BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, March 2023. Vol. **20**(1), p. 35-43

Review on Microalgae Potential Innovative Biotechnological Applications

Kelemu Mulluye[1]*, Yibrehu Bogale[2], Dilnesa Bayle[3] and Yimeslal Atnafu[4]

[1]Department of Biotechnology (ULMD) Haramaya University Ethiopia.
[2]Department of Chemistry, Haramaya University, Ethiopia.
[3]School of Natural Resources Management and Environmental Sciences, Haramaya University, Ethiopia.
[4]School of Biological Sciences and Biotechnology, Haramaya University, Ethiopia.

http://dx.doi.org/10.13005/bbra/3066

(Received: 17 December 2022; accepted: 30 February 2023)

Novel compounds can be found in marine creatures, many of which have amazing biotechnological capabilities. Microalgae, in particular, have a drawn interest as a potential basis for new industrial creation routes. Many biologically active compounds, such as antioxidants, immunostimulants, antivirals, antibiotics, hem agglutinates, polyunsaturated fatty acids, peptides, proteins, biofuels, and pigments, are derived from these species. Recently, there has been a rise in interest in microalgal biotechnology to create beneficial, sustainable, and ecologically friendly bioproducts. Microalgae biomass is in high demand for a wide range of potential uses, most of which are now the subject of ongoing research. Microalgae are important groups of photosynthetic organisms that use light and carbon dioxide more efficiently than terrestrial plants to produce biomass and use it for biotechnological purposes such as environmental protection, biofuel production, pharmaceutical production, human food supplements, animal feed components, coronavirus treatments, and so on. This paper presents an overview of current advancements in the application of microalgal biotechnology in several industries.

Keywords: Biomass; Microalgae; Microalgae biotechnology; Unicellular photosynthetic.

A diverse group of creatures, algae range widely in size, shape, and chemical makeup. They can be colonial, filamentous, branching, leafy, unicellular, or multicellular, and contain both microalgae and macroscopic algae (macroscopic). Microalgae can group to form colonies and filaments that are observable at a macro scale[1]. Giant kelp, or the macroalgae species *Macrocystis pyrifera*, may grow to a length of 60 meters [2], whereas *Chlorella*, a freshwater or soil-dwelling microalga, contains spherical cells with a diameter ranging from 2 to 10 meters and lives in water or the soil [3]. With a few examples of mixotrophic and heterotrophic organisms, most microalgae species are autotrophic. Unlike terrestrial plants, microalgae lack the same mechanism for cell differentiation and specialization [4]. Chlorophyll is the principal pigment used by all photosynthetic algae to capture energy (primary producer). Carotenoids and phycobilins, two more types of accessory pigments, may also exist.

Recently, interest in algae biotechnology, which is the technological use of algae (both

*Corresponding author E-mail: kelemumuluye@gmail.com

macroalgae and microalgae) or their derivatives for different purposes, has been increasing. This, using microalgae for vast applications got the highest priority, since microalgae are photosynthetic microorganisms that can easily produce biomass in water bodies using sunlight, CO_2, and different nutrients. This biomass contains crucial primary metabolites like sugars, oils, and lipids. These valuable compositions of microalgae can be processed to create high-value substances and goods, which make them, have many applications. For instance, they have great applications in alternative energy sources such as transportation fuels, industry, health sectors like the recent COVID-19 treatment and other diseases, aquaculture, the removal of various toxins from the environment, and pharmaceuticals. Due to the wide variety and scope of prospective applications, the study of microalgae is a relatively new and quickly expanding research subject. This is reflected in the amount of current research and its growing evolution.

Based on this, this study combines the most recent data on microalgal biotechnology applications across a range of industries, and it will be useful in informing decisions that must be taken in the future to maintain the success of microalgae research.

Biotechnological Applications of Microalgae in Various Sectors

Environmental

The recovery of contaminated streams and air is being done using microalgae. It is being used to take advantage of the ability of various microalgae species to absorb CO_2 from the atmosphere and remove a variety of contaminants from various water-based effluent flows, such as those from industrial processes, biological reactors, agricultural run-off, and many more [5]. It has been discovered that microalgae may provide remedies to a variety of issues brought on by human economic activities.

Utilizing organisms singly or in combination to reduce the amount of contaminants carried by effluent flows from any productive activity is known as bioremediation (including aquaculture). This method makes use of those organisms' natural or altered capacities to minimize and/or change waste products [6].

