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Diatoms: Fundamentals and Applications

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Abstract- Diatoms are unicellular, photosynthetic algae that are found in nearly every aquatic environment on Earth. They are characterized by their intricate and diverse cell walls which are made of silica. Diatoms are a versatile and valuable group of organisms with a wide range of applications. Diatoms play a vital role in the global food chain, serving as the primary food source for many zooplankton and fish. They also play a key role in the global carbon cycle, sequestering carbon dioxide from the atmosphere. In addition to their ecological importance, diatoms have a wide range of applications in human society. Some of the most important applications include water quality monitoring, Paleoclimatology, Nanotechnology, and Biotechnology. In addition to the applications listed above, diatoms are also used in a variety of other ways, such as food and feed, cosmetics, and construction materials.

Keywords- Diatoms, applications, environmental monitoring, biofuel, food, medicine

Introduction-

Diatoms are unicellular algae with chrysophyte-like photosynthetic pigments. The cell wall is silicified to form a frustule, comprising two valves, one slightly larger than the other and both fitting together like a box and lid (Cameron et al. *2004*). Diatoms evolved date back 180 million years, and at present, more than 100,000 species have been reported (Kroth *2007*). They play a significant role in many of the earth's biogeochemical cycles like carbon, phosphate, and silicon (Falciatore and Bowler *2002*). Diatoms are microfossils and have been recorded and classified for over 200 years. They are single-celled marine algae. Diatoms are one of the largest groups of organisms on earth and are present in varied forms, sizes, and shapes, nevertheless, diatoms are easily decipherable due to a unique cell wall structure. Carbon trapped inside silica frustules of diatoms acts as a major component of the carbon cycle on Earth (Street-Perrott and Barker *2008*). A silica body can sequester up to 50% of its weight of C (Elbaum et al. *2009*). Diatom algae are used as indicators for climate change in lacustrine sediments due to their high temporal sensitivity, so they also act as indicators of temperature increase which is an early indication of climate change (Kilham et al. *1996*). They are found in all aquatic habitats, from oceans to freshwater lakes and rivers. They are an integral part of the aquatic food web and constitute 40% of the primary producers (Thomas et al. *2015*). They are one of the most abundant groups of phytoplankton on Earth and play an important role in the marine food web. Diatoms are also known for their intricate and beautiful cell walls, which are made of silica. Though Diatoms are unicellular organisms, they can form colonies of various shapes and sizes. Their cell walls are composed of two halves, called thecae, which are fitted together like a pillbox. The thecae are perforated with intricate patterns, which are unique to each species of diatom. Diatoms are photosynthetic organisms, and they use sunlight to convert carbon dioxide and water into oxygen and carbohydrates. They are an important food source for zooplankton, which in turn are eaten by fish and other marine animals. Diatoms can be distinguished from other non-heterokont algae through the possession of (a) chlorophyll *a*, *c*, fucoxanthin, and β-carotene pigments, (b) four plastid membranes with the outer membrane functionally bound to the Golgi apparatus, and (c) the utilization of chrysolaminarin as a photosynthetic product. Diatoms also play a role in the global carbon cycle, by absorbing carbon dioxide from the atmosphere and releasing oxygen which helps to regulate the Earth's climate.

Diatoms have a wide range of applications, both in nature and in human society. Diatoms are used both as living organisms and as fossils. Living diatoms can be used to produce biofuels, food, and other products. Fossil diatoms can be used to reconstruct past environmental conditions and to identify oil and gas deposits. Diatoms are also a valuable tool for scientific research. Diatoms have been used to study a variety of topics, including evolution, climate change, and palaeoecology. Some of the most important applications of diatoms include-

[1] Environmental monitoring-

Diatoms are sensitive to changes in their environment and can be used to assess the health of aquatic ecosystems. For example, diatoms can be used to detect pollution, changes in salinity, and other environmental stressors.

[2] Bioremediation-

Diatoms can be used to clean up polluted water and soil. For example, diatoms can absorb heavy metals and other toxins from water. Diatoms can also be used to produce biofilters that can remove pollutants from water.

[3] Food production-

Diatoms can be used as a food source for livestock and fish. Diatoms are also a good source of omega-3 fatty acids, which benefit human health. Diatom-based food products are becoming increasingly popular, as consumers are looking for healthier and more sustainable food options.

One challenge in using diatoms for food production is that they have a hard silica cell wall. This cell wall can make diatoms difficult to digest. Researchers are developing new methods to break down the silica cell wall so that diatoms can be more easily digested and consumed. Another challenge is that diatoms have a relatively low biomass. This means that a large number of diatoms is needed to produce a small amount of food. Researchers are working to develop methods to increase the biomass of diatoms so that they can be more efficiently used for food production. Diatoms can be used to produce a variety of food products, including-

i. Bread- Diatom flour can be used to make bread high in protein and fiber. Diatom bread is also a good source of omega-3 fatty acids.

ii. Pasta- Diatom flour can also be used to make pasta. Diatom pasta is high in protein and fiber, and it has a unique flavor and texture.

iii. Snacks- Diatom can be used to produce a variety of snack foods, such as energy bars, granola bars, and cookies. Diatom snacks are a good source of protein, fiber, and omega-3 fatty acids.

iv. Biomaterials- Diatom silica is a strong and lightweight material, and can be used to produce a variety of products, including filters, insulation, and abrasives. Diatom silica is also being investigated for use in biomedical applications, such as bone implants and drug delivery systems.

