

Diatoms

From Silica Shells to Sustainable Solutions

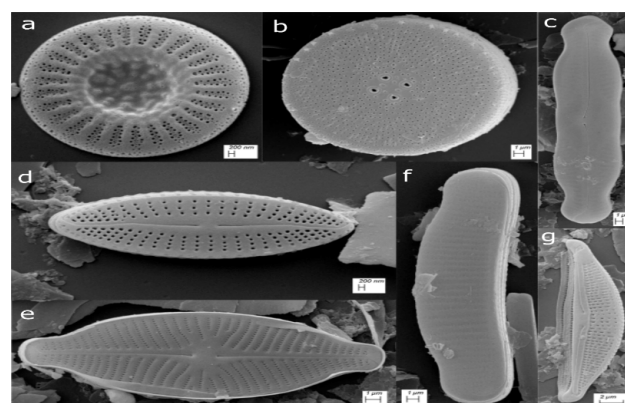
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TODAY's ocean is dominated by eukaryotic phytoplankton such as diatoms, dinoflagellates, and coccolithophores. According to fossil records, diatoms were a minor component of the sea until the Cretaceous Era (145.5-66 mya). Modern continents formed when the supercontinent Pangea broke down, creating much space in the marine ecosystem and delivering more nutrients to the oceans. The increase in ocean nutrients favoured the selection of large-celled phytoplankton such as diatoms and other algae. In the Cenozoic era (66-0 mya), diatom diversity increased, and two major speciation events occurred, namely in the boundary interval of the Eocene/Oligocene (33.9-23 mya) and in the mid-to-late Miocene (16-5.3 mya). These events took place because of environmental changes such as changes in ocean chemistry, the availability of silica, a rise in sea level, and predation. Today, diatoms dominate all aquatic habitats where there is sufficient light and nutrients. They are now well adapted to survive in conditions of nutrient and light limitation if silicon is not limiting.

Diatoms are single-celled, microscopic organisms that belong to the class Bacillariophyceae of the kingdom Protista. They are photosynthetic eukaryotic microalgae and the most abundant group across continents and oceans. They are ubiquitous and diverse microalgae across aquatic systems, with almost 64000 to 100000 species belonging to nearly 1200 genera. They are one of the leading primary producers of the ocean and are responsible for about 20–25% of global oxygen production.

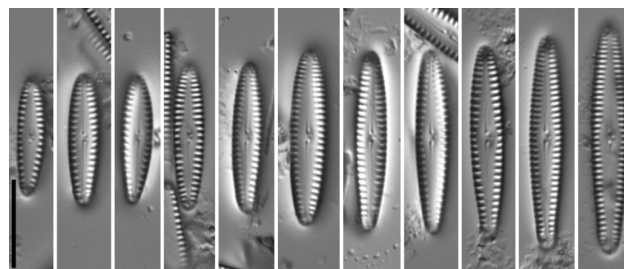
Diatoms are found in various shapes and sizes, ranging from $5\mu\text{m}$ to 0.5mm . They are golden brown because fucoxanthin and beta-carotene mask the green effects of chlorophyll a and c. The main characteristic of diatoms is their siliceous cell wall (SiO_2). Each species has its unique siliceous marking, which is used for identification. They can be planktonic (free-floating) or benthic (attached to a substratum). Some diatoms grow in colonies, and some grow alone.

Diatoms are often called “life in glass houses” because they reside inside a glass-like silica shell. This siliceous, box-like cell wall is called a frustule. The word “diatom” is derived from the Greek word ‘diatomos’ meaning ‘cut into two’ because the frustule consists of two overlapping valves. The larger valve is called the epivalve, and the smaller valve



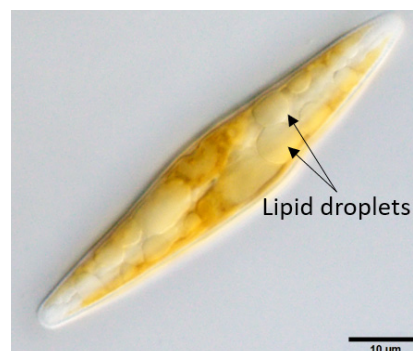
Scanning Electron Micrographs showing the morphological groups of diatoms (a & b) Centrics, (c, d & e) Symmetric Pennate, (f & g) Asymmetric pennate (a) *Cyclotella meneghiniana* (b) *Orthoseira roeseana* (c) *Pinnularia* sp. (d) *Achnanthisidium subhudsonis* (e) *Placoneis* sp. (f) *Eunotia* sp. (g) *Halomphora* sp.

Photos by Radhakrishnan Cheran



Differential Interference Contrast (DIC) light micrograph showing the size diminution series of *Gomphonema* sp. The scale bar refers to 10 microns.