Water and air pollution are two aspects of a huge problem that humanity is currently experiencing and is anticipated to continue getting worse. The inability of current natural systems to slow the increase in carbon dioxide concentrations in the atmosphere, oceans, and seawater is causing significant changes in the global carbon cycle. Microalgae have become an interesting scientific and technological option for absorbing the CO_2 in the atmosphere that is caused by emissions from several sources.

Industrial wastewater poses entirely distinct issues because the toxicity and content of the water, as well as the resistance of the chosen microalgae species, will vary greatly. The ability of the microalgae to assimilate or decompose the pollutants contained in the wastewater determines how well they can remove the toxins [7].

Food Production

Microalgae can create meals with a balanced nutritional profile that are abundant in proteins, carbs, fatty acids, and other ingredients that are highly wanted in the diet of humans. The numerous species of microalgae can be explored through species bioprospecting, underlining the importance of native organisms and their potential biotechnological applications. Due to its naturally intrinsic characteristics, microalgae may one day be utilized in the food production chain. It has been a staple of the human diet for a very long time. Variants of Nostoc and Spirulina were utilized as food before 1900 [8].

Even the rheology of the new food products is influenced by microalgal biomass: *Arthrospira platensis* and *Chlorella Vulgaris* were tested in 3D-printed cookies, resulting in stable structures and baking resistance [9]. The bread had microalgae added to it, but other textural qualities like chewability and hardness were unaltered. Even though microalgae are natural sources of color and can be used as a food additive, the effects were largely seen in the color change of the crust and crumbs into greener or yellowish tones. [10].

The complete production process, including shelf life, must be planned for the food item. A chocolate bar that had been enhanced with the lyophilized and capsuled microalga *Scenedesmus obliquus* showed oxidative stability and low peroxide levels. [11]. After 28 days of storage, yogurt with 0.25 percent spirulina held more water and interacted less with whey [12]. Adding spirulina-LEB-18 to chocolate milk improved the sedimentation rate, hygroscopicity (by around 10%), and solubility.[13].

Utility Manufacturing

The fight to move away from fossil fuels emphasizes the necessity to cut back on the consumption of plastics made by petrochemical processes. Significant environmental issues occur as a result of the buildup of plastic in landfills and marine habitats, which puts pressure on the already-stressed market conditions [14]. Then, especially in the packaging sector, these concerns lead to regional, national, and worldwide activities. As an alternative to petrochemicals, bio-based polymers with the ability to break down through biodegradation can be offered. These can be classified as renewable because they are produced using natural resources that are also renewable, biodegradable but based on petroleum, or a combination of the two. [15]. It would be possible to directly harvest CO_2 from the atmosphere by using microalgae to create bioplastic.

There are many approaches to converting microalgae into bioplastics, including using biomass directly as bioplastic, combining it with petroleum polymers, transitional processing in biorefineries, and genetic engineering techniques to establish strains that produce bioplastics[14].

Aquaculture

The production of omega-3 polyunsaturated fatty acids is proof that microalgae are used as dietary supplements for both humans and animals. [16]. The most popular species among the ones under investigation are those belonging to the genera *Chlorella, Tetraselmis, Isochrysis, Pavlova, Phaeodactylum, Chaetoceros, Nannochloropsis, Skeletonema, and Thalassiosira*. This is mostly due to the great nutritional value of these foods and the colors, vitamins, minerals, and antioxidant chemicals that they contain [17].

Many different microalgae genera, including *Anabaena, Nonstock, Botryococcus, Synechococcus, Chlamydomonas, Scenedesmus, Perietochloris,* and *Porphyridium*, have been used to produce essential compounds such as vitamin precursors, antioxidants, immune system boosters, and anti-inflammatory agents. Other essential compounds include beta-carotene, lutein, astaxanthin, chlorophyll, and phycobilin [18].

Pharmaceutical and Health

A wide variety of algae species and their metabolites have amazing therapeutic qualities. When microalgae biomass was incorporated into pills, powders, or water additives, its medical effects were first studied. Finding and utilizing valuable medical components in algae has become the subject of an increasing number of studies in recent years. Some of the therapeutic substances that have drawn the greatest attention include fatty acids, phycobiliproteins, polysaccharides, phenolic compounds, and carotenoids. A large variety of bioactive metabolites are produced by algae[19].

