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DIATOM AND ITS EXPANDING RESEARCH HORIZON: A REVIEW

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ABSTRACT

Diatoms are the ubiquitous microalgae present all over the world. They are specialized organisms on the planet with the cell wall composed of opaline-silica ornamented with intricate and striked patterns. They are the most prominent as well as successful photosynthetic lower eukaryotes plays a vital role in light trapping. The cell wall nanostructured frustules enhance the light absorption capacity in the multi-layered materials applied as photoanodes. Frustules, the siliceous porous shells of diatoms possess architectures with considerable mechanical strength. Formation of bio-silica shells, optical and fluidic properties along with their flexibility to convert into various nanomaterials have been studied by different biologists, physicists and chemists respectively. In the process of energy generation, conversion and conservation, diatoms play very significant role. Solar fuel is also one of the emerging solutions for increasing future energy demands and to come across this requirement, photocatalysis with the help of diatom's frustules is mostly preferred. Lipid production in diatoms becomes prior objective for biotechnologists also triggers the work in metabolic engineering since it can be act as an alternative to fossil fuels. Apart from these, the fields like wastewater management also use diatoms as a unique source. The present article inculcates the diverse usage of diatoms in the fields like nanotechnology, biotechnology, environment, biochemistry, biophysics, metabolic engineering and many more. Along with this, the prior focus is on the diatoms as a potential source of nanomaterials, bio-electrolyte and biofuel.

Keywords: Photocatalysis, Dye sensitized solar cells, TiO_2 Nanocrystals, Niobium doping, Lipid extraction

INTRODUCTION

Diatom (Dia-tom-os meaning cut in half), the single celled microalgae near about 1 to 500 mm in length comes under the class *Bacillariophyceae* and division *Bacillariophyta.* Such phytoplankton is generally ordered in two major groups such as centric and pennate. The first order, i.e. centric diatoms belong to *Coscinodiscophyceae* whereas pennate diatoms are *Bacillariophyceae*. Both of the groups either exits as single celled or colonized, filaments or strips. Diatoms are the peculiar markers for the evolved way of life, all around adding to practically 25% of the essential efficiency (Scala & Bowler, 2001). Multiplication is generally asexual; where each cell produces two daughter cells, each of them gets inherited by the parental characters. But the interesting part is that, among them each of the cell gets benefited with the valves from parental cell, along with this one smaller additional valve also grows. They are omnipresent, across the board, single-celled eukaryotic microalgae, therefore making them a perfect living being for tremendous scope of uses including ecological sign, oil investigation, and legal assessment. As indicated by the progressing research, diatoms have a wide scope of uses in biotechnology and nanotechnology fields, for example, chemo-sensing and biosensing, examining environmental issues, nanofabrication strategies, immunodiagnostics, molecule arranging, medicate conveyance, and eutrophication. They are answerable for devouring anthropogenic carbon outflows. Diatoms because of their physiological highlights and natural perspectives can be utilized for squander corruption. Being delicate to ecological pressure, they can without much of a stretch identify the level of water contaminants. They are the predominant gathering of phytoplankton liable for the evacuation of supplements and disintegrated oxygen matter present in the water bodies. Without putting lots of efforts one can obtain the cells of diatoms from external surrounding and can proceed for the various uses. Cultivating the diatoms is not much tedious job since it does not require any costly media, not any expensive instrument. Looking towards the recent trends there are different fields of life science where the research on diatoms is preferred, the areas like biotechnology, nanotechnology, metabolic engineering and many more. Along with the fact, diatoms are photosynthetic organisms which are found in marine and new water situations. They have species explicit hierarchically composed three dimensional permeable exoskeletons included silica, which are called as frustules. The frustules come in two covering parts which separate for multiplication and large separate during handling of the frustules for functionalization. The pores fluctuate in the size from 50 nm to more than one micron and the life form themselves can go between a one micron to a millimeter relying on the species.

Diatoms are liable for around one fifth of the creation of natural mixes from carbon dioxide on the earth and make up a fourth of all planet life by weight.

Diatom frustules give an economical road to getting to complex 3D structures planned in the nature explicitly for dispersing and catching the light. Diatoms started involving the silica frustules which help to focus carbon dioxide and permit light into the living being expanded the pace of photosynthesis, making diatoms one of the best life forms on earth. With the quick advancement in research on diatom bio-nanotechnology in the previous 10 years, a few fantastic audits have been distributed with some of them being exceptionally extensive and educational. For instance, Gordon *et al.,* (Gordon *et al*., 2009) presented the history and fundamental idea of the diatom and its ongoing application in nanotechnology in an intriguing and reasonable way. Losic *et al*., 2009 carried out an intensive audit on the mechanical, optical and microfluidic properties of the diatoms, material modification and biosensor applications as well as nanofabrication systems. Prof Rorrer has audited the diatom nanobiotechnology ‘s capabilities for use in cells, batteries and electric light gadgets based on sunlight (Jeffryes *et al.,* 2011). Also, a few great surveys on biosilica development (Dickerson *et al*., 2008; Martin-Jézéquel *et al*., 2000), cell and atomic science (Bozarth *et al*., 2009; Hildebrand, 2003), biohybrids (Nassif & Livage, 2011), (Sánchez *et al*., 2019), fuel extraction (Ramachandra *et al*., 2009), ecological checking (Brayner *et al*., 2011), and phytolith nanotechnology (Neethirajan *et al*., 2009) have likewise been distributed.

