler types of red algae. These forms are found not only in marine but also in freshwater and even terrestrial environments. They may occur as unicellular organisms, such as *Porphyridium*, or in filamentous forms like *Goniotrichum* and *Bangia*. In some species, the thallus appears as a flat, membranous sheet, such as in *Porphyra*. Growth in these algae occurs either diffusely or intercalarily, and pit-connections are either absent or found in very few instances.

The second sub-class, Florideae, comprises the majority of red algae, most of which are marine. These forms are typically filamentous and exhibit two types of thallus organization. In the uniaxial type, a single central filament acts as the main axis and may be either corticated or uncorticated, bearing lateral branches as seen in *Dumontia* and *Batrachospermum*. In contrast, the multi-axial type consists of several axial filaments and their branches, forming a dense, pseudoparenchymatous thallus. Growth in these forms takes place through an apical cell that undergoes transverse divisions to form a row of cells. Each of these can then divide tangentially to produce pericentral cells that surround the central axis. In the family Rhodomelaceae, these pericentral cells usually do not divide further, while in other groups, they may undergo vertical divisions to form a cortex or even initiate new branches. In more advanced forms, such branching results in a compact thallus showing internal differentiation into an outer photosynthetic zone, a cortical region, and a central medulla composed of elongated filaments, as observed in *Gelidium*. Despite these variations, the basic body plan in all red algae remains filamentous, and true parenchymatous tissue is absent. The filaments often branch extensively, and in many primitive genera, a

heterotrichous form is seen during the early stages, which may sometimes persist into maturity.

Cell Structure

The cells of red algae are typically surrounded by a mucilaginous envelope located external to the cell wall. The cell wall itself is composed of two distinct layers: an inner microfibrillar layer made up of cellulose, and an outer gelatinous layer rich in pectic substances and polysulphate esters. These outer components are industrially significant species such as *Gelidium*, *Gracilaria confervoides*, and *Chondrus crispus* are notable sources of agar, extracted from the pectic layer. In members of the family Corallinaceae, calcium carbonate and magnesium carbonate are deposited within the cell wall, giving them a calcareous texture and contributing to reef-building. In the sub-class Florideae, pit connections are found at the center of each transverse cell wall. These structures help maintain cytoplasmic continuity between adjacent cells and are believed to assist in the transfer of nutrients.

The chloroplast (chromatophore) structure varies between the two sub-classes. In Bangioideae, each cell typically contains a single stellate, centrally located chromatophore with a naked central pyrenoid. In contrast, species of Florideae possess multiple parietal chromatophores, which are discoid or band-shaped and lack pyrenoids.

Red algal chromatophores contain a variety of pigments that contribute to their distinctive coloration and photosynthetic ability. These include.

Chlorophylls: *Chlorophyll a* and *Chlorophyll d*

Carotenes: *β -carotene*, *ϵ -carotene*

Xanthophylls: *Flavicin*, *Violaxanthin*, *Flavoxanthin*, *Neoxanthin*, *Fucoxanthin*, *Neofucoxanthin-A*, *Neofucoxanthin-B*, *Diatoxanthin*, *Diadinoxanthin*, *Dinoxanthin*, *Neodinoxanthin*, *Peridinin*, *Myxoxanthin*, and *Myxoxanthophyll*

• **Phycobilins:** *r-phycoerythrin*, *r-phycoerythrin*, *β -phycoerythrin*

Ultrastructural studies reveal that chromatophores are bounded by a double membrane and contain loosely arranged single thylakoids, which are widely spaced. In *Porphyridium*, specialized pigment-protein complexes called phycobilisomes are arranged linearly on the surface of the thylakoids. Phycobilisomes containing phycoerythrin are generally spherical, while those containing phycocyanin are disc shaped.

Other cellular organelles such as dictyosomes (Golgi bodies), endoplasmic reticulum, and

tonoplast-bound vacuoles have also been reported in several red algae species. The nuclear arrangement varies cells of Bangioideae are usually uninucleate, whereas those in Florideae may be uninucleate or multinucleate. In some advanced forms like *Griffithsia*, a single cell can contain up to 4000 nuclei, reflecting a high degree of cellular complexity.

Reproduction

In red algae, vegetative reproduction is generally rare and mostly confined to unicellular species. However, both asexual and sexual reproduction are commonly observed and are the primary means of propagation in most forms.

A wide variety of asexual spores are produced during reproduction. In the Bangioideae, monospores and neutral spores are common, whereas members of Florideae produce carpospores, bispores, tetraspores, and polyspores, depending on the stage and species.

Sexual reproduction in red algae is typically oogamous, involving distinct male and female gametes. The plants are usually dioecious (separate male and female individuals), though monoecious forms do occur in rare cases. The male and female plants are usually similar in appearance; however, in *Martensia fragilis*, the male plants are noticeably smaller.

The male reproductive structure is called the spermatangium (or antheridium), which produces non-motile male gametes known as spermatia. The female reproductive organ, known as the carpogonium, consists of a basal egg cell and an elongated neck-like projection called the trichogyne. In Bangioideae, carpogonia are sessile, whereas in Florideae, they are typically stalked.

Fertilization occurs when a spermatium, transported by water currents, adheres to the trichogyne. A passage forms between the trichogyne and the egg cell, allowing the male nucleus to travel down and fuse with the female nucleus, forming a zygote. This process is highly uniform across all red algae.

In Florideae, fertilization is followed by a complex series of post-fertilization changes, resulting in the development of a separate generation called the carposporophyte. This structure is diploid and grows as a parasite on the female gametophyte. It produces carpospores, which are also diploid.

The development of the zygote varies among different orders.

- In Nemalionales, the zygote undergoes meiotic division, resulting in haploid gonimoblast filaments.
- In Gelidiales, the zygote divides mitotically, producing diploid filaments.
- In other groups, the zygote nucleus migrates into an auxiliary cell via a pit or tubular connection and divides mitotically, forming gonimoblast filaments.

The gonimoblast cells act as carposporangia, each producing a single carospore. Upon germination.

- Haploid carospores form new haploid plants in Nemalionales.
- Diploid carospores give rise to a diploid tetrasporophyte in other groups.

The tetrasporophyte bears tetrasporangia, where meiosis occurs to form four tetraspores typically two give rises to male gametophytes, and two to female gametophytes. Although most species produce separate male and female plants, a few may form monoecious individuals. Both the carposporophyte and tetrasporophyte represent the asexual (diploid) phases of the life cycle in Rhodophyceae, completing the triphasic alternation of generations characteristic of most red algae.

Life cycle

In the red algae (Rhodophyceae), two major types of life cycles have been identified based on the number and nature of the alternating generations.

The first type is the Haplobiontic life cycle, which involves two alternating haploid generations. In this type, a haploid gametophyte alternates with a haploid carposporophyte. This cycle is referred to as haplobiontic or diphasic haplohaplontic, as both phases are haploid. The term was introduced by Svedelius in 1915, based on the life cycle pattern observed in species like *Scinia furcellata*, *Nemalion multifidum*, *Batrachospermum moniliforme*, and *Asparagopsis hamifera* (order Nemalionales).

The second and more complex type is the Diplobiontic life cycle, also named by Svedelius in 1915 as the Polysiphonia type, which is typical of most Florideae members. In this case, the life cycle includes three distinct phases: a haploid gametophyte, a diploid carposporophyte, and a diploid tetrasporophyte. Thus, the life cycle is triphasic diplobiontic. While the gametophyte and tetrasporophyte are morphologically similar and free-living, the carposporophyte remains parasitic on the female gametophyte and is attached to it.

Further classification of red algal life cycles was proposed by Prescott in 1969, who grouped them based on the number and morphology of the phases involved.

