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Industrial Applications of Microalgal Biotechnology: A Novel Approach to Disease Mitigation

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Abstract
A new sustainable method of disease prevention is offered by microalgal biotechnology, which takes advantage of microalgae's special qualities as "cellular factories." A wide range of bioactive substances with medicinal qualities can be produced by cultivating these small photosynthetic organisms. The prevalence of chronic diseases and the emergence of drug-resistant bacteria are two health issues that this industrial application promises to address. The creation of novel antimicrobial agents such as antibiotics, antivirals, and antifungals is one of the main uses. These medicines are desperately needed to fight drug resistance. Additionally, microalgae can be genetically modified to generate monoclonal antibodies and subunit vaccinations, providing a secure and affordable substitute for conventional techniques. They are also a great source of antioxidants and anti-inflammatory substances including polyunsaturated fatty acids (PUFAs) and carotenoids, which are essential for controlling and avoiding chronic illnesses. In addition to direct therapies, microalgal cells can be utilized as sophisticated drug delivery systems, as well as sources of functional foods and nutraceuticals that improve general health. By eliminating contaminants, their function in bioremediation reduces the spread of antibiotic resistance and enhances environmental health. This analysis emphasizes the diverse potential of microalgal biotechnology as a cutting-edge and significant approach to the prevention of disease worldwide.

Keywords: Industrial, Application, Microalgal, Biotechnology, Disease, Mitigation.

Introduction

A vast variety of typical and extreme aquatic environments, including freshwater, lacustrine, soda lakes, riverine, marine, estuarine, brackish, thermophilic, saline, and hyper-saline ecosystems, are home to abundant eukaryotic photosynthetic microorganisms known as microalgae (Leliaert et al., 2012). microalgae are therefore found in almost all environments (Selvarajan et al., 2015). But according to Lee et al. (2014), this broad definition also encompasses cyanobacteria, which are blue-green photosynthetic prokaryotic microorganisms. As major primary producers in nature, microalgae form the base of the food chain in aquatic environments (Malapascua et al., 2014). Whereas terrestrial higher plants have about 250,000 individuals, microalgae have an estimated 200,000 to several million unique strains, indicating a high level of biodiversity (Delrue et al., 2016). There is a lot of untapped potential for the enormous bioresource in terms of prospective biotechnological applications because there are now less than 10,000 microalgal strains known to exist (Delrue et al., 2016).

Microalgae are a diverse group of micro-eukaryotic organisms that can tolerate heterotrophic, mixotrophic, and photoautotrophic environments. Numerous metabolites are produced by them. Since autochthonous marine and freshwater microalgae are a very diverse group of oligotrophic organisms with low nutrient requirements, they can flourish in any type of natural environment (Vu et al., 2018). They are also a great source of antioxidants and anti-inflammatory substances including polyunsaturated fatty acids (PUFAs) and carotenoids, which are essential for controlling and avoiding chronic illnesses. In addition to direct therapies, microalgal cells can be utilized as

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sophisticated drug delivery systems, as well as sources of functional foods and nutraceuticals that improve general health. By eliminating contaminants, their function in bioremediation reduces the spread of antibiotic resistance and enhances environmental health. This analysis emphasizes the diverse potential of microalgal biotechnology as a cutting-edge and significant approach to the prevention of disease worldwide. According to Suganya et al., (2016), the diameters of these species can vary from a few micrometers (μm) to hundreds of micrometers. Variations in the kinetics of microalgae growth are caused by the primary growth-controlling factors that are currently in existence. Microalgae are appealing candidates for the synthesis of high-value metabolites because of their rapid growth in comparison to certain terrestrial plants like coconut and jatropha (Kirrolia et al., 2013). Compared to maize (172 L/ha), soybeans (446 L/ha), jatropha (1892 L/ha), coconut (2689 L/ha), and palm (5950 L/ha), microalgae are reported to generate 58,700 L/ha when oil is the primary emphasis (Chisti, 2007).

Importance of Microalgae in Biotechnology

Microalgae are superior options for mitigating climate change because they are carbon neutral. As a result, microalgae can be appealing and appropriate options for bio-factories that can produce a variety of substances. The efficiency of carbon fixation and subsequent cellular mechanisms that transform photosynthate into beneficial precursors and end metabolites are critical components of microalgal production (Hildebrand *et al.,* 2013). Concerns about food security have led to a surge in the microalgal biotechnology sector since metabolite extraction and microalgal production do not compromise food security. Microalgae-biomass is processed very differently than regular feedstock for biorefineries. Since microalgae grow in liquids, a number of procedures are needed to create a substrate for chemical extraction. Cultivation, harvesting, and extraction are the three main phases of microalgae biomass production. A bio-refinery turns microalgal biomass resources into high-value byproducts and biofuels using eco-friendly chemical and bioprocessing techniques (Radmer, 1996).