1. Diatom’s bio-silicification

The microalgal diatoms have favored with a very unique capacity for taking up silicon from earth and storing it along with their cell walls. It generally means the diatom’s cell wall is composed of one transparent i.e. silica. These organisms have an ability to fix dissolved silicic acid (natural source of silicon) from the external environment and to store it in their cell wall. That means diatoms take this silica as a building block of cell, ultimately leads to the formation of additional multi-organized structures called as frustules which varies from species to species. That is the reason that diatoms have become role models for studies of natural bio-silicification (Yang *et al*., 2020).

2. Diatoms as multifunctional microbial source

Not only diatoms themselves, the frustules present in their cell wall also possess countless applications. Almost each and every field of life science comprises the multidisciplinary uses of diatoms. Areas like biotechnology, nanotechnology, metabolic engineering prominently use these microalgae for various purposes. Let’s focus on the multidisciplinary role of diatoms in different fields of life science (figure 1 and table 1).

In nanotechnology

As the name implies, there must be some uses of diatoms and their other parts like frustules under nanoscale. It is accepted fact that diatoms are own-replicating organisms for whom no any special requirements are needed and this is the reason why they are considered as cost effective and commonly affordable industrial raw material. As pure diatoms possess silicon in the form of silicic acid, many research works have already done for replacing this silicon with different metal oxides like titanium, germanium, zinc and many more (Rorrer *et al.,* 2005) (Jeffryes *et al*., 2008a, 2008b). While attempting this type of work, synthesis of metal oxides in the scale of a nanometer is mandatory and for completing this task, diatoms play a very important role. In short, diatoms have very good potential to work as a source for synthesis of nanomaterials.

a) In biotechnology

Apart from these nano scaled applications, another sort of field where diatoms can easily get suited is biotechnology. As like nanotechnology, biotechnological subfields also inculcate the versatile applications with diatoms. Putting these microalgae in the emerging areas like synthesis of biodevices gives very considerable results. Looking towards industrial sector, diatoms are preferably involved in the production of different metabolites by applying different techniques. The intracellular metabolic products (which are synthesized within the cell) are commonly essential lipids, various amino acids, different pharmaceuticals and many more nutraceuticals also. Species like *Navicula saprophila, Phaeodactylum tricornutum* are preferred for the production of eicosapentaenoic acid (EPA) (Abedi & Sahari, 2014; Bozarth *et al*., 2009; Wah *et al.,* 2015; Wen & Chen, 2001a and 2001b). Additionally, the species like *S. costatum, Haslea ostrearia* are used for producing polyunsaturated oils in short lipids (Hildebrand *et al*., 2012; Lebeau & Robert, 2003). Next to this, another area where diatoms are used under the biotechnological concepts is biofuel production. Taking a little attention from current scenario of fossil fuel exemption, we can say it’s a good option for placing as an alternative. Diatoms possess very great potential for synthesizing lipids, which are prominently acting as a biofuel. Last but not the least, the sector of producing biosensors using diatom’s frustules is also very wide spreading. As already stated, diatoms possess the potential of light trapping and harvesting it up to a certain extent. As the name indicates optical properties of diatom frustules helps to use them in the production of biosensors in different fields. Apart from these mentioned areas of knowledge, there are many more applications in the fields of biotechnology regarding diatoms.

b) In medicine

Along with above mentioned technological fields, there are lot branches or we can say sectors where diatoms are chosen as first preference. Medicine and medication are some of the branches. Immuno-diagnosis is a sector where diatoms are applied for synthesizing immune-enhancing products. Frustules present in the diatom’s cell wall are basically possessing meso-porosity and that is the reason for using them as a transporter of nutrients. Overall

c) In environment

Apart from the above-mentioned fields, diatoms are also known for their vital contribution in environment. As they are major contributor of carbon fixation over the world (around 20%), diatoms directly relate themselves to climate change in the form of acidification, eutrophication. Along with this, they involve in water pollution determination (Hildebrand, 2008; Mishra *et al*., 2017). Excess presence of heavy metals in the water bodies leads dimensions of these frustules can be modified according to the need and purpose. Another area of the medical field is delivery of drugs using diatoms (Mishra *et al*., 2017). As just we have cleared, the diatom's frustules are acting as a vehicle for transporting the nutrients, they can be also used for transporting drugs throughout the body. There is no any kind of side effect of the usage of diatoms in transport of body fluids, so this is the only one reason for using them in the medical field.