Microalgae can create bioactive compounds that are challenging to chemically synthesize, including antibiotics, subunit vaccines, monoclonal antibodies, hepatotoxic and neurotoxic chemicals, hormones, enzymes, and other compounds with pharmacological and therapeutic applications[20].

The health benefits of microalgae pigments include protection against diseases like cancer, heart disease, neurological issues, and eye disorders. Microalgae are an excellent host to produce recombinant proteins due to their distinctive properties, such as their quick growth rate and inexpensive, simple media, as well as the fact that their post-translational modifications are more similar to those of mammalian cells than bacterial cells [21].

Cosmetics and Cosmeceuticals

Any material or mixture that applies to the skin or other exposed parts, such as the lips, external sexual organs, teeth, and mucous membranes of the mouth, is referred to as a cosmetic and can clean, scent, change the way they look, protect them from damage, maintain their health, or reduce body odors [22]. Cosmetics with biologically active chemicals, known as cosmeceuticals, should provide therapeutic or drug-like effects [23]. As antioxidants, free-radical collectors, stress relievers, immune system boosters, odor maskers, makeup pigments, sunscreen protectors, and anti-aging agents, microalgae and bioactive components derived from microalgae are utilized in cosmetics. According to [24], active ingredients extracted from microalgae have a variety of effects, including the prevention of blemishes, repair of damaged skin, and improvement of seborrhea, inhibition of inflammation, speeding up the healing process, and keeping the skin hydrated.

Due to their antioxidant, moisturizing, antiaging, and anti-tanning characteristics, both micro and macro algae are widely used in cosmeceuticals. To reduce the risk of contamination, it is typically utilized as an extract in the production of skin sensitizers, sunscreens, thickening agents, anti-aging creams, hair care products, and moisturizers [25].

Covid 19 Treatment

The coronavirus disease, which is currently the world's biggest health problem and has the potential to kill hundreds of thousands of people, urgently needs effective treatments[26]. Studies have shown that acute respiratory distress syndrome, a disease associated with cytokine storm syndrome, is one of the major causes of death in COVID-19 patients. A cytokine storm produces immune system hyperactivity and acute lung damage by increasing the production of pro-inflammatory cytokines and chemokines[27].

The carotenoid astaxanthin is used medicinally for a variety of conditions and has anti-inflammatory, immunomodulatory, and antioxidant properties. Haematococcus Pluvialis is a type of microalga that naturally contains astaxanthin. Studies suggest that administering this carotenoid to COVID-19 patients could lessen the cytokine storm and prevent ARDS and ALI [26]. Specific mono- and oligosaccharides are bound by certain proteins known as lectins. It has been discovered that the lectin cyanovirin-N, which was isolated from the cyanobacterium Nostoc ellipsosporum, has antiviral activity against the Ebola, influenza, and HIV viruses.

A sulfated polysaccharide of microalgal origin called carrageenan can prevent viral attachment, transcription, and replication in host cells. A polysaccharide generated from spirulina called calcium spirulina prevents the replication of various viruses, including HIV, measles, and influenza [28].

Antimicrobial Agents

Many microalgae extracts have antiviral, antibacterial, antifungal, and antiprotozoal properties. Some examples are indoles, phenols, fatty acids, and volatile halogenated hydrocarbons. *Ochromonas* sp. and *Prymnesium parvum*, two species of blue-green algae, also produce toxins that may be used in medications [20].

Antiviral activities

Three stages are frequently present in viral infections. The virus enters the host cell and attaches itself to it in the initial stage. The virus replicates inside the host cell during the second stage. The virus then releases its particles into the nearby tissue in the third stage. Microalgal antiviral substances have an impact on viral infections at various stages. For instance, the first step is hampered by sulfated polysaccharides [29].

Antibacterial activities

At this time, antibiotic resistance is thought to be a significant barrier to treating infectious illnesses. Therefore, finding new antibiotics is crucial. In a study, numerous chlorella-derived fatty acids having antibacterial characteristics were identified. It appears that certain gram-positive and gram-negative bacteria can be killed or has their growth restricted by the free fatty acids produced by microalgae. Besides having antimicrobial properties, microalgae, and bio compounds have also shown anti-biofilm qualities, which are essential for the management of infectious diseases. For instance, dental plaque is produced by two bacteria that create a biofilm on teeth: Streptococcus mutans and Lactobacillus sp. Dental caries could be avoided by using extracts of C. Vulgaris and D. salina [29].