Pharmaceuticals are among the many industrial products that can be made from microalgae. Environmental biotechnology uses microalgae for environmental-toxicant monitoring and bioremediation, including bioassays. Two of the most common application areas are sewage treatment and the decrease of carbon dioxide emissions. They are among the most significant suppliers of bioactive substances. Microalgae have antiviral, antibacterial, nutritional, anti-cancer, and anti-HIV qualities (Apt & Behrens, 1999).

Biomass of Microalgae

The processing of microalgae biomass differs significantly from that of normal bio-refinery feedstocks. Because microalgae develop in liquids, obtaining material for biochemical separation requires many processes. Cultivation, harvesting, and extraction are the three main phases in producing microalgal biomass (Babu & Economy, 2008; Boateng et al., 2008). Microalgae that are robust are vulnerable to natural stress and can thrive in various environments.

The type of microalgae species, nutrients available, environment, production mode autotrophic and heterotrophic, but, most crucially, the final application of biomass all influence the cultivation system used (Maxwell et al., 1985). The doubling time and biomass production of microalgae are used to gauge their progress. The production of biomass is inversely related to the density of the culture. Various factors influence biomass productivity, including microalgae species, nutrients, sunlight, temperature, pH, mix concentration, and culture purity. The growth conditions must be tuned to produce optimal biomass productivity. Microalgae can explore their surroundings to conserve resources and efficiently use them. Photosynthesis necessitates an adequate amount of carbon source and light for microalgae cultivation (Moheimani, 2005).

Bioactive Compounds of Microalgae

Microalgae are a major source of bioactive metabolites, particularly cytotoxic compounds with applications in cancer treatment. Antibiotic compounds were listed from marine microalgae, such as Phaeocystis sp. blooms. Acrylic acid, which makes up around 7.0% of the dry weight, is one of the compounds that Phaeocystis pouchetii is known to create. The resulting antibiotic compounds are identified in Antarctic penguins' digestive tracts and are passed up the food chain. It is known that the halotolerant algae Dunaliella sp. produces vitamins and ß carotene. These substances are crucial to mariculture operations (Lipton, 2003). Cyanobacteria are among the most promising families of organisms from which novel and biochemically active natural chemicals can be isolated. Spirulina,

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Anabaena, Nostoc, and Oscillatoria are among the many cyanobacteria that create a variety of secondary metabolites. Additionally, cyanobacteria have been shown to decrease cholesterol in both people and animals and to create anticancer, antiviral, and antifungal chemicals (Iwata *et al*., 1990). Cyanobacterial toxins and significant prospects for anti-cancer medications are among the many peptide-based pharmaceutically interesting chemicals found in cyanobacteria. Common in cyanobacteria, peptide synthetases are in charge of producing various peptides, including cyanobacterial hepatotoxins. The manufacture of some cyanobacterial bioactive substances, such as microcystins, is also aided by polyketide synthetases. A number of extracts were shown to be particularly effective in defending human lymphoblastoid T-cells from the cytopathic effects of HIV infection. Phormidium tenue and Lyngbya lagerheimii were used to identify active substances, which were sulfolipids with various fatty acid esters.

The cyanovirin protein, which is present in an aqueous cellular extract of Nostoc elipsosporum, inhibits the citopathic and in vitro reproduction of monkey retroviruses. The active ingredient Cryptophycin 1, which was isolated from the Nostoc strain, binds to the ends of microtubules and stops the cell cycle in the mitotic metaphase, hence having antiproliferative and antimitotic actions. Cryptophycin-52, a synthetic equivalent, is currently undergoing Phase II clinical trials because of its strong anticancer properties. Spirulan is a calcium sulfated polysaccharide. It is discovered that a new water-soluble cyanobacteria extract has antiviral properties. This substance seems to be specifically blocking enveloped viruses' ability to enter host cells, which stops them from replicating. The impact was reported for a variety of infections, including HIV1, measles, and Herpes simplex. Chlorella vulgaris culture supernatant produces a glycoprotein that, in contrast to other eukaryotic microalgae, has been shown to protect mice from tumor metastasis and chemotherapy-induced immunosuppression (Barsanti & Gualtiery, 2006).

Health and Industrial Applications of Microalgae

Numerous biochemicals used in medical and gastronomic research can be produced by microalgae (Brennan et al., 2010). A valuable renewable resource, microalgae can be exploited for a number of commercial applications, such as CO2 mitigation and sewage treatment. Human diet, animal as well as aquatic life feeding. high value cosmetic chemicals such as astaxanthin, carotene, and phycobiliproteins are pigments from microalgae (Raja et al., 2008). Antimicrobial and anticancer substances are usually synthesized by microalgae. Arthrospira, Dunaliella, Iisochrysis, Chaetoceros and Chlorella are some of the most common microalgae used to make commercial products (Lee, 1997).