Table 1. Multipurpose uses of diatoms in life science

Field	Role of Diatoms	Part used	Product obtained	Description	References
Nanotechnology	Source of nanomaterials	Frustules	Titanium nanotubes	Leads in formation of different nanoscaled substances. Are the cost-effective raw materials.	(Jeffryes *et al.,* 2008a; Rorrer *et al.,* 2005)
	Synthesis of nano-metal oxides	Frustules	TiO_2, ZnO_2, GeO_2	Frustules used from diatoms help in synthesis of nano-metal oxides.	(Jeffryes *et al.,* 2008a; Rorrer *et al.,* 2005)
	Nanomedicines	Derived frustules and live cells	Physical therapy nanotechnology applications.	Non-toxic, biodegradable and easily available diatoms cells can be used as raw material for nanomedicine production.	(Mishra *et al.,* 2017)
Biotechnology	Synthesis of biodevices	Cultured live cells	2D Array	Following the process of self-assembled monolayer (SAM), diatoms cultured on modified glass surface. After post adhesion, these cultured diatoms can be used in development of biodevices with 2D array.	(Mishra *et al.,* 2017)
	Metabolites production	*In-vitro* cultured cells	Lipids, Amino acids, PUFA	Metabolites obtained from diatoms are intracellular and extracellular and can be used as pharmaceuticals and nutraceuticals as well.	(Abedi & Sahari, 2014; Lebeau & Robert, 2003; Wah *et al.,* 2015; Wen & F. Chen, 2001a and 2001b)
	Biofuel production	Diatoms during vegetative phase	Neutral lipids	Oil from diatoms is comparatively much more than soybeans and palm. Under deficiency if Si contains and N, cells produce high lipid. This can be taken as biofuel if it contains ester group. If it is so, then it will be alternative for fossil fuels.	(Hildebrand *et al.,* 2012; Lebeau & Robert, 2003)
	Biosensors	Frustules of appropriate pore size	Metabolic biosensors with fluorescent probes	Filtration ability of Diatoms helps in designing different biosensors. Flexible frustules incorporated in specific chamber leads to selective tracking of molecules.	(Mishra *et al.,* 2017; Siebman, Velev, & Slaveykova, 2017)
	Photocatalysis	Live/dead cells	Solar cells with enhanced efficiency	As compare to conventional solar cells, the DSSCs with diatoms frustules gives much more high performance. After incorporating frustules along with dye and doping material, DSSCs efficiency enhances up to 30%.	(McMillon-Brown *et al.,* 2017)

Field	Role of Diatoms	Part used	Product obtained	Description	References
Nanomedicine and Medical sector.	Immunodiagnostics	Frustules	Frustules act as vehicles for nutrients	Because of the mesoporous nature of frustules, they can transport nutrients in body. Customized structure of frustules form basis of immunodiagnostics.	(Mishra *et al.,* 2017)
	Drug delivery	Modified biosilica and frustules	Frustules used as drug delivery vehicles	Because of different favorable properties of frustules, they can be referred as vehicles for drugs. Used as transporter of SiR-NA in tumor cells. Used as solid carrier for drugs with oral administrations.	(Mishra *et al.,* 2017; Vasani *et al.,* 2015; Zhang *et al.,* 2013)
Environment	Water purifier(Aqueous filtering agent)	Dead diatoms	Cost effective natural filtering agent.	Dead diatoms with considerable filtration ability with homogeneous permeability and fixed pore size.	(Hildebrand, 2008; Mishra 2017)
	Pollution monitoring sensors	Live cells	Diatoms cells act as pollution indicators.	The live diatoms cells indicate the climate changes, acidification and eutrophication in the environment. Excess of heavy metals in the water bodies can be detected by the decrease in diatom's number. Usually constituted 61% in pure water which reduces up to 25% due to excess pollutants.	(Dixit *et al.,* 2002)
Forensics	Diagnosis of drowning deaths	Live cells	Used to diagnose the drowning deaths	Most of the times, death cases by drowning can be diagnosed by detecting the presence of diatoms in lungs. If death occurred by drowning, the diatoms cells enter into lungs and then enter into blood stream. Presence of these diatoms means death is occurred due to drowning.	(Rana & Manhas, 2018)
Food science	Potential nutraceutical and food supplement	Live cells and derivatives	Vitamins, pigments, fatty acids, polysaccharides etc.	Different kinds of vitamins (Vit A, B12, C, D, K), pigments (Chlorophylls, Carotenoids), Fatty acids (PUFA) can be extracted from diatoms and most of times used as nutraceuticals. Other than this, diatoms itself act as food for different aquatic lives.	(Mishra *et al.,* 2017)

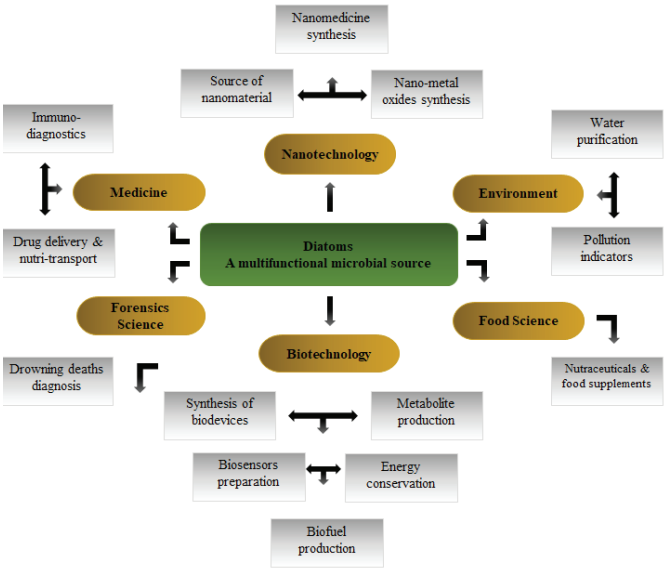

Figure 1. Multipurpose uses of diatoms in Life Sciences

to the reduction in diatoms number (61% to 25%) and hence named as pollution monitoring sensors. Another way to praise diatoms is, they can act as water purifier as they have potential to clarify a heterogeneous mixture of water and gives homogeneous permeability to the water. This is the reason to name them as an aqueous filtering agent.