- Monomorphic life cycle: This type features only one kind of thallus, as seen in *Porphyra*, where the gametophytic and sporophytic generations are morphologically identical.
- Dimorphic life cycle: This involves two morphologically distinct individuals, one producing gametangia (gametes) and the other forming sporangia (spores). This type is further divided into:

Homomorphous type: Both generations are morphologically similar, as in *Polysiphonia*.

Heteromorphous type: The two generations are morphologically different, as seen in *Asparagopsis*.

These variations in life cycle patterns demonstrate the evolutionary complexity and diversity of reproductive strategies among the red algae.

Classification of Rhodophyceae

Classification of Rhodophyceae by Fritsch (1945)

Fritsch (1945) categorized the class **Rhodophyceae** into **two subclasses** and **seven orders**, of which **six orders** belong to the subclass **Florideae**.

A. Subclass: Bangioideae

- These forms are generally simple in structure and exhibit diffuse growth.
- **Pit-connections** are absent.
- **Carposporangia** arise directly from the **zygote** through division.
- Species may be found in both **marine** and **freshwater** habitats.

Order: Bangiales

- The sole order within Bangioideae.
- Shares the same simple structural features.
- **The** life cycle is haplobiontic.

B. Subclass: Florideae

- Comprises filamentous forms, often forming compact pseudoparenchymatous thalli.
- Pit-connections are always present between adjacent cells.
- Carposporangia develop on gonimoblast filaments, which originate from the zygote.

- Most forms are marine.
1. Nematiales
 - Thallus typically heterotrichous, with uni- or multiaxial construction.
 - Cells usually contain a single chromatophore.
 - Gonimoblasts commonly develop from the carpogonium.
 - Reproduction includes mono- or tetraspores.
 - The life cycle is haplobiontic, and some species inhabit freshwater.
 2. Gelidiales
 - The thallus has a uniaxial structure.
 - Tetrasporangia are arranged in a cruciate pattern.
 - A compound procarp is present.
 - The life cycle is diplobiontic.
 3. Cryptonemiales
 - Thalli may be **uni- or multiaxial**, with **indistinct heterotrichy**.
 - Auxiliary cells may be situated far from the carpogonium; both appear on accessory laterals.
 - Tetraspores may be cruciate or zonate.
 - The life cycle is diplobiontic.
 4. Gigartinales
 - The thallus structure is uni- or multiaxial.
 - A procarp is usually present with auxiliary cells located in the carpogonial branches.
 - Tetraspores appear in cruciate or zonate arrangements.
 - The life cycle is diplobiontic.
 5. Rhodymeniales
 - Thallus is multiaxial with obscure heterotrichy.
 - Auxiliary cells form only after fertilization.
 - Tetraspores are cruciate or tetrahedral.
 - The life cycle is diplobiontic.
 6. Ceramiales
 - Thallus is uniaxial and lacks heterotrichy.
 - The procarp contains a four-celled carpogonial branch, borne on a pericentral cell.
 - The auxiliary cell is produced after fertilization.
 - Tetraspores are tetrahedral.
 - The life cycle is diplobiontic.

Relationships of Rhodophyceae

1. Relationship with Chlorophyceae: Some structural and reproductive similarities suggest a possible evolutionary link between Rhodophyceae and certain green algae, especially Coleochaete and Prasiola.

(A) Similarities with Coleochaete: Both possess:

1. **Spermatangia**, 2. **Carpogonium** (Rhodophyceae) and oogonium (Coleochaete) with trichogyne 3. Cystocarp and spermocarp structures 4. Haplobiontic life cycle

(B) Similarities between Prasiola (Chlorophyceae) and Porphyra (Rhodophyceae):

Notable common features include Stellate chloroplasts, Similar thallus morphology and Comparable spore formation methods

2. Relationship with Ascomycetes (Fungi)

Certain reproductive features also show resemblance with Ascomycetes: the Presence of a trichogyne in female reproductive structures. Formation of spermatia in both groups.

Genera: Batrachospermum

Class-Rhodophyceae Sub-class Florideae Order-Nemalionales

Family-Batrachospermaceae Genus Batrachospermum

Occurrence of *Batrachospermum*: *Batrachospermum* is a genus of freshwater red algae comprising around 40 known species. These algae are widely distributed across tropical, subtropical, and temperate regions. They are typically found in clean, slow-moving streams and rivers, although some species are also capable of growing in fast-flowing waters. In India, *Batrachospermum moniliforme* is a commonly observed species and has been reported from locations such as Dehradun, Bareilly, and Kanpur. Due to its gelatinous, bead-like appearance, the alga is often referred to as "frog spawn." Most species within this genus are annual, but a few, like *Batrachospermum vagum*, can persist for more than one season and are considered perennial.

The plant body

Structure of *Batrachospermum*

The thallus of *Batrachospermum* is smooth, slimy to the touch, and exhibits a range of colors commonly blue-green, olive green, violet, or reddish. This color variation is influenced by the intensity and depth of light in the aquatic environment: plants found in deeper waters tend to appear reddish, while those growing closer to the surface are blue-green or olive green.

To the naked eye, the plant resembles a branched, beaded chain. It is differentiated into two main parts.

- **Prostrate system:** This portion remains attached to the substrate, anchoring the plant.
- **Erect system:** This part extends into the water and floats freely.

The plant can grow up to 15 cm in length. Its main axis is composed of elongated, cylindrical cells arranged in a series, forming distinct nodes and internodes. In mature plants, the central axis is corticated, meaning it is surrounded by a layer of loosely arranged cortical cells derived from the nodal regions.

Branching Pattern: From each node, two types of branches arise.

1. **Branches of limited growth:** These are short and arise in whorls near the upper end of the axial cell, just below the septum. Each branch is typically of uniform length and produces further branches, forming dense clusters known as glomerules, which give the plant its characteristic beaded appearance. In younger plants, these clusters are so dense that they often obscure the central axis.
2. **Branches of unlimited growth:** These are longer and arise singly in a **monopodial** manner. They structurally resemble the main axis, being divided into nodes and internodes, and can also give rise to branches of limited growth from their nodes. The cells in these branches are generally longer than those in the limited-growth branches. The older regions of the thallus are covered by loosely arranged cortical cells, which form a protective outer layer.

Cellular Structure

Each cell in *Batrachospermum* is **uninucleate** and contains multiple parietal chromatophores, each with a single pyrenoid. The chromatophores contain a variety of pigments, notably r- phycoerythrin and r-phycoerythrin, as well as chlorophyll, contributing to the plant's coloration. The axial cells are elongated and cylindrical, and they display pit connections, a notable feature in red algae. Cells in branches of limited growth are typically narrower at the base and broader or hemispherical at the apex defining characteristic of the genus.

Growth and Branch Formation

Both the main axis and branches of unlimited growth develop through the activity of a single apical cell. This apical cell divides transversely, giving rise to a uniseriate filament of cells. These cells later differentiate into nodes and internodes. From each nodal cell, 4 to 6

pericentral cells arise as lateral outgrowths. Each pericentral cell then forms a septum and acts as an initial cell for a branch of limited growth. These cells continue to divide repeatedly, producing the dense, beaded clusters characteristic of *Batrachospermum*. (Fig. 6.1)

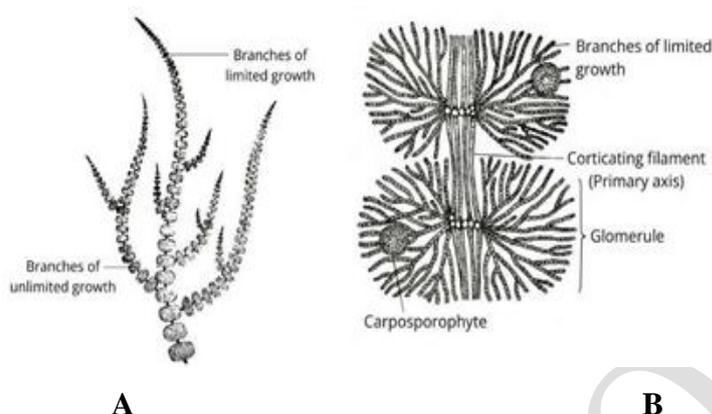


Fig. 6.1 A) Plant body of *Batrachospermum* showing both types of branches, B) *Batrachospermum* whorls enlarged.