Nutraceuticals and Pharmaceuticals

The capacity of microalgae to create bioactive compounds through biological processes that are challenging to produce using chemical methods has led to its recognition as a natural source of bioactive molecules. Microalgae have the potential to create pharmacologically active compounds, growth regulators, poisons, antibiotics, and algicides (Borowitzka, 1995). Alcohols, bromophenols, polysaccharides, and terpenoids are among the chemically diverse antibiotics that certain microalgae can create. Additionally, microalgae produce a number of neurotoxic and hepatotoxic compounds. The pharmaceutical industry may find application for these compounds (Metting, 1996). Toxins that are valuable in the pharmaceutical industry are produced by a variety of blue-green microalgae, including Prymnesium parvum and Ochromonas sp. The three most widely used microalgae species for human supplementation are Scenedesmus, Spirulina, and Chlorella. Microalgae increases immunological response, weight control, skin, fertility and coat lustre. However, prolonged use at high doses, particularly when using cyanobacteria, could be detrimental (Spolaore et al., 2006).

i. Antimicrobial agents

Microalgae produce a variety of antibacterial chemicals, including volatile halogenated hydrocarbons, phenols, fatty acids, terpenes, acetogenins, and indoles. Chaetoceros muelleri produces supercritical extracts with antibacterial properties because of its lipid content. A number of extracts with antimicrobial properties are produced by Dunaliella salina, including fatty acids, ionone, cyclocitral, neophytadiene, and phytol. Extracts from microalgal cells are being investigated as food and feed additives to replace the synthetic antibacterial chemicals now in use. They serve as sub-therapeutic dosages of antibiotics used in prophylaxis in animal breeding. Large photobioreactors that can generate biomass and metabolites at high enough levels and under aseptic conditions may be the only way to carry out this procedure. Because some bacterial and viral strains might develop resistance as a result of improper

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antibiotic use, especially when working with cattle, and because domestic Plant Science consumers who self-prescribe can also contribute to this issue (Adeola *et al*., 2024). Therefore, it is necessary to use new technologies that won't create viral pools, and microalgae appear to be a viable source of antiviral medicines in this regard. Viruses proliferate in three phases, however antiviral activity often happens at one or more of these stages: Adsorption and cell invasion comprise Stage I; the cell is compelled to produce many copies of the virus during Stage II, also known as the eclipse phase; and the virus matures and releases its particles during Stage III. At stage II, the antiviral drug acyclovir has anti-HSV activity, while at stage I, the anti-HSV component of the microalgae *Dunaliella sp*. deactivates the viral activity. Because of their wide range of antiviral activity against viruses like HIV-1 and HSV, sulphated exopolysaccharides from marine microalgae are thought to interfere with Stage I of several enveloped viruses. By interacting with the virus's or the cell surface's positive charges, they stop the virus from entering host cells. Furthermore, by specifically inhibiting reverse transcriptase in the case of HIV, they prevent the production of new virus particles following infection.

Some substances, such as polyunsaturated aldehydes produced by diatoms (microalgae), such as Thalassiosira rotula and S. costatum, have strong antibacterial properties. 292 Science of Plants *Pseudomonas aeruginosa*, MRSA, *Haemophilus influenza*, *E. coli*, *Staphylococcus aureus*, and *Staphylococcus epidermidis* are among the major human pathogens that decadienal, which is derived from polyunsaturated arachidonic acid (C20:4 n-3), exhibits high activity against (MIC values of 7.8 and 1.9 µg/mL, respectively).

ii. Antioxidants

Amino acid oxidase, glycolate oxidase, and urate oxidase assist microalgae in performing certain enzymatic functions. They generate hydrogen peroxide through these enzymatic activities as well as other metabolic processes such as respiration, photosynthesis, and photorespiration. This is accomplished by the enzyme Superoxide Dismutase (SOD) converting superoxide (O2-), which is created when an electron is transferred from ferredoxin of photosystem I (PSI) to O2 (Mehler reaction). Antioxidants shield our skin from UV rays, claim Barsanti and Gualteri (2018). Green microalgae like Chlorophyceae and red microalgae like Rhodophyta have high antioxidant levels, which makes them potentially useful for human health.