d) In forensic science

Diatoms can be used in forensic science in an assortment of ways, the most incessant being the analysis of death by drowning (Zhou *et al.,* 2020). At the point when person drowns, he will start suffocation due to lack of oxygen and as a result water will enter into his body. Along with the water, diatoms cells will also enter the lungs afterwards enter the circulatory system by bursting the fringe alveoli prior to being conveyed to different organs like liver and heart. The presence of diatoms in the respiratory system of victim helps to detect the death case is occurred by drowning.

e) In food science

Diatoms are liable for more than 40% of photosynthesis on the planet's seas and without them the sea would be not able to help the measure of life that it does. Diatoms are a vital wellspring of food and energy for different life forms in numerous freshwater environments also. Side by side, the various products obtained from them can be used as nutraceuticals like different lipids, vitamins and pigments (Mishra *et al*., 2017). Diatoms itself act as food supplements for different aquatic lives.

Though ubiquitous diatoms are diversely playing very important roles approximately in every field of life, but in this piece of information we will try to focus only on two applications i.e. photocatalysis and biofuel synthesis.

3. Solar cells as an alternative to fossil fuels

Despite the fact that sustainable sources of energy are being used, discontinuous accessibility remains an important problem, which implies the need for effective techniques to store vitality. An interesting response to this question from past developments is the transformation of sustainable energy into a fuel that can be put off, and used as needed. The photoelectrochemical devices (PEC), which involve the photo-anode of a n-type semi-conductor and the photo-cathode of a p-type semi-conductor, can be used to do this. Such gadgets may impersonate regular photosynthesis properly used and are commonly referred to as counterfeit photosynthesis systems. In nature, life forms provided a sort of response to complex optical problems by manipulating structural features from the nano-to-micrometer scale popularly. Diatoms; a major collection of single cells photosynthetic yellow brown growth-gradual permeable silica structures have been streamlined to enhance photosynthesis in light and strength. Fuhrmann *et al.,* 2004 have demonstrated that diatom frustule structures couple approaching light into wave guides with unmistakable photonic band holes and consequently go about as living photonic crystals. In close proximity to the silica cell dividers are chloroplasts. In recent developments, researchers have shown that a laser pillar focusing on one particular area of the live diatom can act on chloroplast glow throughout the entire diatom, thus proposing an organic importance for light harvesting of the diatom permeable structure. Based on these models, they construed that misusing minimal effort, progressively organized common fossilized diatoms might upset the manner by which they manufacture photovoltaic, vitality stockpiling, and optoelectronic gadgets.

The primary motivation behind the fact that local diatom frustules are currently not used in order to change solar energy is that the frustules are made of biomineralized silica, which is not suitable for use with PEC gadgets. Some methods were studied in order to change silica into the material with a newer and more efficient optical, electrical and attractive feature, depending on metal and nanoparticles, compound fumes affidavit, and nuclear layer statement. Titanium dioxide (TiO_2) coated diatom silica was later presented for the use of diatom frustules as photovoltaic material for Dye Sensitized Solar Cells, DSSC. The cell efficiency achieved with sunlight was around 6.7%, which was further improved with the use of a plasma polymerized TiO_2 covering. These covering models demonstrate that a methodology is available for changing silica diatoms into nanostructured semiconductor materials. Silicon, which has a 1.1 eV band-hole, is an undeniable objective semiconductor here, and is therefore highly appropriate for the processes of sun powered vitality change (Gautam *et al*., 2016). Moreover, built nanostructured types of silicon, for example, permeable silicon and silicon nano wires have recently been appeared to improve photocatalytic activities in the solar cells. Nanostructured titanium dioxide (TiO_2) semiconductor materials have special

optoelectronic properties that empower an assortment of uses, especially for photocatalysts and sun-oriented cells (Chen & Selloni, 2014). Control of the spatial association of nanoscale TiO_2 inside an intermittent, structure offers extra upgrades for light catching in these applications. There is gigantic enthusiasm for bioinspired approaches for the combination of semiconductor and metal oxide nanomaterials, as they offer the open door for self-gathering into various levelled structures. Specifically, cell culture, frameworks has been identified as a stage for the biosynthesis of photonic nanostructures. Although biomineralization of TiO_2 is uncommon in nature, bio silica (shapeless SiO_2) is integrated from dissolvable silicon into complex structures by an assortment of amphibian living beings, as exemplified by the diatoms. Diatoms are single-celled green growth, which make silica shells called frustules that are unpredictably designed at both the nano- and microscale. The occasional pore structures of diatoms have photonic precious stone properties (Fuhrmann *et al*., 2004).