Growth of the Thallus

The growth of *Batrachospermum* takes place by the dome-shaped apical cell. The apical cell divides by transverse division and forms a series of segments towards the posterior side. These segments increase the length in the older portion of the thallus.

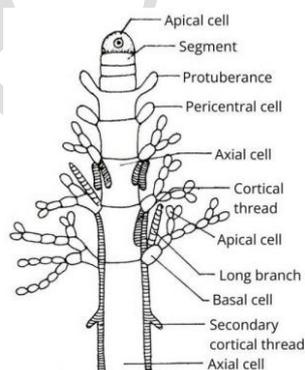


Fig 6.2 Apical part of the thallus.

Life cycle

Reproduction in *Batrachospermum*: *Batrachospermum* reproduces both **asexually** and sexually.

Asexual Reproduction

Asexual reproduction occurs through the formation of **monospores**, which are: **Uninucleate** (having a single nucleus), non-motile (incapable of movement), Produced singly within a

monosporangium. These monosporangia are found only at the apices of the Chantransia stage, a filamentous phase in the life cycle. Upon germination, each monospore gives rise to a new Chantransia stage, continuing the asexual cycle.

Sexual Reproduction

Sexual reproduction in *Batrachospermum* is of the advanced oogamous type, where there is a clear distinction between the male and female gametes. The species may be monoecious (both male and female reproductive structures on the same plant). (Fig. 6.3)

Male Reproductive Structures: Spermatangia

- Spermatangia develop singly, in pairs, or groups of four.
- They are formed on terminal or subterminal cells of branches of limited growth.
- Each spermatangium originates from a spermatangial initial and is a small, rounded, colorless structure that is distinguishable from vegetative cells.
- The content of each spermatangium becomes a single, uninucleate, non-motile spermatium (the male gamete).
- Spermata are released through a narrow slit in the wall of the spermatangium.

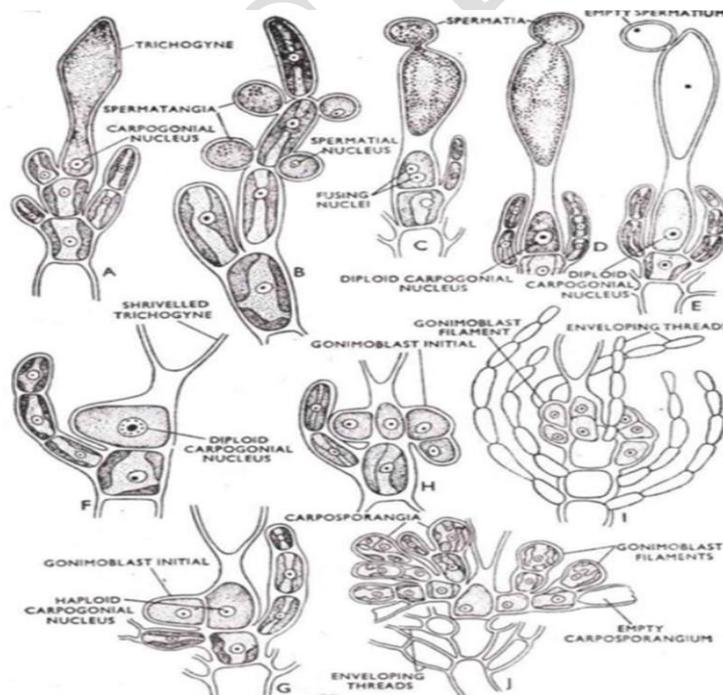


Fig. 6.3: *Batrachospermum* sp. A. Mature carpogonium. B. Spermatangial branch bearing spermatangia. C-F. Stages in fertilization. G-H. Development of the gonimoblast initial. I. Development of the gonimoblast filament and enveloping threads. J. Mature gonimoblast filaments, carposporangia, and enveloping threads.

Female Reproductive Structures: Carpogonia

- A carpogonium develops at the tip of a short, 4–5 celled carpogonial branch.
- This branch arises from the basal cell of a branch of limited growth.
- The carpogonial initial divides transversely to form the carpogonial branch.
- Each carpogonium is flask-shaped, with.

An upper long, enucleate trichogyne (a hair-like receptive structure), and A lower swollen base that contains a single, uninucleate egg cell.

- A median constriction is typically seen near the base of the carpogonium.

Reproduction in *Batrachospermum*

Batrachospermum, a red alga, reproduces both **asexually** and **sexually**.

1. **Asexual Reproduction:** Asexual reproduction occurs through the formation of **monospores**, which are: **Uninucleate** (contain a single nucleus), **Non-motile**, Produced singly within a monosporangium.

These monosporangia are found only at the apices of the Chantransia stage (a juvenile filamentous phase). Upon germination, the monospores give rise to a new Chantransia stage, which may again reproduce asexually, thus serving as an accessory mode of multiplication.

2. Sexual Reproduction

Sexual reproduction in *Batrachospermum* is of the oogamous type and is considered advanced among red algae. The plant is often monoecious, meaning both male and female reproductive organs can occur on the same individual.

- a. Male Reproductive Organs: Spermatangia

- Spermatangia arise singly, in pairs, or in groups of four.
- They are borne on terminal or subterminal cells of branches of limited growth, called spermatangial initials.
- Each spermatangium is a small, rounded, colorless structure, easily distinguishable from nearby vegetative cells.
- The content of each spermatangium transforms into a single non-motile, uninucleate spermatium (male gamete).
- Spermata are released through a narrow slit in the spermatangial wall.

- b. Female Reproductive Organ: Carpogonium

The carpogonium develops at the tip of a short, 4–5 celled carpogonial branch, which

originates from the basal cell of a branch of limited growth. This branch forms through a transverse division of the carpogonial initial cell. Each carpogonium is flask-shaped, with two distinct parts: An upper, long, enucleate trichogyne (a receptive hair-like extension) and a swollen basal portion containing a single, uninucleate egg.

- A median constriction is often seen near the carpogonial base.

3. Fertilization: The released spermatium is carried passively by water currents to the trichogyne of the carpogonium. It adheres to the trichogyne tip, and the wall of the spermatium dissolves, allowing the male nucleus to travel down the trichogyne and fuse with the egg nucleus, forming a zygote.

4. Post-Fertilization Changes: Development of the Cystocarp

Following fertilization.

- The trichogyne shrivels and the zygote nucleus undergoes meiotic division, producing four haploid nuclei.
- At the same time, small protuberances develop on the carpogonial wall. A nucleus enters each protuberance, which separates and becomes a gonimoblast initial.
- These gonimoblast initials divide repeatedly to form gonimoblast filaments, which may be branched or unbranched.
- The terminal cell of each filament transforms into a carposporangium, containing a single non-motile carpospore.
- The entire cluster of gonimoblast filaments and carposporangia is called the carposporophyte, which grows parasitically on the female gametophyte.

Meanwhile, surrounding vegetative and sterile cells from the carpogonial branch form a protective sheath around the carposporophyte. Together, they form a distinctive fruiting structure known as the cystocarp.

5. Chantransia Stage

The carpospore, upon germination, develops into a heterotrichous protonemal filament, which represents the juvenile phase of the *Batrachospermum* life cycle. Due to its unique appearance, this stage was previously described under a separate genus, Chantransia. However, because of its connection to the life cycle, this phase is now referred to as the Chantransia stage.

- Chantransia thalli reproduce asexually by forming monospores, aiding in further multiplication.

