ISBN: 978-93-48091-57-4

7. Algae: Exploring Its Nutraceutical Potential and Products

Pratibha, Nitesh Kumar

Department of Biosciences,
Himachal Pradesh University,
Summer Hill Shimla.

Sushila Devi, Sanya Chauhan, Neha

Department of Microbiology,
Himachal Pradesh University,
Summer Hill Shimla.

Abstract:

Algae, encompassing both microalgae and macroalgae, are emerging as a remarkable resource in the nutraceutical industry due to their exceptional Nutritional and biological attributes. Algae, which are high in proteins, vital fatty acids, vitamins, minerals, and antioxidants, have gained popularity due to their ability to improve health and prevent disease.

Substances like these polysaccharides, phycobiliproteins, and omega-3 fatty acids further underscore algae's therapeutic value, offering anti-inflammatory, anti-cancer, and detoxifying benefits.

Historically used in traditional diets and medicine, algae are now at the forefront of modern innovation, featured in products ranging from dietary supplements and functional foods to skincare solutions.

Their sustainability and ability to thrive in diverse environments with minimal resources make them an eco-friendly alternative to conventional nutrient sources. This article explores the vast nutraceutical potential of algae, examining their health benefits, applications in disease prevention, and the diverse range of innovative products derived from them, highlighting their role as a key component in the future of health and wellness.

Keywords:

Algae, Anti-cancer, Nutraceutical, Products, Therapeutic.

7.1 Introduction:

Algae, often seen as simple aquatic plants, are rapidly gaining recognition as a powerhouse of nutrition and health benefits (Yadav et al., 2021). These ancient organisms, which thrive in a variety of aquatic environments, from oceans to freshwater lakes, are rich in a remarkable array of nutrients and bioactive compounds (Mironiuk & Chojnacka, 2018; Naik et al., 2024). For centuries, algae have been used in traditional diets and medicine, especially in Asian cultures, where seaweeds like nori, kelp, and wakame have long been valued for their health-boosting properties (Anwar et al., 2018; Sun et al., 2022). However, in recent years, the scientific community has begun to explore the untapped potential of algae, particularly microalgae and macroalgae, in the burgeoning field of nutraceuticals (Rao et al., 2021). Nutraceuticals are natural products that provide health benefits beyond basic nutrition, offering a preventative or therapeutic effect on diseases (Rao et al., 2021). Algae have become prominent in this area thanks to their remarkable nutritional content. They are packed with essential amino acids, proteins, vitamins (A, B, C, D, E, and K), minerals such as iron, calcium, and magnesium, as well as antioxidants (Ahmed et al., 2024; Kesharwani et al., 2025). Notably, algae are one of the few plant-based sources of omega-3 fatty acids, such as DHA and EPA, which are critical for brain health, cardiovascular function, and reducing inflammation (Saini et al., 2021). Beyond their role as a nutrient source, algae contain unique compounds like polysaccharides, phycobiliproteins, and bioactive peptides, which have been shown to have antimicrobial, anti-inflammatory, and anti-cancer properties (Ahmed et al., 2024; Ghosh et al., 2022). These compounds make algae not only an essential addition to a healthy diet but also a promising candidate in the development of new therapeutics (Alves et al., 2018). Furthermore, certain algae, such as *Spirulina* and *Chlorella*, are known for their detoxifying effects, helping to eliminate heavy metals and toxins from the body (Narula et al., 2015). Incorporating algae into modern products is becoming increasingly popular. Today, algae-based supplements, functional foods, and beverages are widely available, offering consumers an easy way to harness the health benefits of these natural organisms (Sharma & Sharma, 2017). From algae-based protein powders and energy bars to algae-infused oils and skincare products, the applications are vast. Moreover, algae are being explored as a sustainable source of nutrients, offering an eco-friendly alternative to traditional agricultural practices (Samoraj et al., 2024). Their ability to grow in diverse conditions with minimal resources makes them a promising solution to address global challenges like food security and climate change (Zou et al., 2021). This exploration will dive into the vast potential of algae as a

nutraceutical powerhouse, examining their nutritional benefits, their role in disease prevention and health maintenance, and the innovative products derived from algae that are shaping the future of health and wellness (ElFar et al., 2021). The use of algae dates back centuries and spans various cultures: In Asian diets, seaweeds like nori and kombu have been staples, celebrated for their nutrient density and medicinal properties. In Mesoamerica, the Aztecs harvested *Spirulina* from lakes, using it as a protein-rich food source. Traditional medicine systems such as Ayurveda and Chinese medicine recognize algae for their detoxifying and vitality-enhancing properties (Jacquier et al., 2024). By unlocking the full potential of algae, we can harness nature's hidden treasures to promote better health, reduce our environmental footprint, and pave the way for a more sustainable future (Mallik et al., 2024). This chapter explores algae's immense potential as a nutraceutical powerhouse (Osuala & Ezemba, 2022). It delves into their nutritional composition, health benefits, and innovative applications in products ranging from supplements to functional foods (Vlaicu et al., 2023). Additionally, it highlights algae's role in sustainable health solutions, emphasizing their environmental benefits and low ecological footprint (Osuala & Ezemba, 2022).