4. Biofuel extracted from Diatoms serve as the best alternative for fossil fuel exemption

Diatoms are composed of lipid droplets, primarily triacylglycerole (TAG), which is enclosed by a polar lipid monolayer and is composed of a core of neutral lipid. In the diatoms LDs can store energy stores, layer parts, carbon skeletons, carotenoids and proteins. A number of different equivalent words, such as fat, lipid parts, oils, oil globules, cytoplasmic ingredients, oleosomes, adiposomes and many other words, have been used to depict this organelle. However, Lipid Droplet is abbreviated in LD as its most common name, due to its current widespread usage within the scientific network. LDs can reduce pressure caused by an excess of fat, carbon or protein, complete the redox homeostasis in a sink of vitality during electron flow times or by a supplementary shorter. This allows them to buffer the inward stoichiometry of cells from their shifts. Proteasomal decay, autophagy, beta-oxidation, photosynthesis and lipid digestion facilitate their capabilities. It fills the capacity and trade between different cell compartments as a metabolic system center. These may occur as immediate contacts, as close physical affiliations or as vesicular trafficking between compartmental associations. The heap elements of LDs are handled and regulated by a variety of proteins, limited by several systems to LDs. Although physiologically concentrated, diatom lipid digestion has long been, late progress in the diatomic science and in LD science in various living beings adds to an increased and more complex understanding. Although continuous proteomic screens have identified additional competitors for future examination, only a few diatom LD proteins have been described. The environment, CO_2 rates has been rising and growing several percent since the mechanical revolution, mostly as a result of the use of non-renewable energy resources. Expanded CO_2 leads to a harmful divergence of the atmosphere and global surface temperature. The latest IPCC study also shows clearly that unusual shifts in weather will likely happen somewhere in the 2030-2052 range at 1.5°C, unlikely to start rising at the moment (IPCC SR1.5°C, 2018). There are possible risks of extreme weather, species suffering and eradication, food health and human well-being that are considerably higher if the global temperature increases are 2.0°C rather than 1.5°C (IPCC SR1.5°C, 2018). With no or restricted 1.5°C excess, worldwide net anthropogenic CO_2 outflows should be reduced, as compared with 2010 by about 45% by 2030, and a net zero by 2050. The use of carbon zero filling is an important way of lowering CO2 emissions and reducing the harmful variance in the atmosphere. Biofuels are the highest intrigued between the various potential sources of inexhaustible, carbon-zero energy and are dependent on them to take over a fundamental role in the worldwide energy system (Mishra & Goswami, 2018). Yellow brown growth can, in contrast to various feedstocks, produce a high return of biofuels without containing crop arable soil and thus increase increasing consideration (Pandey *et al.,* 2018). Even if all accounts for carbon-zero energy, it is important that, in principle, all phases, including the development, restoration, and post-preparedness are subordinate to vitality. Thus, it is unlikely that microalgae biodiesel will undoubtedly benefit earth when considering the entire cycle, although green development injects CO_2 when developed. There have been numerous green growth studies for use in biofuels, including small and full-scale, terrestrial, and marine water (Adeniyi *et al*., 2018). Microalgae like *Chlorella* and *Daniella* have gained much attention due to their versatility in development and lipid material (Dickinson *et al*., 2017; Sakarika & Kornaros, 2019).

Diatoms are one of the world's most important and adaptable eukaryotic microalgae. These are the major contributors to the world's carbon fixation by approximately 20% (Gao *et al*., 2019). Diatoms also have a strong limit for light management and temperature fluctuations that offer outdoor growth potential (Souffreau *et al*., 2010; Yuan *et al*., 2018). Diatoms are not commonly considered to be bio-oil production relative to green microalgae, although many studies indicate that diatoms are potential bio-fuel sources (Hildebrand *et al*., 2012; Levitan *et al*., 2014). One reason is that diatoms often have not enough oil than green microalgae (Shuba & Kifle, 2018; Sison-Mangus *et al.,* 2016). Nitrogen deficiency is an effective way to treat microalgae accumulation of lipids (Brennan & Owende, 2010). In diatoms, silicon deficiency is used to improve the lipid content. While nitrogen or silica deficiency may lead to more lipids, its production has significantly reduced under these conditions, leading to low lipid content. Since lipid development varies from the way in which culture conditions can be improved to achieve both rapid growth and a high level of lipid content, it is an ongoing study.