- The mature *Batrachospermum* plant eventually arises as a lateral outgrowth from this stage.
- Structurally, the Chantransia stage forms the prostrate system, while the *Batrachospermum* filament becomes the erect system, contributing to the heterotrichous nature of the thallus. The life cycle of *Batrachospermum* consists of two gametophytic phases alternating with one sporophytic phase, which is, however, confined in the zygotic stage. The early gametophytic phase Chantransia stage, is formed by the germination of the carpospore, which is the product of post-fertilization stages. In the late gametophytic phase, the main *Batrachospermum* plant is developed from the Chantransia stage.

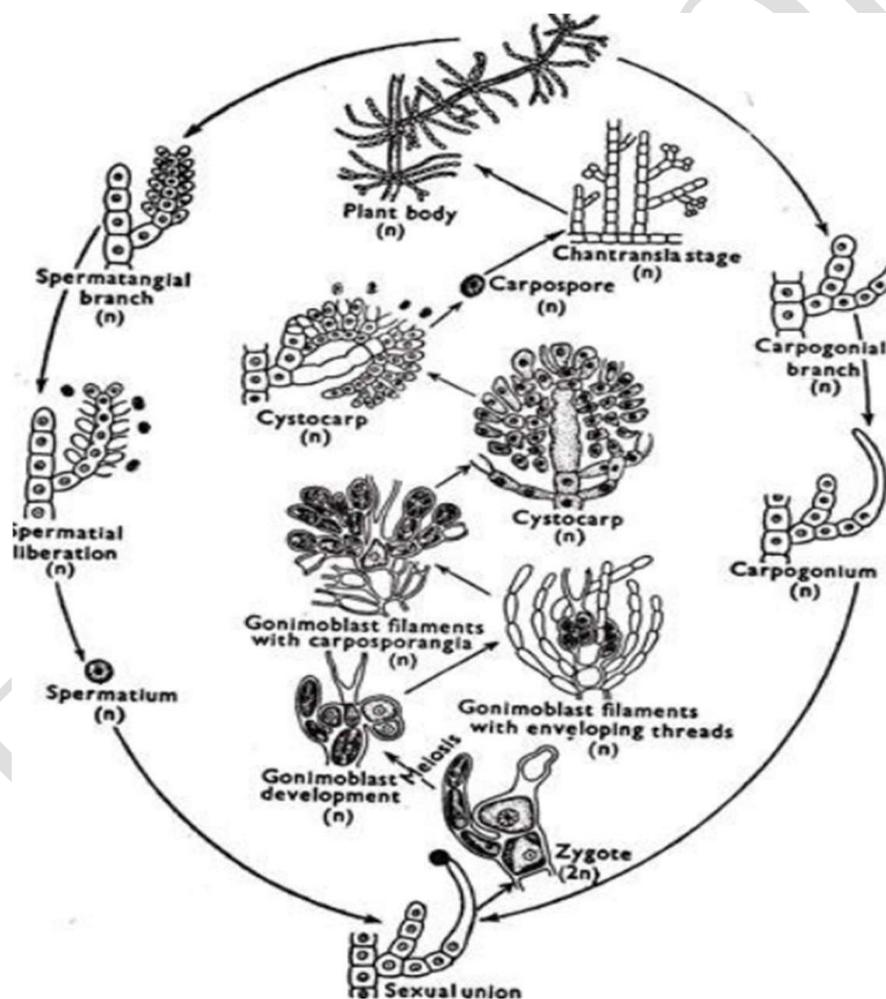


Fig. 6.4: Sexual cycle of *Batrachospermum* sp.

Genus: Polysiphonia

Class Rhodophyceae Sub-class-Florideac Order Coremiales Family Rhodomelaccac Genus Polysiphonia

The genus *Polysiphonia*, consisting of around 10 species, is exclusively marine and typically found in calm aquatic environments. These algae grow in dense, bushy tufts and are most commonly observed in the littoral zones of tidal marshes, brackish estuaries, and tide pools. Geographically, *Polysiphonia* species are widespread. In the British seas and along the Atlantic coast of North America, they are frequently encountered. In India, the west coast is a notable habitat, with species such as *P. variegata*, *P. platycarpa*, *P. elongata*, and *P. ferulacea* being commonly recorded. Notably, *P. platycarpa* is an endemic species, often found growing on wooden structures at Kumari Harbour.

A distinct *Gelidium-Polysiphonia-Ceramium* belt is observed in the lower midlittoral zone of coastal areas like Okha Port, Dwarka, and Mumbai. Here, *Polysiphonia* stands out due to its dense, dark red, ball-shaped appearance. Dominant species in these regions include *P. elongata*,

P. ferulacea, and *P. variegata*.

Many *Polysiphonia* species grow epiphytically, attaching themselves to other marine algae. For example, *P. fastigiata* attaches to the thallus of *Ascophyllum nodosum*, and occasionally to *Fucus*, acting as a semiparasite that can damage host cells. *P. unceolata* and *P. ferulacea* grow as epiphytes on *Laminaria* and *Gelidium pusillum*, respectively. Meanwhile, *P. elongata* is lithophytic, anchoring directly to rocks in its environment.

The Plant Body

Structure. As is evident by its name, the thallus of *Polysiphonia* is polysiphonous. The plant body often reaches a length of 10 cm. or even more. The thallus is branched which appears as a delicate, beautiful, and feathery structure. The colour of the thallus varies from brownish red to dark-purple-red.

The plant body is heterotrichous, consisting of two kinds of filaments,

- (i) Basal prostrate filaments. The basal portion of the plant creeps and anchors on the substratum with the help of elongated, unseptate rhizoids. The tips of the rhizoids are flattened into lobed discs or haptera. Rhizoids arise from pericentral cells facing the substratum. In some species (*P. elongata* and *P. violacea*), prostrate filaments are absent and the plant body is anchored to the substratum by unseptate rhizoids.
- (ii) Erect, upright, or vertical filaments. These arise from the prostrate filaments and are laterally or dichotomously branched. Such a system consists of a main axis and branches

of unlimited and limited growth (trichoblasts). (Fig. 6.5)

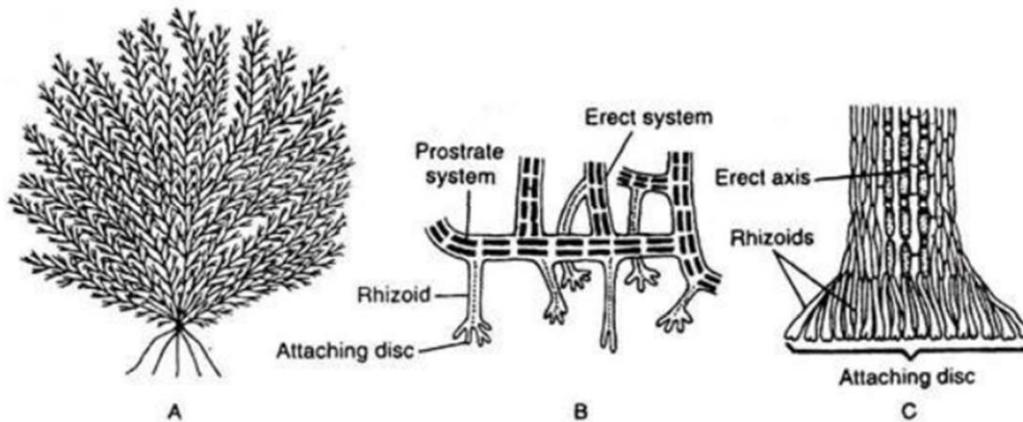


Fig 6.5 Polysiphonia sp. A. Habit of Plant body, B. Lower portion of thalpus with attaching disc and some erect Slament developed on it, and C. Lower portion of *P. violacea* with a massive attaching disc.