[4] Nanotechnology- Diatom silica can be used to produce a variety of nanomaterials, such as nanoparticles and nanowires. These nanomaterials have a wide range of potential applications, including energy production, electronics, and medicine. Diatom silica nanoparticles are being used to develop new types of batteries and solar cells.

[5] Diatomaceous earth (DE)-

It is a powder made from the fossilized remains of diatoms. DE is used in a variety of products, including filters, abrasives, and pesticides. DE is also used as food as a food additive for poultry and other livestock.

[6] Biofuels-

Diatoms are a promising source of biofuels because they have a high lipid content and can be cultivated on non-arable land. Diatom lipids can be converted into biodiesel through a transesterification process. Diatom carbohydrates can be converted into bioethanol through a fermentation process.

Researchers are developing new methods to increase the lipid content of diatoms and to make it easier to extract lipids from diatom cells. They are also developing new fermentation processes to convert diatom carbohydrates into bioethanol more efficiently. Some of the applications of diatoms in biofuels are-

i. Biodiesel- Diatom biodiesel is a renewable and sustainable alternative to conventional biodiesel made from vegetable oils. Diatoms have a high lipid content, and their lipids can be easily converted into biodiesel using various methods, such as transesterification and pyrolysis. Diatom biodiesel has similar properties to conventional biodiesel, but it has some advantages, such as a higher cetane number and lower emissions of particulate matter and nitrogen oxides.

ii. Bioethanol- Diatom bioethanol is another renewable and sustainable alternative to conventional bioethanol made from corn or sugarcane. Diatoms have a high carbohydrate content, and their carbohydrates can be converted into bioethanol using various methods, such as fermentation and hydrolysis. Diatom bioethanol has similar properties to conventional bioethanol, but it has some advantages, such as a higher energy density and lower emissions of greenhouse gases. Researchers are also exploring the use of diatoms to produce biogas and other biofuels. Diatoms can be used to produce biogas through anaerobic digestion, and they can also be used to produce hydrogen and other fuels through photobiological processes.

[7] Nutraceuticals-

Diatoms can be used to produce nutraceuticals, which are products that have both nutritional and medicinal benefits. Diatoms contain a variety of bioactive compounds, such as antioxidants, anti-inflammatory compounds, and vitamins. These compounds have several potential health benefits. For example, diatom antioxidants can protect against cell damage, diatom anti-inflammatory compounds can reduce inflammation, and diatom vitamins can support various bodily functions.

Diatoms are being used to develop a variety of nutraceutical products, such as dietary supplements, functional foods, and cosmetics. Diatom dietary supplements can boost the immune system, improve cardiovascular health, and protect against cancer. Diatom functional foods can be used to improve the nutritional value of processed foods and beverages. Some specific examples of diatom nutraceuticals include-

i. Diatom oil- Diatom oil is a good source of omega-3 fatty acids, which are essential for heart health, brain health, and eye health.

ii. Diatom astaxanthin- Diatom astaxanthin is a powerful antioxidant that can protect cells from damage caused by free radicals. Astaxanthin has also been shown to reduce inflammation and improve cognitive function.

iii. Diatom fucoxanthin- Diatom fucoxanthin is a carotenoid that has been shown to have anti-cancer properties. Fucoxanthin has also been shown to boost metabolism and promote weight loss.

[8] Cosmetics-

Diatoms can be used to produce cosmetics, such as skincare products and toothpaste. Diatoms are a good source of silica, which is a natural exfoliant that can help to improve the appearance of the skin. Silica can help to remove dead skin cells, revealing the fresh and healthy skin underneath. Diatoms are being used to develop a variety of cosmetic products, such as skincare products and toothpaste. Diatom skincare products can be used to exfoliate the skin, reduce wrinkles, and improve the skin's overall appearance. Diatom toothpaste can be used to remove plaque and tartar, whiten teeth, and freshen breath. Some specific examples of diatom cosmetics include-

i. Diatom exfoliator- Diatom exfoliators are made from crushed diatom shells. They are used to remove dead skin cells and reveal the fresh and healthy skin underneath.

ii. Diatom face mask- Diatom face masks are made from a mixture of diatom powder and water. They are used to cleanse the skin, remove impurities, and reduce inflammation.

iii. Diatom toothpaste- Diatom toothpaste is made with diatom powder. It is used to remove plaque and tartar, whiten teeth, and freshen breath.