Also found in some microalgae is astaxanthin, a naturally occurring keto-carotenoid with remarkable antioxidant properties. It is 1000 times more efficient than vitamin E, 200 times stronger than tea polyphenols, and 17 times more potent than grape seeds, according to Han et al., (2020). It also contains ten times the effectiveness of other carotenoids like lutein, canthaxanthin, β-carotene, and zeaxanthin. The anti-oxidant, anti-aging, anti-inflammatory, and anti-atherosclerotic qualities of natural astaxanthin are numerous. Several human pharmaceutical treatments contain it as an active ingredient (Farruggia et al., 2018), and livestock feed contains it as a nutritional supplement (Rahman et al., 2017). Natural astaxanthin is the market leader, despite the fact that it can be generated artificially (Fang et al., 2019). The bacteria that produce astaxanthin are *Tetraselmis sp., Scenedesmus sp*., *Haematococcus pluvialis, Chlorella zofingiensis, and Chlorella sorokiniana.* However, some adverse effects, including liver damage and carcinogenesis, may be caused by these antioxidants.

Antimicrobial Activity of Microalgae

Because they naturally produce antifungal, antibacterial, antibacterial, and antiprotozoal chemicals, a variety of microalga extracts and extracellular products have antimicrobial qualities. Both agriculture and the creation of new antibiotics can benefit from the use of these antimicrobial compounds. Tolypothrixtji panensis produces indole (2,3-a) carbazoles that are similar to those produced by slime molds and actinomycetes, with the exception of the pyrrole 3,4-c ring (Bonjouklian et al., 1991). Without controlling the environment, microalgae toxins can be involved. For instance, Fischerella muscicola releases fischerellinis (Gross et al., 1991), Oscillatoria species, and the algaecide Scytonema hofmanni (Fernández et al., 2003). generates an extracellular substance that is unknown (Chauhan et al., 1992). They can all be applied to lessen algae blooms.

Cyanobacteria also have herbicidal properties. The microalga cell possesses antibacterial qualities against both gram-positive and gram-negative bacteria, as was previously described. Dinoflagellates, green algae, and diatoms also possess antifungal properties. Pharmaceutical products contain microalga toxins made by Ochromonas species, blue-green algae, and Prymnesium parvum (Katircioglu et al., 2006).

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Anti-Cancer Activity of Microalgae

Bioactive chemicals found in microalgae have anticancer properties. Anticancer properties of cyanobacteria are isolated from various environments. *Poteriochromonas malhamensis*, for example, creates a chlorosulfonic lipid that suppresses tyrosine kinase function. Similarly, cyanobacteria produce anti-cancer bioactive chemicals; these chemicals induce apoptosis or alter cell signaling by activating protein-kinase C group signaling enzymes (Sithranga & Kathiresan, 2010). *Scytonema-pseudohofmanni* produces scytophycins, polyketide-derived macrolides that suppress various mammalian cells, especially epidermoid carcinoma cell lines. These chemicals can protect against lung cancer and lymphocytic leukemia if injected intra-peritoneally. *Scytonemapseudo-hofmanni*is known to produce anticancer toyocamycin, tubericidin and Scytophycin while *Nostoc* (ATCC 53789), an alga that produce cryptophytes which is a compound that is efficient at killing cancer cells (Schwartz *et al*., 1990).

Future Perspective

The biotechnology industry is expanding rapidly, and the future appears bright given the pace of research developments, especially in the fields of biomass harvesting technologies, growth bioreactor designs, and genetic modification of superior microalgal strains. The complete economic feasibility of algae-based biodiesel is still hampered by low biomass and lipid productivity (Kwak et al., 2016).

Using a high-value co-product strategy can make the synthesis of microalgae biofuel more economical. Future developments in microalgal production and market conditions for biofuel technologies could increase the economic viability of biofuels (Stephens et al., 2010). Biofuel is often produced from microalgal lipids. The production of valuable products, such as proteins, carbohydrates, and polyunsaturated fatty acids, from microalgae-based biomass, on the other hand, can be processed for a number of purposes (Lammens et al., 2012). Thus, microalgae constitute an important source of bio-based chemicals and biofuels. It is necessary to address the problems that algal bio-refinery technology encounters. Among the most important problems are high installation and operating costs. Major challenges include maintaining cultural control, bacterial contamination of the media, uneven light supply, unfavorable weather, and isolating or choosing strains of cyanobacteria and microalgae that can grow readily throughout the growth media based on desired products and survive heat stress. Utilizing an effective and economical microalgae growth system can increase biomass production, and selecting the right culture media can increase the required product output (Chen et al., 2011).

Conclusion

Microalgae are effective primary producers that may create a variety of complex substances for use in pharmaceutical and biological applications, including carotenoids, polyunsaturated fatty acids, and penicillin binding proteins (PUFAs, PBPs). Large-scale applications of microalgae are not feasible until their biomass yield is increased or integrated with other technologies. Because of their special qualities, microalgae can be used as a substitute feedstock in a variety of biorefinery applications. Because of their unique qualities, microalgae can be applied in both industrial and environmental settings. Products made from microalgae include fertilizer, medications, cosmetics, and feed for animals and aquaculture.

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