5. The role of diatoms in water treatment

Water contamination rises at an unprecedented rate mainly due to squandering caused by synthetic activities,

like domestic, industrial and agricultural squanders, released directly to the water bodies. Uncontrolled release of rich waste supplement presents real hazardous eutrophication. Due to the extreme proximity of supplements in the water body, more eutrophication happens which is responsible for thick plant growth. The expansion of the immense amount of contamination means that, despite recognition of reasonable water, water assets are seriously endangered by the management procedures throughout the world. Thus, it is essential to investigate the optional trend towards innovations in wastewater treatment and ensure that appropriate treatment actions are taken to meet the nearby conditions. The main purpose of wastewater treatment is to dispose of guideline poisons such as suspended solids, biochemical oxygen demand (BOD), natural and inorganic supplements, toxicity and coliform microbes. A regular wastewater framework includes expulsion by the sedimentation of the disintegrated natural problem and suspended solids. The primary treatment of waste expels 60% of the massive strength materials via the entire planned sedimentation tank and approximately 35% of the BOD transmitted via sewers which are responsible for preventing the flow through the plant and harmful equipment. Materials such as heavy particles of coarseness, clothes, fecal materials and wood can be expelled by screen bars. The auxiliary treatment method expects to reduce 85% of suspended solids and BOD by decreasing naturally occurring problem. This can be achieved primarily by a mixed population of heterotrophic microscopic organisms with the ability to use the natural element for vibrancy and growth. The auxiliary wastewater treatment system is composed of fixed film and suspended production reactors. 95% of natural particles should be removed by tertiary treatment methods. This can be achieved organically or synthetically, but it's a very costly process. Propelled treatment focused on diverse creative approaches includes concoction, assimilation, adsorption of carbon or ozonation. Such methods evacuate nutrients like phosphorus or nitrogen, which may activate surface water eutrophication. Frameworks are used to remove fine particles for small tasks like land application, filtration and tidal pond storage. In some areas, a few necessary and optional treatment plants were familiar with settled materials and the oxidation of natural wastewater material. Similarly, the 100 percent expulsion from nearby waste loads cannot be normal significantly after tertiary treatment, and many living beings remain on the water bodies (Kumar & Saravanan, 2018). The growth in diatoms is ultimately cost-effective for the treatment of waste water that is the best food for Zoo tiny fish. The important snag is to speed up the development of diatoms, for which silica is necessary. Nualgi is a revolutionary product developed by T Sampath Kumarin, which uses nano silica to produce diatoms as a micronutrient, along with the iron and nine following metals (Mn, Mo, B, Ca, Mg, Zn, Co, etc.). It is expected that only 1kilogram of nualgi can remove 400–1400 kg of carbon from the water and supply oxygen by diatoms. In addition, they are eaten by small fish, which maintain a normal way of life in the water along these lines. The nano-sizes of nualgi allow nualgi to remain suspended in water and increase the bio-availability of microalgae supplements and to invade very little space in a subterranean environment. Nualgi is safe and does not require waste water to be treated with power in various strategies (Li *et al*., 2017).

CONCLUSION

Glancing through the above context, it can be easily stated that, along with the other microspecies, diatoms also perform fundamental roles in all fields of life science. Biosiliciated cell membrane of diatom makes them different from other microbes. Along with this feature, they show huge variation in in their own community itself just due to the varying size, shape, opacity and many more factors of their frustules. Of course, this is a considerable feature of diatoms. Almost in every field of life science, diatoms can be applied. As a point of view of research, they are the best source to implement your work. Starting from nanoparticle synthesis up to drug delivery, industrial applications up to the medical field, they can be easily fitted and hence are multipurpose applied. Though it is true fact, this review is based on the two vital applications such as photocatalysis and lipid extraction. Looking towards the photocatalysis, presence of diatom frustules in the solar cells enhances their efficiency 30% more. Next to this, if these frustules are doped with some nanomaterials like titanium, silicon, germanium, zinc etc. It will ascendingly lead to enhancing an efficiency of solar cell. Application of dyes into the solar cells accompanying with photoelectrodes, it becomes a highly enhanced performance. Ruthenium is the best example for this purpose. Apart from this, biofuel synthesis is also very highly significant application of diatom. As mentioned, Lipid Droplets (LDs) are the reservoir of fatty acid in the diatoms. For extracting an adequate amount of lipid, some culture conditions like nutrient limitation (Si, N, C etc.) are recommended. Extracted lipid from diatom cells possess several considerable characteristics like flaming property, different commercial, pharmaceutical and nutraceutical values, which can be beneficially implemented. Considering the above benefits of these two applications, we can easily conclude that DSSCs with high enhanced efficient performance and lipid with beneficial advantageous features, both are acting as the best alternative to fossil fuels. DSSCs is the replacement of traditional solar cells, where lipid obtained from diatoms replaces fossil fuels and acts as the biofuel. In short, both the products are highly advantageous organosynthetic sources which ultimately lead to energy conversation.

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REFERENCES

Abedi, E., & Sahari, M. A. (2014). Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties. *Food science & nutrition, 2*(5), 443-463.

Adeniyi, O. M., Azimov, U., & Burluka, A. (2018). Algae biofuel: current status and future applications. *Renewable and sustainable energy reviews, 90*, 316-335.

Bozarth, A., Maier, U.-G., & Zauner, S. (2009). Diatoms in biotechnology: modern tools and applications. *Applied microbiology and biotechnology, 82*(2), 195-201.

Brayner, R., Couté, A., Livage, J., Perrette, C., & Sicard, C. (2011). Micro-algal biosensors. *Analytical and bioanalytical chemistry, 401*(2), 581-597.