Photos by Radhakrishnan Cheran



Differential Interference Contrast (DIC) light micrograph showing the diatom *Gomphonema* sp. live with lipid droplets



Hemendrakumar Prithviraj Gandhi (1920–2008) is regarded as the father of Indian freshwater diatom science. He carried out pioneering work on the taxonomy and systematics of diatoms from freshwater and brackish water habitats and their application as bioindicators. HP Gandhi described nearly 300 new diatom taxa from Maharashtra, Karnataka, Gujarat and Jammu & Kashmir. He has authored more than 35 research publications, including one book.



Thamarapu Vedanta Desikachary (1919–2005) is “the father of modern algology in India.” Although he was an expert on blue-green algae, he had authored many research papers on diverse groups of algae. He published six volumes of the “Atlas of Diatoms of the Indian Coast” during 1986–1989. He described nearly five new genera and 56 novel taxa of diatoms, mainly from the Bay of Bengal, Arabian Sea, and Indian Ocean. He taught Indian diatom researchers the use of electron microscopy to study the structure of diatom frustules.

Aquatic Food Web

Many animals in the aquatic food chain are directly or indirectly dependent on diatoms for their survival. They convert dissolved carbon dioxide into oxygen in water since they are photosynthetic organisms. They are responsible for about 40% of the photosynthesis in the world’s oceans. Hence, they are an essential part of the aquatic food chain. Diatoms are considered primary producers in the aquatic food web because they are the primary food source for higher organisms such as small fish and invertebrates like snails and clams. Further experimental studies confirm that the diatom

is called the hypovalve. These valves are held together by ribbon-like structures known as “girdle bands.” Diatoms are classified into two major groups based on valve symmetry: centric (circular, radial symmetry) and pennate (elongate, bilateral symmetry). The reproduction process in diatoms can occur sexually and asexually.

Silica cell wall

Diatoms’ silica cell walls are a living instance of nature’s architectural creations’ exquisite beauty and usefulness. The structure and shape of the silica cell wall in diatoms are highly species-specific. Silica is taken up by diatoms as orthosilicic acid $\text{Si}(\text{OH})_4$ by specific Silicic Acid Transporter proteins (SITs). The formation of silica takes place inside diatoms within a specialised membrane-bound compartment called Silica Deposition Vesicles (SDVs). While SDVs are general organelles in all protists, SITs are only in diatoms. After the completion of silica morphogenesis in SDVs, the silica is deposited on the cell surface through SDV exocytosis. The function of many organelles in diatoms, including the silica cell wall, is still unknown. The primary role of the cell wall may be to protect the cell from other phytoplanktonic predators.

Researchers have recently discovered two functions of the silica cell wall: The cell wall of *Thalassiosira weissflogii* acts as a proton buffer that may help in CO_2 capture via an extracellular carbonic anhydrase, and on the girdle bands of *Coscinodiscus granii*, a marine diatom, there are holes in the square lattice pattern, which acts as a photonic crystal and may help capture light for photosynthesis. The diatoms have several applications in different areas:

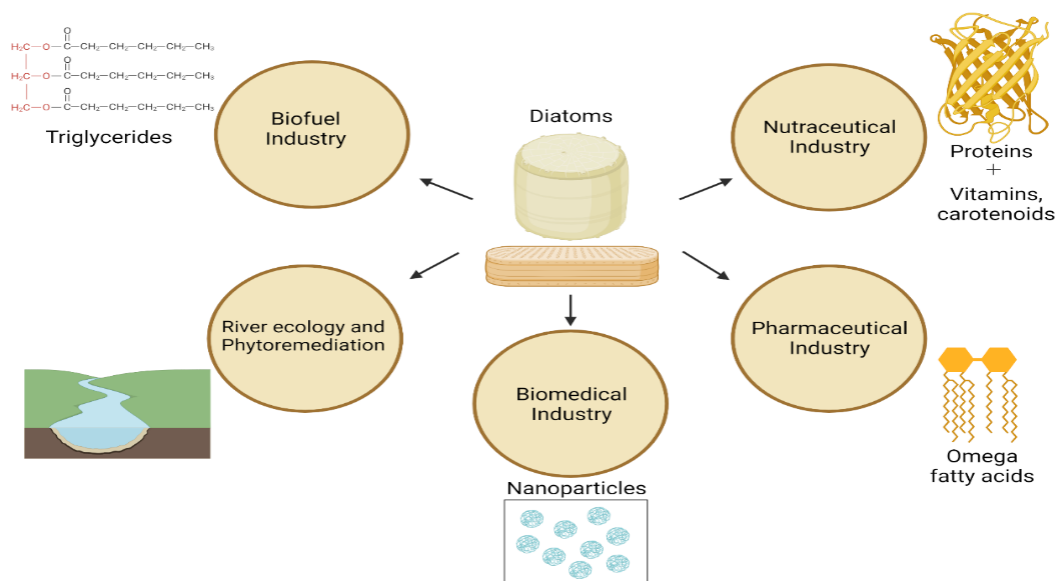
diet enhances the reproductive ability of many invertebrates, such as zooplankton.