Main axis. While the main axis is fundamentally uniaxial, in its older regions it appears multiaxial due to the presence of closely appressed additional rows of filaments running parallel to each other. Here, a row of filaments is called a siphon. A close examination of the main axis reveals that its older portion consists of a central siphon of large, elongated, and uninucleate cells. It is surrounded by pericentral siphons of narrower cells. But the terminal portion of the main axis always consists of the central siphon alone. The orderly arrangement of siphons suggested a marked tendency for differentiation of filaments into nodes and internodes. The number of pericentral siphons surrounding the main axis varies from four to twenty, sometimes even twenty-four, as in *P. spiralis*; they are only 4, but 6 in *P. variegata*, 6- 8 in *P. Brodiaei*, and up to 20 in *P. nigrescens*. From these pericentral siphons, further smaller siphons called cortical siphons may arise by anticlinal and periclinal divisions as in *P. violacea* and *P. fastigata*. In *P. Brodiaei*, cortication results by means of filamentous outgrowth from cells at the basal end of pericentral cells. The pericentral siphons of *P. spiralis* do not run parallel to the central siphon but are spirally twisted around it.

The cells of the siphon are found interconnected by pit-connections, a characteristic to red algae. Pit-connections occur between and among the central and pericentral siphons. Later, secondary connections may be established between the overlying pericentrals. Branching. The main axis bears two types of branches.

(1) Branches of limited growth (short branches). They are also known as trichoblasts. Each

trichoblast is simple, hair-like, and monosiphonous and consists of a single row of cells with pit connections between the successive cells. Trichoblasts are dichotomously forked and are spirally inserted on the main axis or large branches. These are more or less colourless and are shed before winter and redeveloped in spring in perennial species. The distribution of trichoblasts in a plant body may be restricted to certain regions, more commonly the terminal.

(ii) Branches of unlimited growth (long or lateral branches). These are polysiphonous vegetative branches similar to the main axis.

Structure of the cell. The cells are thick-walled. Each vegetative cell has a single nucleus, usual discoid chromatophores, and floridean starch (floridosine) as a reserve food material. The chromatophores are distributed towards the periphery in the cytoplasm due to the presence of a large central vacuole. Pyrenoids are absent. Trichoblast cells are colourless on account of a lesser number of chromatophores and the presence of leucoplasts.

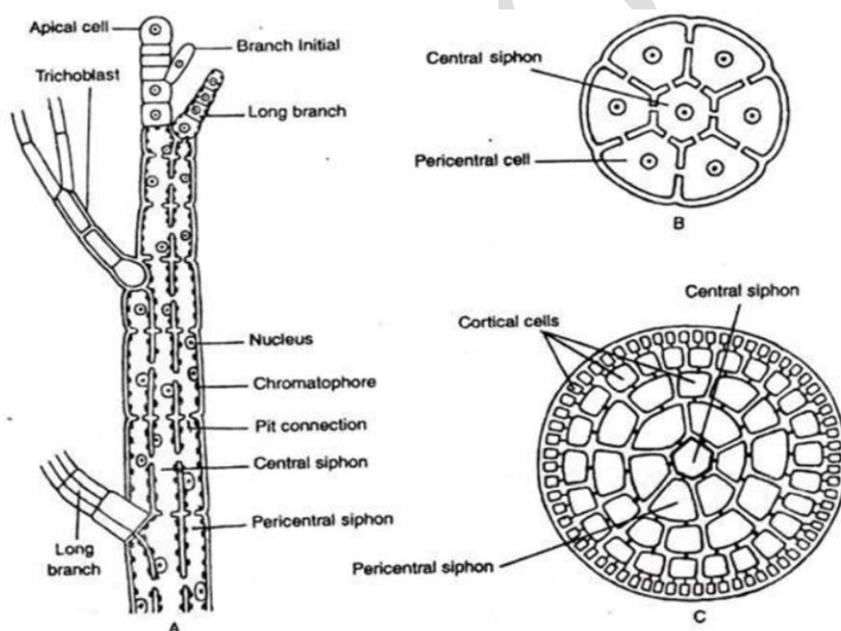


Fig 6.6: Polysiphonia sp. A. Apical portion of a plant body showing central siphon, pericentral siphon, long branch, and trichoblast, B. T.S. of thallus showing central siphon, surrounded by pericentral cells, and C. T.S. of old thallus showing cortical cells in addition to central and pericentral siphons.

Growth. The thallus grows using a dome-shaped apical cell of the main axis. It divides repeatedly to form a row of axial cells, all of which, excluding the first few cells, undergo periclinal divisions and form a peripheral layer of a specific number of pericentral cells around the axial row of central cells. Both central and pericentral cells elongate into their

pectise siphons. Development of branches. The trichoblast initial arises from an axial cell, 4 to 5 cells away from the apical cell, by a diagonal division. It divides repeatedly to form trichoblast. The cells of trichoblast are arranged linearly (monosiphonous).

The origin of branches of unlimited growth follows the same pattern. However, unlike the trichoblast initial, the initial of these branches behaves exactly like the apical cell of the main axis and produces, first of all, a transverse file of axial cells. From which, in due course, the peripheral layer of pericentral cells arises. Occasionally, a branch of unlimited growth may arise from the axil of trichoblast, in which case its basal cell behaves as a branch initial.

Reproduction in Polysiphonia

Polysiphonia reproduces both asexually and sexually. Sexual reproduction is of the oogamous type. In the life cycle of Polysiphonia, three kinds of plants are recognised.

These are

1. Diploid tetrasporophyte,
 2. Haploid gametophyte, and
 3. Diploid carposporophyte (Fig. 6.13).
1. **Diploid Tetrasporophyte:** It develops from the direct germination of a carpospore ($2n = 40$), thus, the plant is diploid ($2n$). It is an independent plant which, instead of developing sex organs, develops tetrasporangia. The diploid nucleus of tetrasporangia undergoes meiosis and develops four (4) haploid ($n = 20$) tetraspores.
 2. **Haploid Gametophyte:** It develops on direct germination of a tetraspore (n); thus, the independent plant is haploid (n). Most of the species are heterothallic; thus, the spermatangia (male sex organ) and carpogonia (female sex organ) are developed on different plants.
 3. **Diploid Carposporophyte:** This stage is diploid ($2n$) and dependent on haploid gametophytic plants. The union between a haploid (n) spermatium (developed inside a spermatangium) and haploid female gamete (developed inside a carpogonium) forms a diploid ($2n$) nucleus inside the carpogonium. Further development of the diploid nucleus forms diploid carposporophyte. Later carpospores are formed by mitotic division of carposporangium. The carpospore on direct germination forms a diploid tetrasporophyte plant.

Asexual Reproduction: Asexual reproduction takes place by haploid non-motile tetraspores.

The carpospores ($2n$) on direct germination develop diploid tetrasporophytic plants. The plants are independent and polysiphonous. Some pericentral cells of the thallus near the apical region develop sac-like tetrasporangia. The diploid nucleus of the tetrasporangium undergoes meiosis and forms four tetraspores. The spores are arranged tetrahedrally (Fig. 6.7).

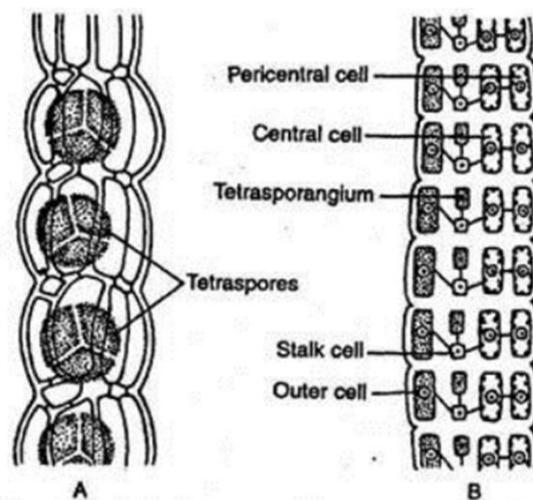


Fig 6.7: Polysiphonia sp.: A. Portion of tetrasporophytic plant ($2n$) with tetraspores, and B. Portion of tetrasporophytic plant showing development of tetraspores.