[9] Oil and gas exploration-

Fossil diatoms can be used to reconstruct past environmental conditions and to identify oil and gas deposits. Diatoms are found in sedimentary rocks that were deposited in marine and freshwater environments. By studying the types of diatoms that are present in these rocks, geologists can determine the conditions that existed at the time the rocks were deposited. This information can be used to identify areas that are likely to contain oil and gas deposits.

For example, if a geologist finds a layer of sedimentary rock that contains fossils of diatoms that are typically found in deep-water environments, then the geologist can infer that the rock was deposited in a deep-water environment. This information can be used to identify areas that are likely to contain oil and gas deposits.

[10] Medicine-

Diatoms are being explored for their potential use in the development of new drugs and therapies for a variety of diseases including cancer, Alzheimer's disease, and Parkinson's disease.

Diatoms produce a variety of bioactive compounds that have potential medicinal properties. For example, some diatom compounds have been shown to have anti-tumor activity, while others have been shown to protect against neurodegeneration.

i. Cancer- Diatoms produce a variety of compounds that have been shown to have anti-tumor activity such as fucoxanthin, astaxanthin, and diatom carotenoids. These compounds can be used to develop new drugs and therapies for cancer. For example, fucoxanthin has been shown to inhibit the growth and proliferation of cancer cells while astaxanthin has been shown to protect against cancer-induced oxidative stress.

ii. Alzheimer's disease- Diatoms produce a variety of compounds that have been shown to protect against neurodegeneration, such as omega-3 fatty acids, antioxidants, and vitamins. These compounds can be used to develop new drugs and therapies for Alzheimer's disease. For example, Omega-3 fatty acids have been shown to reduce the risk of developing Alzheimer's disease, while antioxidants have been shown to protect against the damage caused by free radicals, which are thought to play a role in the development of Alzheimer's disease.

[11] Materials Science-

Diatoms are being explored for their potential use in the development of new materials such as biocomposites, optical devices, and sensors. Diatom shells are made of a strong and durable material called biosilica, which has several unique properties. For example, biosilica is lightweight, transparent, and heat-resistant.

i. Biocomposites- Diatoms produce biosilica, which is a strong and durable material that can be used to develop new biocomposites. Biocomposites are materials that are made from a combination of natural and synthetic materials. Diatom biocomposites can be used to develop a variety of products such as lightweight and strong structural materials, biodegradable packaging material, and medical implants.

ii. Optical Devices-Diatom shells have unique optical properties that can be used to develop new optical devices. For example, diatom shells can be used to develop lenses that can focus light more efficiently than traditional lenses. Diatom-based optical devices are used in a variety of applications, such as solar cells, medical imaging devices, and telecommunication devices.

iii. Sensors-Diatom shells can be used to develop new sensors that can detect a variety of substances, such as heavy metals, pollutants, and biological agents. Diatom-based sensors can be used in a variety of applications such as environmental monitoring, food safety, and medical diagnostics.

[12] Environmental monitoring-

Diatoms can be used to monitor the health of aquatic ecosystems. Diatoms are sensitive to changes in environmental conditions, such as water quality and temperature. By studying the type and abundance of diatoms in a particular body of water, scientists can assess the overall health of the ecosystem.

i. Water quality monitoring-Diatoms are sensitive to changes in water quality, such as nutrient levels, salinity, and temperature. By studying the types and abundance of diatoms in a particular body of water, scientists can assess the overall health of the ecosystem. For example, if a scientist finds a decrease in the diversity of diatoms in a particular body of water, it may indicate that the water quality is declining.

ii. Climate change monitoring-Diatoms are also sensitive to changes in climate. By studying the types and abundance of diatoms in sediment cores, scientists can reconstruct past climate conditions. This information can be used to predict how climate change is likely to impact aquatic ecosystems in the future.

Some specific examples of ongoing research on the applications of diatoms are-

1. A team of researchers at the University of California, Berkeley is developing a new type of diatom-based battery that is more efficient and durable than traditional lithium-ion batteries.

2. A team of researchers at the University of Minnesota is developing a new type of diatom-based water filter that can remove a wide range of pollutants from water, including heavy metals, pesticides, and bacteria

3. A team of researchers at the University of Cambridge is developing a new type of diatom-based drug delivery system that can deliver drugs to specific cells or tissues in the body.

Conclusion-

Diatoms are a diverse and important group of algae. They have a wide range of potential applications in different fields. Diatoms have several characteristics, including their widespread occurrence, sensitivity to environmental water quality, good preservation, easy detection, and prevalence in high numbers (100 to 200 per cm3) for a good statistical base for quantitative interpretations. Diatoms applications such as energy, biomedical products, and environment monitoring, all these applications have the potential to contribute toward a greener tomorrow. The use of diatoms in research is to increase the sustainable economy by producing various sustainable products like biofuels, feed, bioactive molecules, and services like environment monitoring.

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