Bioenergy

Due to the expansion of cities following the Second Industrial Revolution, fossil fuel use skyrocketed. The combustion of these fuels produces air pollution, which can have negative health effects on the most vulnerable populations, environmental effects from SO_2, and atmospheric CO_2 emissions that contribute to the greenhouse effect. Fossil fuels are a non-renewable resource, and their unchecked use of them has encouraged several nations to invest in various forms of renewable energy, including biofuels. Crops can be used to make biofuels in the first generation, followed by residual agricultural biomass unfit for human food in the second generation, residual microalgal biomass in the third generation, and biomass from genetically engineered microalgae (fourth generation).

The globe is currently considering the development of bioenergy from algae biomass due to global warming and the depletion of biofuels. Other essential strategies to reduce poverty include expanding access and safeguarding energy. Currently, producing biofuels from algae biomass is the only way to replace the consumption and reliance on fossil fuels. Biofuels such as bio-oil, biomethane, biohydrogen, biogas, and bioethanol can all be produced from microalgal biomass.

Bio-Oil

Bio-oil is also known as pyrolysis oil or bio-crude oil. By converting biomass into oil, carbon, and gas at extremely high temperatures and in the absence of oxygen, a thermochemical conversion process yields bio-oil. Bio-oils can replace petroleum oils, even if they are partially related to them. Pyrolysis and thermochemical liquefaction are the two primary processes for making bio-oil. In contrast to algal lipids, bio-oil has a high production and collects a variety of organic substances as lipids, proteins, and carbohydrates. *Spirulina* has been claimed to produce up to 41% of the world's bio-oil, *Scenedesmus* between 24% and 45%, *Dunaliella* 37%, and *Desmodesmus* up to 49%[30].

Bio-hydrogen

An urgent energy concern has been the range of biofuel sources. The production of bio-hydrogen has drawn a lot of attention recently. However, because of the expensive process and low biomass concentration, large-scale production of bio-hydrogen is not yet practical. Numerous biological stressors, such as depriving some types of algae of light, have been proven to cause considerable volumes of hydrogen gas to be produced. However, because this technology is still in its early stages, it may develop further or be improved even further[31].

Biogas

Compared to terrestrial crops, microalgal biomass is an excellent alternative source of biogas. However, there are several difficulties associated with employing algae to make biogas[32]. The efficiency of producing biogas has increased thanks to the usage of algae in addition to conventional