Brennan, L., & Owende, P. (2010). Biofuels from microalgae—a review of technologies for production, processing, and extractions of biofuels and co-products. *Renewable and sustainable energy reviews, 14*(2), 557-577.

Chen, X., & Selloni, A. (2014). Introduction: titanium dioxide (TiO2) nanomaterials. In: *ACS Publications*.

Dickerson, M. B., Sandhage, K. H., & Naik, R. R. (2008). Protein-and peptide-directed syntheses of inorganic materials. *Chemical reviews, 108*(11), 4935-4978.

Dickinson, S., Mientus, M., Frey, D., Amini-Hajibashi, A., Ozturk, S., Shaikh, F., . . . El-Halwagi, M. M. (2017). A review of biodiesel production from microalgae. *Clean technologies and environmental policy, 19*(3), 637-668.

Dixit, S. S., Dixit, A. S., & Smol, J. P. (2002). Diatom and chrysophyte functions and inferences of post-industrial acidification and recent recovery trends in Killarney lakes (Ontario, Canada). *Journal of paleolimnology, 27*(1), 79-96.

Fuhrmann, T., Landwehr, S., El Rharbi-Kucki, M., & Sumper, M. (2004). Diatoms as living photonic crystals. *Applied Physics B, 78*(3-4), 257-260.

Gao, G., Wu, M., Fu, Q., Li, X., & Xu, J. (2019). A two-stage model with nitrogen and silicon limitation enhances lipid productivity and biodiesel features of the marine bloom-forming diatom Skeletonema costatum. *Bioresource technology, 289*, 121717.

Gautam, S., Kashyap, M., Gupta, S., Kumar, V., Schoefs, B., Gordon, R., . . . Vinayak, V. (2016). Metabolic engineering of tio 2 nanoparticles in nitzschia palea to form diatom nanotubes: an ingredient for solar cells to produce electricity and biofuel. *RSC advances, 6*(99), 97276-97284.

Gordon, R., Losic, D., Tiffany, M. A., Nagy, S. S., & Sterrenburg, F. A. (2009). The glass menagerie: diatoms for novel applications in nanotechnology. *Trends in Biotechnology, 27*(2), 116-127.

Hildebrand, M. (2003). Biological processing of nanostructured silica in diatoms. *Progress in Organic Coatings, 47*(3-4), 256-266.

Hildebrand, M. (2008). Diatoms, biomineralization processes, and genomics. *Chemical reviews, 108*(11), 4855-4874.

Hildebrand, M., Davis, A. K., Smith, S. R., Traller, J. C., & Abbriano, R. (2012). The place of diatoms in the biofuels industry. *Biofuels, 3*(2), 221-240.

Jeffryes, C., Campbell, J., Li, H., Jiao, J., & Rorrer, G. (2011). The potential of diatom nanobiotechnology for applications in solar cells, batteries, and electroluminescent devices. *Energy & Environmental Science, 4*(10), 3930-3941.

Jeffryes, C., Gutu, T., Jiao, J., & Rorrer, G. L. (2008a). Metabolic insertion of nanostructured TiO2 into the patterned biosilica of the diatom Pinnularia sp. by a two-stage bioreactor cultivation process. *Acs Nano, 2*(10), 2103-2112.

Jeffryes, C., Gutu, T., Jiao, J., & Rorrer, G. L. (2008b). Peptide-mediated deposition of nanostructured TiO 2 into the periodic structure of diatom biosilica. *Journal of Materials Research, 23*(12), 3255-3262.

Kumar, P. S., & Saravanan, A. (2018). Sustainable Waste Water Treatment Technologies. In *Detox Fashion* (pp. 1-25): Springer.

Lebeau, T., & Robert, J.-M. (2003). Diatom cultivation and biotechnologically relevant products. Part II: Current and putative products. *Applied microbiology and biotechnology, 60*(6), 624-632.

Levitan, O., Dinamarca, J., Hochman, G., & Falkowski, P. G. (2014). Diatoms: a fossil fuel of the future. *Trends in Biotechnology, 32*(3), 117-124.

Li, X.-l., Marella, T. K., Tao, L., Peng, L., Song, C.-f., Dai, L.-l., . . . Li, G. (2017). A novel growth method for diatom algae in aquaculture waste water for natural food development and nutrient removal. *Water Science and Technology, 75*(12), 2777-2783.

Losic, D., Mitchell, J. G., & Voelcker, N. H. (2009). Diatomaceous lessons in nanotechnology and advanced materials. *Advanced Materials, 21*(29), 2947-2958.

Martin-Jézéquel, V., Hildebrand, M., & Brzezinski, M. A. (2000). Silicon metabolism in diatoms: implications for growth. *Journal of phycology, 36*(5), 821-840.

McMillon-Brown, L., Mariano, M., Lin, Y. L., Li, J., Hashmi, S. M., Semichaevsky, A., . . . Taylor, A. D. (2017). Light-trapping in polymer solar cells by processing with nanostructured diatomaceous earth. *Organic Electronics, 51*, 422-427.