This chapter aims to inspire further research, innovation, and integration of algae into mainstream nutraceutical and dietary practices by uncovering the science behind algae's contributions to health and wellness.

7.2 Nutritional Composition of Algae:

Algae are celebrated for their rich and diverse nutritional profile, making them a valuable resource for human health. As a macronutrient source, certain algae, such as *Spirulina* and *Chlorella*, boast exceptionally significant amounts of protein, with some species having as much as 70% protein by dry weight (Mišurcová et al., 2012). These proteins are complemented by all essential amino acids, making algae a complete protein source ideal for both vegetarians and non-vegetarians. Algae are also a rare plant-based source of healthy fats, particularly long-chain omega-3 fatty acids like DHA (docosahexaenoic acid) and EPA (eicosapentaenoic acid), which are essential for brain health, cardiovascular function, and inflammation control (Saini et al., 2021). In terms of micronutrients, algae are rich in vitamins and minerals that contribute to overall well-being. They contain vitamins A, C, D, E, and K, as well as B-complex vitamins, including B12, which is crucial for vegetarians (Fekete et al., 2023). These vitamins support immune function, bone health, skin vitality, and energy metabolism. Algae are also an excellent source of minerals such as iron, magnesium, calcium, and iodine, which are vital for red blood cell production,

muscle function, strong bones, and thyroid health (Motshekga et al., 2023). Beyond their basic nutritional components, algae are a powerhouse of bioactive compounds. Polysaccharides found in algae, such as alginate and carrageenan, provide anti-inflammatory and immune-modulating benefits (Mata et al., 2010). Phycobiliproteins, particularly from *Spirulina*, exhibit antioxidant and potential anti-cancer properties. Carotenoids, including astaxanthin from microalgae and fucoxanthin from brown algae, are potent antioxidants that protect cells from oxidative stress and promote overall health (Ferdous & Yusof, 2021). These antioxidants serve an important role in neutralising free radicals, lowering the risk of chronic diseases, promoting cellular health, and slowing the ageing process (Valko et al., 2007). By combining high-quality macronutrients, essential micronutrients, and unique bioactive compounds, algae stand out as a complete and functional food source with immense potential to enhance health and wellness (Wu et al., 2023).

7.3 Health Benefits of Algae as Nutraceuticals

Algae offer an impressive array of health benefits, positioning them as a cornerstone of modern nutraceuticals (Ayaz et al., 2024). Their rich composition necessary nutrients and bioactive substances supports various aspects of human health, making them invaluable for both prevention and management of chronic conditions (El-Saadony et al., 2023).