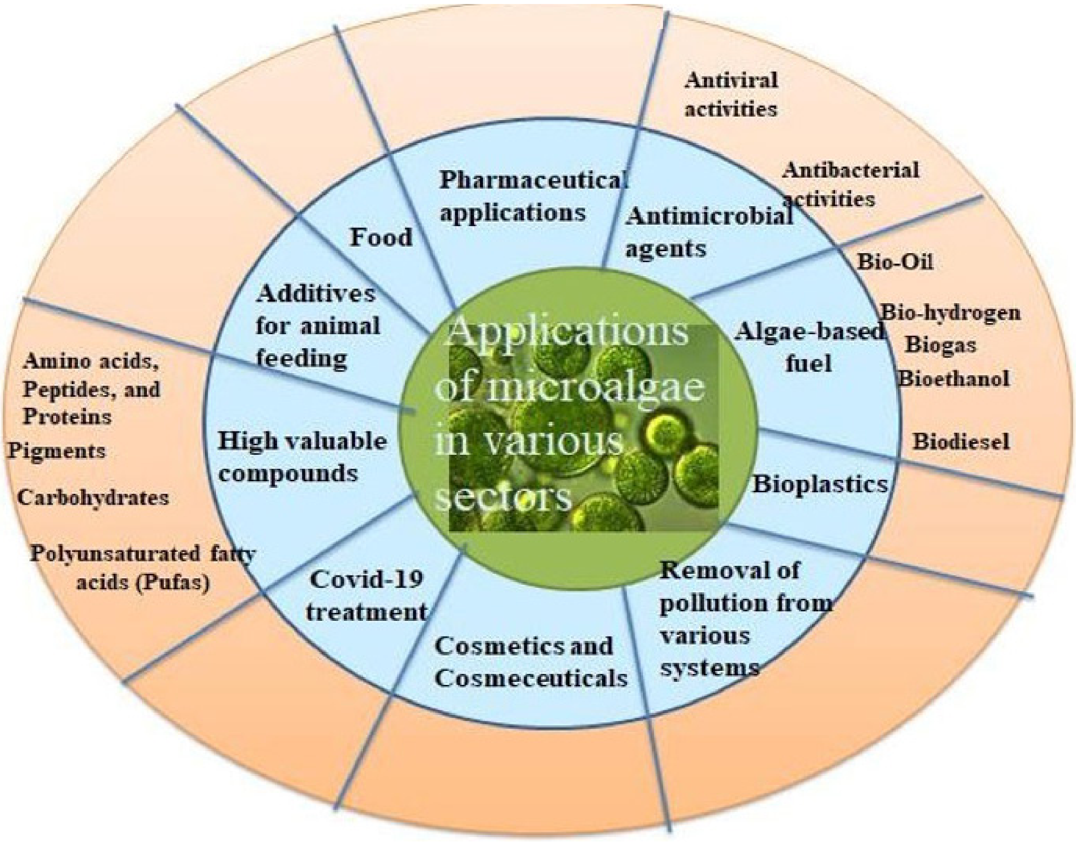

Fig. 1. Graphical abstract of the presented study

feedstocks [33]Algal-derived glucose and glycine were put through thermochemical processing in neutral, acidic, and alkaline environments to find out how they decompose and if they might be used for simultaneous bio-hydrogen and bio-methane fermentation [30].

Algal biomass has been proposed as a potential source for manufacturing bio-methane. A variety of feedstock, such as algae, wood, grass, and solid waste, has been the subject of research into the possibility of manufacturing bio-methane. Although the productivity of biomass algae is often higher than terrestrial plants, the algae's growth is impacted by a variety of nutritional limitations [30].

Bioethanol

Algal bioethanol production has become highly valuable due to these species' higher biomass output, diversity, varied chemical compositions, and improved photosynthetic rates. Because they have an abundance of carbs and polysaccharides and have thin cellulose walls, algae are the best source for the creation of bioethanol. Microalgae include a large proportion of polysaccharides like starch and cellulose as their source of carbohydrates. Microalgae are a preferred source of raw materials for the fermentation of bioethanol due to the high amounts of polysaccharides that can collect in their complex multilayered cell walls[32].

Brown algae are a significant feedstock for ethanol generation among many algae. Because they are simple to grow and have great carbohydrate content, they can be fermented into ethanol. Acid hydrolysis agar has also been showed to convert red algae fermentation into sugars; however, the maximal theoretical yield of up to 45 percent was only met with low ethanol yields. Depending on the kinds of algae utilized, as well as the varied pre-treatment and hydrolysis processes, between 0.08 and 0.12 kg of ethanol are produced from the fermentation of one kilogram of dried seaweed. Algal bioethanol overcomes the main limitations of first-generation (from food crops such as maize, rice, or sugarcane) and second-generation bioethanol [34].

Biodiesel

The cost of producing biodiesel, which accounts for 50% to 85% of the price of fuel overall, depends heavily on the type of raw material used. To generate cost-effective biodiesel, evaluation of the feedstock's efficacy, purity, and possibility for by-product utilization is essential. Transesterification is turning lipids from raw materials, basically triacylglycerol and free fatty acids, into biodiesel that is safe for the environment and non-toxic.