Development of Tetraspores:

Tetraspores are produced in tetrasporangia. A single pericentral cell of each tier, towards apical region, functions as tetrasporangial initial (Fig. 6.7B). This initial cell is smaller than other pericentral cells of any particular tier. This initial cell divides vertically into inner and outer cells.

The inner cell functions directly into the sporangial mother cell, and the outer cell further divides and forms two or more cover cells. The sporangial mother cell divides transversely into a lower stalk cell and an upper tetrasporangial cell.

The latter undergoes further enlargement and develops into a tetrasporangium. The diploid nucleus of the tetrasporangium undergoes meiosis and forms 4 tetraspores or meiospores. The tetraspores are arranged tetrahedrally inside the tetrasporangium.

The mature tetraspores are liberated by rupturing the wall of the sporangium. On germination, they develop a gametophytic polysiphonous plant. Being heterothallic, out of four tetraspores, two produce male and the remaining two produce female gametophytic plants.

Sexual Reproduction: Sexual reproduction is of the oogamous type. Plants are commonly dioecious. The male sex organs, i.e., spermatangia, and female sex organs, i.e., carpogonia, are developed on male and female plants, respectively.

1. Male Reproductive Organ: It is called a spermatangium or antheridium. Initially male trichoblast develops as a side branch on the plant body (Fig. 6.8). It becomes branched. In some species, both the branches become fertile, but in others, only one remains fertile, and the rest undergo repeated dichotomy to form a dichotomous sterile structure.

The monosiphonous fertile branch(es) of the male trichome bears many unicellular and spherical spermatangia. Each spermatangium is a uninucleate structure that produces a single sperm, the male gamete.

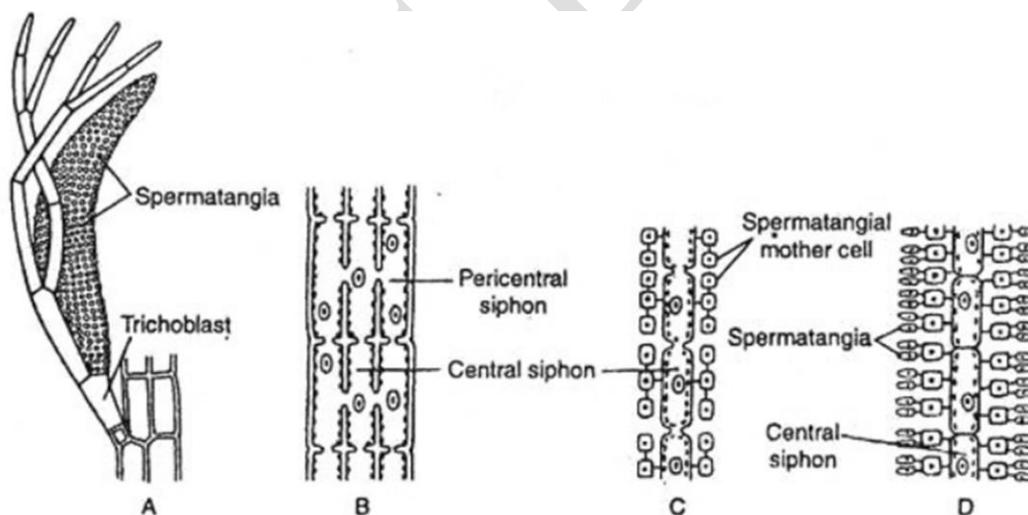


Fig. 6.8 Polysiphonia sp.: Development of male reproductive organ. A. Portion of thallus with antheridial branch and B-D. Sequential development of spermatangia.

During development of spermatangium (Fig. 6.8-D), all cells except a few basal cells divide periclinally and form pericentral cells on both sides. Each pericentral cell undergoes several divisions and forms spermatangial mother cells. Each one cuts off 2-4 unicellular bodies, the spermatangia. Each spermatangium develops into a single non-motile male gamete, the spermatium.

The spermatia are liberated from the spermatangium, through a narrow apical slit on the wall. The spermatia are dispersed through water.

2. Female Reproductive Organ:

The female reproductive organ is called carpogonium.

The carpogonium develops at the top of a 2-5 celled carpogonial filament (Fig. 6.9). The carpogonial filament develops on the female trichogon. The carpogonium is a flask-shaped body, with a basal swollen region containing an egg and an upper elongated neck region, the trichogyne.

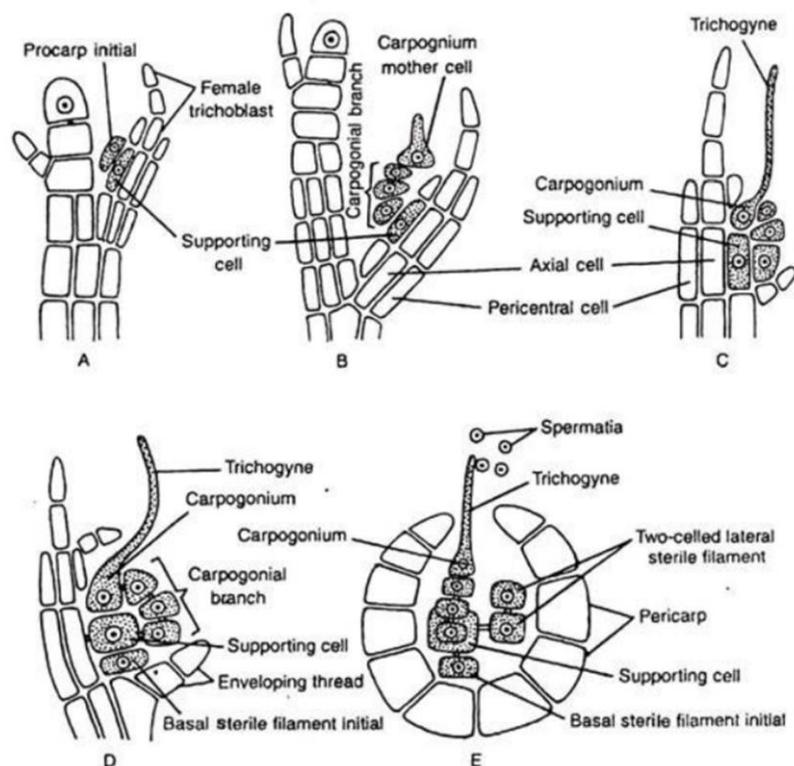


Fig 6.9: Polysiphonia sp.: A-E, Development of carpogonium.

During development of carpogonium, initially a female trichoblast is developed on the central siphon, a few cells (3-4) below the apical cell. The female trichoblast initially then undergoes repeated divisions and forms a female trichoblast of 5-7 cells. The lowermost three cells of the female trichoblast divide vertically and form three tiers of pericentral cells.

Any one of the pericentral cells of the middle tier towards the mother axis becomes the supporting cell. The supporting cell cuts off a small initial at its outside, the procarp initial (Fig. 6.9A). The procarp initially undergoes repeated divisions and forms a 4-celled branch,

the procarp or carpogonial filament (branch) (Fig. 6.9B).

The apical cell of the carpogonial filament functions as the carpogonium mother cell. The cell further develops into a carpogonium. The carpogonium has a swollen basal region containing egg and an elongated tubular region, the trichogyne (Fig. 6.9C).

At the later stage, the carpogonium develops two initials from the supporting cell, one at the base, the basal sterile filament initial (Fig. 6.9D), and another at the lateral side, the lateral sterile filament initial. The lateral sterile initial divides transversely and forms a two-celled lateral sterile filament (Fig. 6.9E).

The carpogonium is ready for fertilisation at this stage. The pericentral cell adjacent to the supporting cell starts growing to cover the fertilised carpogonium. Later on, they form a sheath (the protective covering) around the fruit body, called as pericarp.