Bioindicators

Due to their small size and highly replicative nature, they are sensitive to environmental conditions such as pH, salinity, conductivity, dissolved oxygen, and nutrients. Therefore, they are used as “bioindicators,” i.e., they can indicate the health of the aquatic system, even minor changes in water quality in the rivers, streams, lakes, and other wetlands. The major reasons diatoms are used as bioindicators are: They are abundant in all aquatic habitats, their taxonomy is quite well established, they exhibit both cosmopolitan and restricted distribution, and they have a short life cycle and can rapidly colonise new habitats. Hence, a change in the diatom community indicates environmental change, and their response to this change is rapid. Identifying changes in a particular environment is simple by looking at the diatom community within that habitat.

Diatomaceous Earth

Diatomaceous Earth, also called “diatomite”, is a lightweight sedimentary rock resulting from the compression of silica cell walls of diatoms over a million years. It is soft, porous, fine-grained, and light in weight. 40–70 million dead diatoms may produce a cubic inch of diatomite. The diatomite has a high porosity (around 75–85%) and a lower density (0.12 g/cm^3 – 0.25 g/cm^3). Diatomite is also known as *Tripoli*, *Kieselguhr*, and infusorial earth. Because of its high porosity, low thermal conductivity, low density, and high melting point (1400–1750°C), it is used in many



Schematic diagram illustrating the various commercial applications of diatoms

commercial applications such as filtration, building materials, mineral fillers, absorption, insulation, carriers, and catalysts. The most notable commercial application of diatomite was the production of dynamite. Dynamite was discovered by Alfred Nobel in 1867. Dynamite is a diatomite filled with nitroglycerine. Nitroglycerine is a highly explosive and unstable chemical. But diatomite can absorb it because of its porous and solid structure, making it safe for handling and transportation.

Biofuels

Liquid, solid, or gaseous fuels derived from bio-renewable feedstocks such as plants, bacteria, and microalgae are referred to as “biofuels.” Biofuels include biodiesel, biomethanol, bioethanol, biohydrogen, biomethane, and bio-oil. Photosynthetic organisms are predominantly used for biofuel production because they generate energy (sugar) using atmospheric carbon and sunlight. Diatoms are considered promising feedstock for biofuel production due to their exceptional photosynthetic efficiency and ability to accumulate high lipid concentrations. Diatoms store carbon in the form of lipids, the primary storage compound in the cytoplasm (Fig. 4). Lipids in diatoms are primarily composed of neutral lipids, i.e., Triacylglycerides (TAGs). This TAG can easily be converted into biodiesel by a transesterification reaction using acidic or basic alcohol. Transesterification is a process in which fats (TAGs) react with an alcohol to produce fatty acid methyl esters (biodiesel) and glycerol.

Bioactive compounds

Diatoms produce many bioactive compounds, such as fatty acids, carotenoids, phycobilin, polysaccharides, vitamins, and peptides. These compounds can be used in the pharmaceutical, nutraceutical, cosmetic, and food industries. But the extraction of these compounds is still restricted to a few species of diatoms, as this area is underexplored. Diatoms are the primary source of essential omega-3 fatty acids, such as

Eicosapentaenoic acid (EPA) and Docosahexaenoic Acid (DHA). Linoleic acid and alpha-linolenic acid are also essential fatty acids because of their low production in the human body. Diatoms also produce these essential fatty acids. Other than fatty acids, diatoms also produce bioactive compounds such as astaxanthin, biopeptides, sterols, chrysolaminarin, fucoxanthin, and polyphenols, which have significant applications as antioxidants, anti-ageing agents, immune modulators, anti-cancer agents, and can be used in Alzheimer’s disease treatment.

Conclusion

Diatoms show a remarkable diversity, with more than 100,000 identified species. They are predominantly found in aquatic environments, including oceans, rivers, lakes, streams, and damp terrestrial habitats. In India, nearly 7000 species of diatoms are known; however, the real diatom diversity of India is yet to be discovered. The adaptation of diatoms to freshwater as well as marine ecosystems displays their wide range of distribution. Their intricate silica cell walls make them biologically unique and feature intricate patterns and designs. These silica cell walls provide diatoms with a protective shield and contribute to their unique beauty.

Furthermore, diatoms are crucial in aquatic ecosystems as primary producers, contributing to a wide range of ecosystem services such as global carbon fixation and oxygen production. Moreover, they have applications in diverse fields such as water quality assessment, biofuels, nanotechnology, pharmaceuticals, and paleoclimate research. The study and conservation of diatom diversity are vital for understanding and safeguarding the delicate balance of aquatic ecosystems.

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