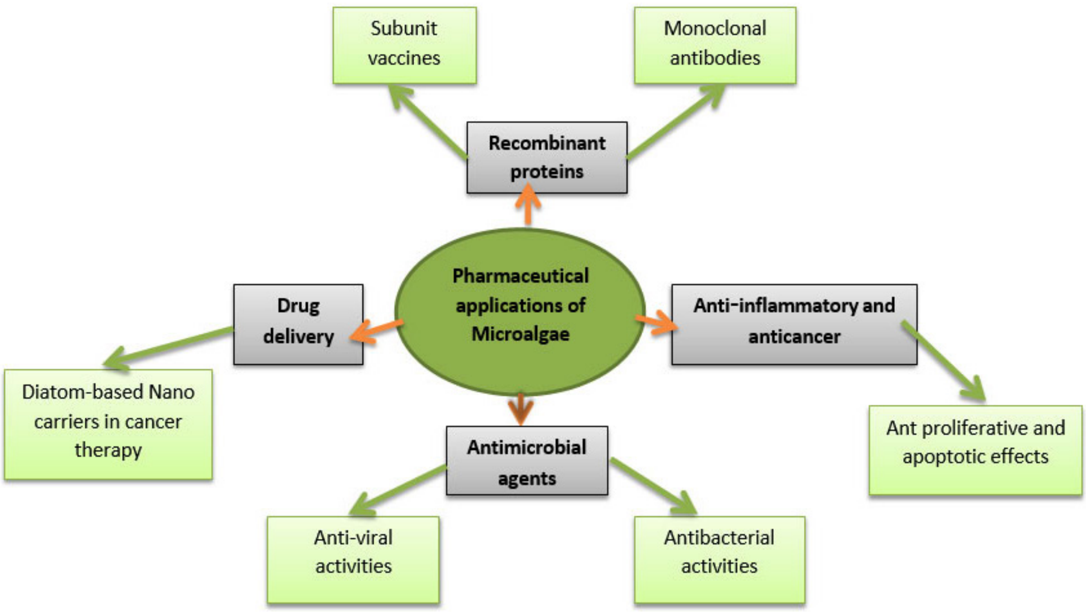

Fig. 2. Pharmaceutical applications of Microalgae

Sector	Stages First stage	Second stage	Third stage
Bioenergy	Bio prospecting of biofuels	Optimization of the production process	Use of biocatalysts, or new routes of biofuels production
Health care, therapeutics	Bioprospecting of health care compounds	Protein recombinant technology	Clinical assays for biomedical purposes
Environment	Biodegradation and biotransformation assays	Selection of phycoremediation or wastewater treatmentprocess	On-site applications in which an integra ted process has been developed
Aquaculture	Selection of strains and evaluation for specific fish or crustacean aquaculture	Balanced diets design	Feed additive production and implementation inaquaculture farms
Cosmetics	Bioprospecting of natural products from microalgae	Skin applications	Medical care supplements for skinapplications
Foods	Natural products	Probiotics	Food supplements

High-viscosity crude algal oil is transformed into fatty acid alkyl esters, which have a lower molecular weight. Essentially, during the transesterification process, crude oil and alcohol combine in the presence of a catalyst; ideally, methanol and methyl esters of fatty acids are formed as a byproduct along with glycerol. Two important species, *Chlorella* Vulgaris and *Chlorella protothecoides* have been studied to produce biodiesel because of their higher oil content [35]. The main component of microalgal biodiesel is unsaturated fatty acids. The algal biomass from wastewater contains a variety of different algae, and as a result, various fatty acid profiles can be produced.

Development Stage of Microalgal Biotechnology Applications

Table 1 covers the numerous fields that are using microalgal biotechnology, such as bioenergy, health care (bioactive phenolic compounds), environmental applications (CO_2 capture, sustainable production from waste material), aquaculture, and raw materials for balanced feed. [36-37]. as stated by [38,] Microalgal biomass's protein, lipids, ash, amino acids, and carbohydrate composition give cosmetic formulations suitable functional properties like wetness, toughness, hardness, and skin protection. microalgal biotechnology can be divided into three stages of development depending on the application area: the first stage, which can be thought of as lasting between two and five years; the second stage, which can be thought of as lasting between three and five years; and the third stage, which can be thought of as lasting seven years or longer and involves developments whose applications are anticipated to have technological aplomb at the industrial level. Advancements in the various application areas are used to measure the amount of time it takes for each stage to be completed before the next.

CONCLUSIONS

The variety of products that algae biomass can produce have led to the development of microalgal biotechnology. In light of the uncertain future that lies ahead due to both a lack of food and energy and climate change, microalgal biomass has been researched as a potential solution to the difficulties that are now becoming apparent. A variety of photosynthetic organisms known as microalgae can remove CO_2 from the atmosphere and add new oxygen to it. Depending on the controlled environment, it can absorb various contaminants for its metabolic processes and produce a range of secondary metabolites as a result. Microalgae are already used as a bioreactor for yielding bioproducts such as pharmaceuticals, cosmeceuticals, cosmetics, food, and other significant added products like antimicrobial agents and feed aquaculture, among other things. In addition, many efforts are currently being made to make microalgae active for the production of bioenergy. Some microalgal-based methods also meet the criteria for application in COVID-19 treatment, biodegradation, bioconversion, bioremediation, or the removal of other pollution-related effects.