Fertilisation

The spermatia are dispersed with the help of water. A few spermatia become attached at the tip of the receptive trichogyne. Out of many, only one becomes successful. The common wall of successful spermatium and trichogyne dissolves at the point of contact, and the male nucleus passes to the female nucleus present at the base of the carpogonium. The fusion between the nuclei results in the formation of zygote.

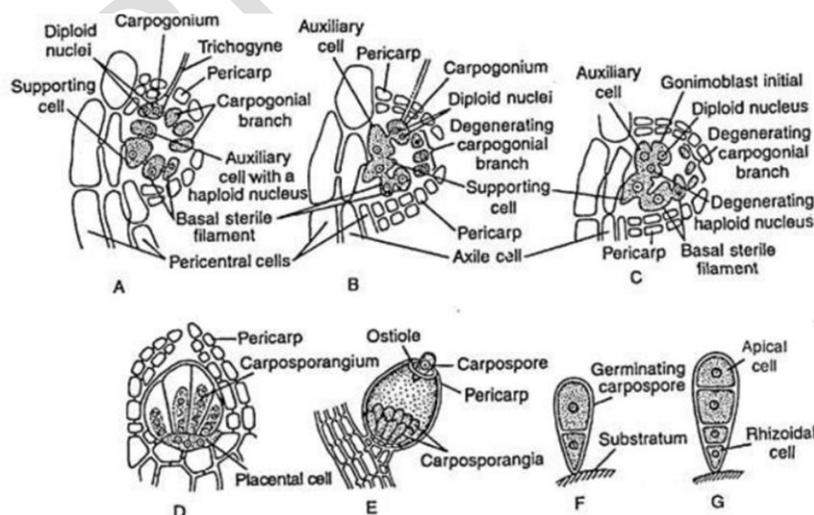


Fig. 6.10: Polysiphonia sp. post-fertilization changes: A. Fertilised carpogonium, B. Continuity between auxiliary cell and carpogonium, C. Degeneration of carpogonial filament, D. Formation of carposporophyte, E. Liberation of carpospore from mature cystocarp, F & G.

Post-Fertilisation Changes

At the start of this phase, an auxiliary cell is developed from the supporting cell situated just below the basal region of the carpogonium (Fig. 6.10 A). Simultaneously, the lateral sterile filament increases in length (4-10 celled) by cell division as well as elongation, and the basal sterile initial divides to form a two (2)-celled filament. The auxiliary cell has a single haploid nucleus.

A tubular connection is then developed between the auxiliary cell and carpogonium (Fig. 6.10B). The carpogonial nucleus ($2n$) divides mitotically into two nuclei, of which one is transported to the auxiliary cell and the other one remains in the carpogonium. Thus, the auxiliary cell contains one haploid and one migrated diploid nucleus. The haploid nucleus (n) is degenerated. Gradually, the trichogyne shrivels (Fig. 6.10 B).

Many vegetative filaments then develop from the adjacent vegetative pericentral cells, which gradually develop the total covering. The diploid nucleus of the auxiliary cell then divides mitotically and forms two nuclei. One of them then migrates into the outgrowth developed on the auxiliary cell.

This outgrowth after separating by a partition wall forms a gonioblast initial (Fig. 6.10 C). In this way many gonimoblast initials can develop on an auxiliary cell. Each initial, by repeated mitotic divisions, forms a gonimoblast filament. The terminal cell of the gonimoblast filament develops into a carposporangium, which forms a single diploid carpospore inside (Fig. 6.10 D, E).

During this development, the auxiliary cell, supporting cell, carpogonium, and some cells of basal and sterile filaments fuse and form an irregular cell, the placental cell (Fig. 6.10 D). The haploid nuclei (n) of the placental cell gradually degenerate and have simply a nutritive function.

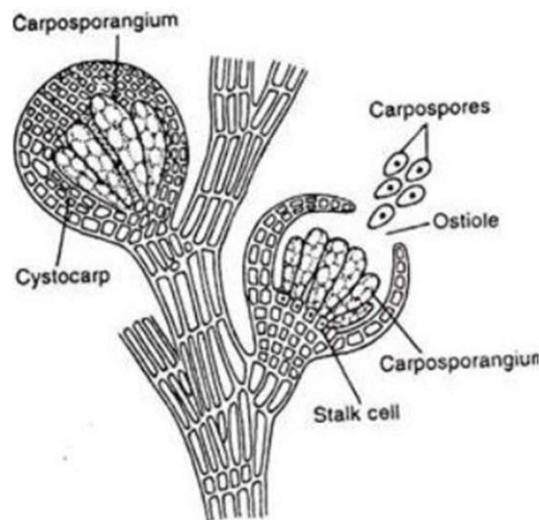


Fig 6.11 Polysiphonia sp. A branch bearing cysto-carps.

The placental cell, gonimoblast filament, and carpogonia are covered by many vegetative filaments and form an urn-shaped structure, the cystocarp (Fig. 6.10 E, 6.11). The outer covering of the cystocarp is called the pericarp. The diploid part of the cystocarp represents the carposporophyte. Some cells of basal and sterile filaments, along with some cells of carpogonial filaments, gradually degenerate.

The carposporangium develops a single diploid carpospore. After liberating from the carpogonium, they come out through the ostiole of the cystocarp (Fig. 6.11).

Germination of Carpospore

Coming in contact with any solid surface, the diploid carpospore gets attached and then undergoes the first mitotic division and forms large upper and small lower cells (Fig. 6.10, G). Both the cells undergo mitotic division and form a 4-celled stage.

The lowermost cell forms the rhizoid, the upper one functions as the apical cell, and the rest cells undergo further development and form the polysiphonous body. This plant body is diploid, i.e., the tetrasporophytic plant, which later develops the tetraspores and completes the cycle.

Life Cycle of Polysiphonia

The life cycle of Polysiphonia consists of three distinct phases: diploid tetrasporophyte, haploid gametophytes, and diploid carposporophyte.

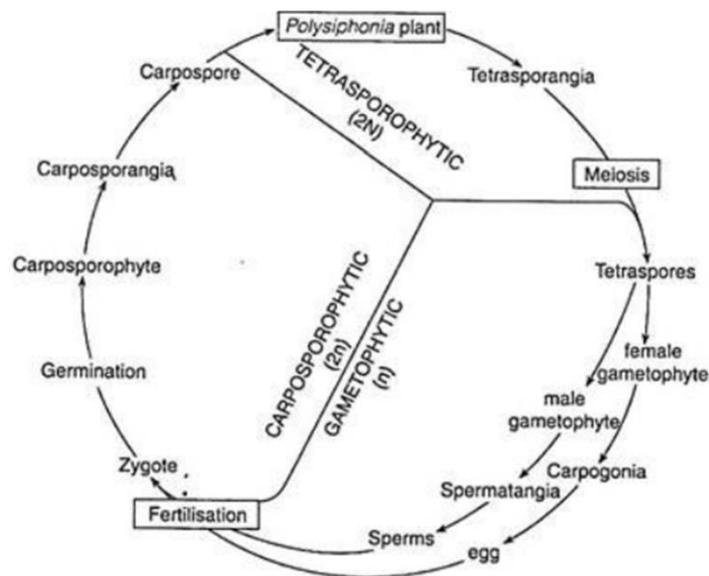


Fig. 6.12 Graphic life cycle of Polysiphonia sp.

Out of 4 tetraspores produced in tetrasporangia on a diploid tetrasporophytic plant, two tetraspores develop haploid (gametophytic) male and the other two haploid (gametophytic) female plants. The male gametophytic plants develop male gametes inside spermatangia and female gametophytic plants develop female gametes inside carpogonia.

Zygote develops inside carpogonium after gametic fusion. With gradual development, gonimoblast filaments, carposporangia, and carpospores are developed inside a composite structure, the cystocarp. It is the carposporophytic stage. Diploid carpospore on germination produces the diploid tetrasporophytic plant again.