Mishra, M., Arukha, A. P., Bashir, T., Yadav, D., & Prasad, G. (2017). All new faces of diatoms: potential source of nanomaterials and beyond. *Frontiers in Microbiology, 8*, 1239.

Mishra, V. K., & Goswami, R. (2018). A review of production,

properties and advantages of biodiesel. *Biofuels, 9*(2), 273-289.

Nassif, N., & Livage, J. (2011). From diatoms to silica-based biohybrids. *Chemical Society Reviews, 40*(2), 849-859.

Neethirajan, S., Gordon, R., & Wang, L. (2009). Potential of silica bodies (phytoliths) for nanotechnology. *Trends in Biotechnology, 27*(8), 461-467.

Pandey, A., Lee, D. J., Chang, J.-S., Chisti, Y., & Soccol, C. R. (2018). *Biomass, biofuels, biochemicals: biofuels from algae*: Elsevier.

Ramachandra, T., Mahapatra, D. M., & Gordon, R. (2009). Milking diatoms for sustainable energy: biochemical engineering versus gasoline-secreting diatom solar panels. *Industrial & Engineering Chemistry Research, 48*(19), 8769-8788.

Rana, A. K., & Manhas, S. (2018). The future of forensic biology. *Journal of Biomedicine, 3*, 13-18.

Rorrer, G. L., Chang, C.-H., Liu, S.-H., Jeffryes, C., Jiao, J., & Hedberg, J. A. (2005). Biosynthesis of silicon–germanium oxide nanocomposites by the marine diatom Nitzschia frustulum. *Journal of nanoscience and nanotechnology, 5*(1), 41-49.

Sakarika, M., & Kornaros, M. (2019). Chlorella vulgaris as a green biofuel factory: comparison between biodiesel, biogas and combustible biomass production. *Bioresource technology, 273*, 237-243.

Sánchez, C., Cristóbal, G., & Bueno, G. (2019). Diatom identification including life cycle stages through morphological and texture descriptors. *PeerJ, 7*, e6770.

Scala, S., & Bowler, C. (2001). Molecular insights into the novel aspects of diatom biology. *Cellular and Molecular Life Sciences CMLS, 58*(11), 1666-1673.

Shuba, E. S., & Kifle, D. (2018). Microalgae to biofuels:'Promising'alternative and renewable energy, review. *Renewable and sustainable energy reviews, 81*, 743-755.

Siebman, C., Velev, O. D., & Slaveykova, V. I. (2017). Alternating current-dielectrophoresis collection and chaining of phytoplankton on chip: Comparison of individual species and artificial communities. *Biosensors, 7*(1), 4.

Sison-Mangus, M. P., Jiang, S., Kudela, R. M., & Mehic, S. (2016). Phytoplankton-associated bacterial community composition and succession during toxic diatom bloom and non-bloom events. *Frontiers in Microbiology, 7*, 1433.

Souffreau, C., Vanormelingen, P., Verleyen, E., Sabbe, K., & Vyverman, W. (2010). Tolerance of benthic diatoms from temperate aquatic and terrestrial habitats to experimental desiccation and temperature stress. *Phycologia, 49*(4), 309-324.

Vasani, R., Losic, D., Cavallaro, A., & Voelcker, N. (2015). Fabrication of stimulus-responsive diatom biosilica microcapsules for antibiotic drug delivery. *Journal of Materials Chemistry B, 3*(21), 4325-4329.

Wah, N. B., Ahmad, A. L. B., Chieh, D. C. J., & Hwai, A. T. S. (2015). Changes in lipid profiles of a tropical benthic diatom in different cultivation temperature. *Asian Journal of Applied Science and Engineering, 4*(2), 91-101.

Wen, Z.-Y., & Chen, F. (2001a). Optimization of nitrogen sources for heterotrophic production of eicosapentaenoic acid by the diatom Nitzschia laevis. *Enzyme and microbial technology, 29*(6-7), 341-347.

Wen, Z. Y., & Chen, F. (2001b). Application of statistically-based experimental designs for the optimization of eicosapentaenoic acid production by the diatom Nitzschia laevis. *Biotechnology and bioengineering, 75*(2), 159-169.

Yang, X., Yan, L., Ran, F., Huang, Y., Pan, D., Bai, Y., & Shao, L. (2020). Mussel-/diatom-inspired silicified membrane for high-efficiency water remediation. *Journal of Membrane Science, 597*, 117753.

Yuan, W., Gao, G., Shi, Q., Xu, Z., & Wu, H. (2018). Combined effects of ocean acidification and warming on physiological response of the diatom Thalassiosira pseudonana to light challenges. *Marine environmental research, 135*, 63-69.

Zhang, H., Shahbazi, M.-A., Mäkilä, E. M., da Silva, T. H., Reis, R. L., Salonen, J. J., . . . Santos, H. A. (2013). Diatom silica microparticles for sustained release and permeation enhancement following oral delivery of prednisone and mesalamine. *Biomaterials, 34*(36), 9210-9219.

Zhou, Y., Cao, Y., Huang, J., Deng, K., Ma, K., Zhang, T., . . . Huang, P. (2020). Research advances in forensic diatom testing. *Forensic Sciences Research*, 1-8.