REFERENCES

1. Konur, O. ed., 2020. Handbook of Algal Science, Technology and Medicine. Academic Press.
2. Britannica, E., 2021. Available online: https:// www. britannica. com/science. Geophone (accessed on 10 March 2021).
3. Klamczynska, B. and Mooney, W.D., 2017. Heterotrophic microalgae: a scalable and sustainable protein source. Sustainable protein sources (pp. 327-339). Academic Press.
4. Patel, A.K., Singhania, R.R., Dong, C.D., Obulisami, P.K. and Sim, S.J., 2021. Mixotrophic biorefinery: A promising algal platform for sustainable biofuels and high value coproducts. Renewable Sustainable Energy Rev. 152, p.111669.
5. Vanhoudt, N., Vandenhove, H., Leys, N. and Janssen, P., 2018. Potential of higher plants, algae, and cyanobacteria for remediation of radioactively contaminated waters. Chemosphere. 207, pp.239-254.
6. Martinez-Porchas, M. and Martinez-Cordova, L.R., 2012. World aquaculture: environmental impacts and troubleshooting alternatives. Sci. World J. 2012.
7. Xiong, J.Q., Kurade, M.B. and Jeon, B.H., 2018. Can microalgae remove pharmaceutical contaminants from water? Trends Biotechnol. 36(1), pp.30-44.
8. Borowitzka, M.A., 2018. Microalgae in medicine and human health: A historical perspective. Microalgae Health Dis. Prev. (pp. 195-210). Academic Press.
9. Uribe-Wandurraga, Z.N., Igual, M., Reino-Moyón, J., García-Segovia, P. and Martínez-Monzó, J., 2021. Effect of microalgae (Arthrospira platensis and Chlorella vulgaris) addition on 3D printed cookies. *Recent Adv. Food Sci.* 16(1), pp.27-39.
10. García-Segovia, P., Pagán-Moreno, M.J., Lara, I.F. and Martínez-Monzó, J., 2017. Effect of microalgae incorporation on physicochemical and textural properties in wheat bread formulation. Food Sci. Technol. Res. *23*(5), pp.437-447.
11. Hlaing, S.A.A., Sadiq, M.B. and Anal, A.K., 2020. Enhanced yield of Scenedesmus obliquus biomacromolecules through medium optimization and development of microalgae based functional chocolate. J. Food Sci. Technol. 57(3), pp.1090-1099.
12. Barkallah, M., Dammak, M., Louati, I., Hentati, F., Hadrich, B., Mechichi, T., Ayadi, M.A., Fendri, I., Attia, H. and Abdelkafi, S., 2017. Effect of Spirulina platensis fortification on physicochemical, textural, antioxidant and sensory properties of yogurt during fermentation and storage. *LWT*. *84*, pp.323-330.
13. De Oliveira, T.T.B., dos Reis, I.M., de Souza, M.B., da Silva Bispo, E., Maciel, L.F., Druzian, J.I., Tavares, P.P.L.G., de Oliveira Cerqueira, A., Morte, E.D.S.B., Glória, M.B.A. and Deus, V.L., 2021. Microencapsulation of Spirulina sp. LEB-18 and its incorporation in chocolate milk: Properties and functional potential. LWT. 148, p.111674.
14. Rahman, A. and Miller, C.D., 2017. Microalgae as a source of bioplastics. Algal Green Chem. (pp. 121-138). Elsevier.
15. Reddy, M.M., Vivekanandhan, S., Misra, M., Bhatia, S.K. and Mohanty, A.K., 2013. Biobased plastics and bionanocomposites: Current status and future opportunities. Prog. Polym. Sci. 38(10-11), pp.1653-1689.
16. Liu, J., Sun, Z. and Gerken, H., 2015. Recent advances in microalgal biotechnology. Potential applications of microalgae in wastewater treatments. Published by OMICS Group eBooks, USA, Chapter.
17. Liang, S., Liu, X., Chen, F. and Chen, Z., 2004. Current microalgal health food R & D activities in China. Asian pacific phycology in the 21st century: Prospects and challenges (pp. 45-48). Springer, Dordrecht.
18. Bishop, W.M. and Zubeck, H.M., 2012. Evaluation of microalgae for use as nutraceuticals and nutritional supplements. J. Nutr. Food Sci. 2(5), pp.1-6.
19. Maheswari, M.U., Reena, A. and Sivaraj, C., 2017. GC-MS analysis, antioxidant and antibacterial activity of the brown algae, Padina tetrastromatica. Int. J. Pharm. Sci. Res. 8(9), pp.4014-4020.