Genus: Gracilaria

Introduction to the Genus Gracilaria

Rhodophyta (Red algae) Class: Florideophyceae Order: Gracilariales Family: Gracilariaceae Genus: Gracilaria.

The genus *Gracilaria* is a widely distributed group of red algae known for its ecological diversity and economic importance. It has been recorded in regions ranging from the Arctic to the tropics, occupying various marine habitats across the globe. The genus was first established by Greville in 1830 with the identification of just four species. Later, in 1852, Agardh expanded the genus to include 23 species through more detailed taxonomic evaluation. Further revisions by Agardh in 1876 and again in 1901 brought the known total to 61 species. Since then, ongoing studies and discoveries from various parts of the world have

increased the number of recognized species to approximately 150. Among these, 24 species have been specifically documented from China, highlighting the genus's widespread distribution and adaptability.

Morphological Characteristics

The external morphology of *Gracilaria* varies widely among species, making it a useful criterion for species identification. Typically, the thallus is erect and arises from a small, discoid holdfast. The shape of the thallus may be cylindrical, depressed, or blade-like, with branching patterns that are lateral, alternate, or subdichotomous. In some species, more than one type of branch may be observed on the same plant, adding to their structural diversity. The apex and base of branches also differ between species and serve as key features for taxonomic differentiation.

Some species show unique growth forms, such as *Gracilaria eucheumoides*, which has compressed thalli that grow horizontally along the substratum and form secondary holdfasts at the margins of branches. In contrast, *Gracilaria textorii* displays blade-like thalli, offering a completely different structural profile. These morphological variations are closely linked to their ecological roles and environments, and they also contribute to their identification in the field.

Anatomical Features

Anatomically, the thallus of *Gracilaria* is composed of two main regions: the cortex and the medulla. The cortex is made up of smaller cells, with the outermost one or two layers being pigmented, which play a role in photosynthesis and protection. Beneath the cortex lies the medulla, consisting of large parenchymatous cells that form the inner supportive tissues of the thallus. The arrangement and size of medullary cells, the number of cortical layers, and the transition between cortex and medulla are all diagnostic features that help distinguish one species from another. These internal structures not only reflect the physiological adaptations of the species but are also crucial in systematic botany and marine biology for accurate classification. Microscopic examination of these features remains a standard method for taxonomic analysis in red algae, especially in morphologically similar species.

Taxonomic Significance and Utility

The combination of external morphological traits and internal anatomical structures provides a comprehensive basis for the identification and classification of *Gracilaria* species. With

ongoing research and exploration, especially in marine biodiversity hotspots, the number of known species continues to rise. This genus is not only of academic interest but also of commercial importance, particularly in the production of agar and as a nutritional resource in coastal communities.

Life Cycle of *Gracilaria*

The life cycle of *Gracilaria*, a red alga, is known as **triphasic and diplobiontic**, meaning it has **three distinct phases** that alternate between haploid and diploid stages. These phases are: the **gametophyte**, **carposporophyte**, and **tetrasporophyte**. This type of life cycle is typical for red algae (Rhodophyta) and is more complex than that of many other algae and plants.

1. Gametophyte Phase (Haploid – n)

The life cycle begins with the gametophyte, which is the haploid (n) generation. This phase is dioecious, meaning male and female reproductive structures develop on separate individuals.

- **Male gametophytes** produce tiny, non-motile male gametes called **spermatia**.
- **Female gametophytes** produce a specialized female sex organ called the **carpogonium**, which has a hair-like extension known as the **trichogyne** to capture spermatia.

Fertilization occurs when a spermatium is passively carried by water currents and comes into contact with the trichogyne of the carpogonium. This leads to the formation of a **diploid zygote (2n)**.

2. Carposporophyte Phase (Diploid – 2n)

After fertilization, the zygote does not become a free-living organism. Instead, it develops directly into the carposporophyte, which grows attached to the female gametophyte. The carposporophyte is diploid (2n) and depends on the female plant for nutrition.

The carposporophyte produces numerous diploid spores called carpospores through mitotic division. These carpospores are then released into the surrounding water.

3. Tetrasporophyte Phase (Diploid – 2n)

The carpospores settle on a suitable surface and germinate to form the tetrasporophyte, which is also diploid (2n). This phase looks morphologically similar to the gametophyte but performs a different function.

Inside the tetrasporophyte, certain cells undergo meiosis to form tetraspores. Each tetrasporangium produces four haploid tetraspores (n).

Return to Gametophyte

These haploid tetraspores are released, and when they germinate, they develop into new male or female gametophytes, thus completing the cycle. This triphasic alternation of generations helps *Gracilaria* maintain genetic diversity, adapt to different environmental conditions, and successfully reproduce in its marine habitat.

EXERCISE

I. Short Answer Questions (5–6 sentence answers expected):

1. Differentiate between haplobiontic and diplobiontic life cycles in Rhodophyceae.
2. What are the main distinguishing features of the order Nemalinales within Rhodophyceae?
3. State two significant similarities between Prasiola (Chlorophyceae) and Porphyra (Rhodophyceae).
4. What structural characteristics differentiate Bangioideae from Florideae in Rhodophyceae?
5. What is the function of the prostrate and erect systems in *Batrachospermum*?
6. Define monosporangium. Where is it formed in the life cycle of *Batrachospermum*?
7. What is a trichogyne, and what role does it play in fertilization in *Batrachospermum*?
8. What is a cystocarp, and how is it formed in *Batrachospermum*?
9. Comment upon the alternation of generations seen in this plant.
10. Give a diagrammatic representation of the life cycle of Polysiphonia illustrating the relative lengths of the haploid and diploid phases.
11. Illustrate the phenomenon of homologous alternation of generation from the life history of Polysiphonia.
12. Describe the life history of any alga studied by you that shows a diplobiontic type of life cycle
13. What is meant by a triphasic life cycle in *Gracilaria*?
14. What is the role of the carposporophyte in the life cycle of *Gracilaria*?

II Essay Questions (Answer in detail):

1. Describe Fritsch's classification of Rhodophyceae and discuss the major features of each included order.
2. Explain the relationships of Rhodophyceae with Chlorophyceae and Ascomycetes, highlighting key morphological and reproductive similarities.

3. Describe in detail the structure of *Batrachospermum*, highlighting its branching pattern and cellular features.
4. Explain the sexual reproduction in *Batrachospermum*, including the process of fertilization and post-fertilization changes leading to the formation of a cystocarp.
5. Describe the habit, habitat, distribution, and organisation of the thallus of *Polysiphonia*.
6. Give a detailed account of the post-fertilisation changes that take place in *Polysiphonia* till the formation of the cystocarp.
7. Give an illustrated account of the sexual process of *Polysiphonia*.
8. Describe with diagrams the important features in the structure and life cycle of *Polysiphonia*.
9. Describe in detail the life cycle of *Gracilaria*. Explain each phase with its role, ploidy level, and significance.



Dr Eluri Komala

Dr. Eluri Komala brings with her an impressive **27 years of teaching experience** and **25 years of dedicated research** in the fields of **Algae, Environmental Studies, Pollution, and Agricultural Sciences**. With a strong academic foundation and a passion for scientific inquiry, she has authored **over 25 research publications**, contributing valuable knowledge to both national and international scientific communities.

She is **presently working as the Head of the Department and Associate Professor of Botany at Kakatiya Government College (Autonomous), Hanumakonda**. In this leadership role, Dr. Komala continues to inspire students and colleagues through her academic excellence and innovative teaching methods.

Dr. Komala has actively participated in numerous **national and international conferences**, where she has presented research papers and contributed to critical discussions in the areas of **environmental sustainability, agriculture, and pollution control**.

Her remarkable career reflects a deep commitment to **education, research, and scientific advancement**. She continues to make significant contributions to the fields of **environmental science, pollution management, and sustainable agriculture**, earning her recognition and respect in both academic and research communities.

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