20. Rizwan, M., Mujtaba, G., Memon, S.A., Lee, K. and Rashid, N., 2018. Exploring the potential of microalgae for new biotechnology applications and beyond: a review. Renewable Sustainable Energy Rev. *92*, pp.394-404.
21. Ramana, K., Xavier, J. and Sharma, R., 2017. Recent trends in pharmaceutical biotechnology Pharm Biotechnol Curr Res. 1(1), p.5.
22. Koller, M., Muhr, A. and Braunegg, G., 2014. Microalgae as versatile cellular factories for valued products. Algal Res. 6, pp.52-63.
23. Letsiou, S., Kalliampakou, K., Gardikis, K., Mantecon, L., Infante, C., Chatzikonstantinou, M., Labrou, N.E. and Flemetakis, E., 2017. Skin protective effects of Nannochloropsis gaditana extract on H2O2-stressed human dermal fibroblasts. Front. Mar. Sci. 4, p.221.
24. Teuling, E., Schrama, J.W., Gruppen, H. and Wierenga, P.A., 2019. Characterizing emulsion properties of microalgal and cyanobacterial protein isolates. Algal Res.39, p.101471.
25. Joshi, S., Kumari, R. and Upasani, V.N., 2018. Applications of algae in cosmetics: An overview. Int. J. Innov. Res. Sci. Eng. Technol, 7(2), p.1269.
26. Talukdar, J., Dasgupta, S., Nagle, V. and Bhadra, B., 2020. COVID-19: Potential of microalgae derived natural astaxanthin as adjunctive supplement in alleviating cytokine storm. Available at SSRN 3579738.
27. Yang, X., Yu, Y., Xu, J., Shu, H., Liu, H., Wu, Y., Zhang, L., Yu, Z., Fang, M., Yu, T. and Wang, Y., 2020. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. Lancet Respir. Med. 8(5), pp.475-481.
28. Singh, S., Dwivedi, V., Sanyal, D. and Dasgupta, S., 2020. Therapeutic and nutritional potential of Spirulina in combating COVID-19 infection. AIJR Preprints, 49(1), pp.2-8.
29. Mostafa, S.S., 2012. Microalgal biotechnology: prospects and applications. Plant Sci. 12, pp.276-314.
30. Chen, H., Wang, X. and Wang, Q., 2020. Microalgal biofuels in China: The past, progress and prospects. Gcb Bioenergy. 12(12), pp.1044-1065.
31. Saifuddin, N. and Priatharsini, P., 2016. Developments in bio-hydrogen production from algae: a review. Res. J. Appl. Sci., Eng. Technol. 12(9), pp.968-982.
32. Giordano, M. and Wang, Q., 2018. Microalgae for industrial purposes. Biomass and Green Chemistry, pp.133-167.
33. Miao, H., Wang, S., Zhao, M., Huang, Z., Ren, H., Yan, Q. and Ruan, W., 2014. Codigestion of Taihu blue algae with swine manure for biogas production. Energy Convers. Manage. *77*, pp.643-649.
34. Chen, H., Zhang, Y., He, C. and Wang, Q., 2014. Ca2+ signal transduction related to neutral lipid synthesis in an oil-producing green alga Chlorella sp. C2. Plant Cell Physiol. 55(3), pp.634-644.
35. Sharma, P.; Sharma, N., 2017. Industrial and Biotechnological Applications of Algae: A Review. Journal of Advances in Plant Biology, 1, pp.1-25
36. Madeira, M.S., Cardoso, C., Lopes, P.A., Coelho, D., Afonso, C., Bandarra, N.M. and Prates, J.A., 2017. Microalgae as feed ingredients for livestock production and meat quality: A review. Livest. Sci. 205, pp.111-121.
37. Kapoor, S., Singh, M., Srivastava, A., Chavali, M., Chandrasekhar, K. and Verma, P., 2021. Extraction and characterization of microalgae derived phenolics for pharmaceutical applications: A systematic review. J. Basic Microbiol.
38. Tibbetts, S.M., MacPherson, T., McGinn, P.J. and Fredeen, A.H., 2016. In vitro digestion of microalgal biomass from freshwater species isolated in Alberta, Canada for monogastric and ruminant animal feed applications. Algal Res. 19, pp.324-332.