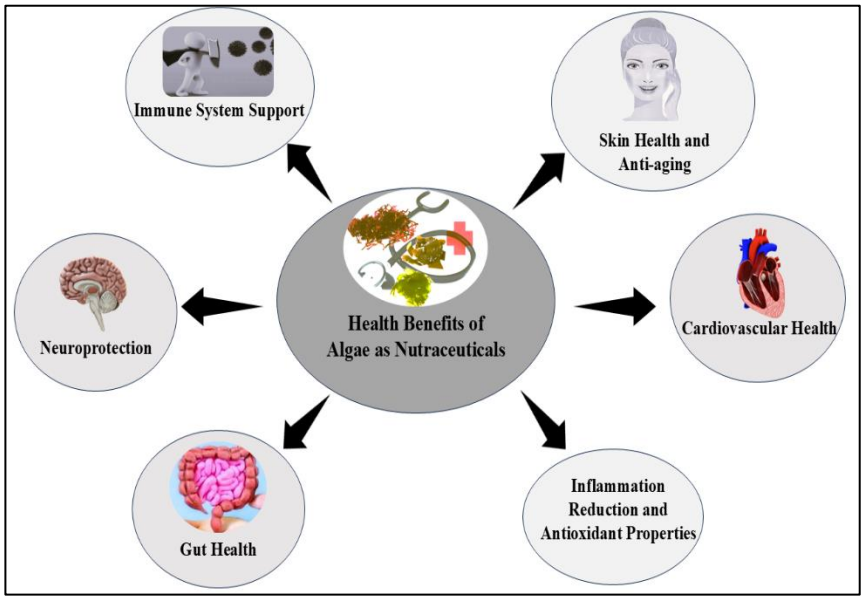

Figure 7.1: Health Benefits of Algae as Nutraceuticals

- **Immune System Support:**

Algal polysaccharides, such as those found in species like Chlorella and Spirulina, exhibit strong immunomodulatory properties (Montuori et al., 2022; Yu et al., 2022). For instance, Spirulina contains phycocyanin, a pigment-protein complex known to enhance the immune response and reduce the risk of viral infections (Carbone et al., 2021). Algal beta-glucans, found in species like Laminaria (kelp), have been shown to modulate immune activity, providing protection against pathogens while maintaining immune balance (Singh et al., 2022).

- **Cardiovascular Health:**

Algae are important for heart health since they contain a high concentration of omega-3 fatty acids such as DHA and EPA. These fatty acids are known to reduce LDL cholesterol levels, increase Lowering blood pressure and increasing HDL cholesterol can lessen the risk of cardiovascular disease (Saidaiah et al., 2024). Microalgae such as Schizochytrium are used as sustainable sources of omega-3s in supplements and fortified foods (Saidaiah et al., 2024). Furthermore, antioxidants like fucoxanthin in brown algae (e.g., wakame) protect the cardiovascular system by reducing oxidative stress and inflammation in blood vessels, improving overall circulation and heart function (Cardoso et al., 2015).

- **Inflammation Reduction and Antioxidant Properties:**

Persistent inflammation and oxidative stress are significant factors to diseases like arthritis, diabetes, and cancer. Astaxanthin-rich algae (Haematococcus pluvialis) (Pradhan et al., 2020). Astaxanthin is 6,000 times more powerful than vitamin C in neutralizing free radicals, making it a highly effective compound for reducing inflammation and protecting cells from damage (Balta et al., 2021). Research has demonstrated that regular use of astaxanthin can alleviate symptoms of rheumatoid arthritis and protect against UV-induced skin damage. Similarly, phycobiliproteins from Spirulina have been linked to decreased markers of inflammation and oxidative stress, supporting overall cellular health (Ito et al., 2018).

- **Gut Health:**

Algae contribute significantly to gut health, primarily through their high content of dietary fibers and prebiotic compounds. For example, algal polysaccharides like agar and alginate, found in red and brown seaweeds, promote healthy gut flora, such

as Bifidobacteria and Lactobacillus (Zheng et al., 2020). These fibers improve digestion, enhance nutrient absorption, and support a balanced gut microbiome. Additionally, the prebiotic properties of Spirulina and Chlorella fibers help maintain a healthy gut environment (Patel et al., 2021).

- **Neuroprotection:**

Algae's neuroprotective properties are gaining attention for their role in brain health and the prevention of neurodegenerative diseases like dementia and Parkinson's (Ankita & Gagandeep Singh, 2024). Algal oils derived from microalgae like Schizochytrium provide a plant-based source of DHA, supporting memory, focus, and overall brain health.

Additionally, antioxidants like astaxanthin and phycocyanin combat oxidative stress in the brain, reducing the possibility of age-related cognitive deterioration. (Yang et al., 2024). Some studies suggest that regular intake of algae-based supplements can enhance mental clarity and protect against neurological disorders.

- **Skin Health and Anti-Aging:**

Algae are widely used in cosmeceuticals due to their hydrating, anti-aging, and protective properties. Fucoidan and astaxanthin, compounds found in brown algae, serve to counteract indications of ageing by enhancing skin suppleness, decreasing wrinkles, and guarding against UV damage (Ariede et al., 2017). Algae-derived vitamins, minerals, and antioxidants nourish the skin, promoting a healthy, radiant complexion.

For instance, topical formulations containing Chlorella extract have shown efficacy in reducing dark spots and enhancing skin firmness (Thiyagarasaiyar et al., 2020). Additionally, seaweeds like Laminaria are used in skincare products for their moisturizing and soothing effects, making them ideal for sensitive or dry skin types (Wang et al., 2015).

Through their diverse bioactive compounds and rich nutrient profile, algae offer substantial benefits for immune health, heart function, inflammation management, gut integrity, brain health, and skin vitality (Saini et al., 2024) . Their applications in nutraceuticals and cosmeceuticals not only promote overall well-being but also highlight algae as a cornerstone of sustainable and innovative health solutions.

7.4 Algae-Based Nutraceutical Products:

Algae's versatility and rich nutrient profile have led to its incorporation into a wide range of nutraceutical products that cater to diverse consumer needs. Below is a detailed exploration of the various product categories:

1. Supplements: Algae-based supplements are among the most popular nutraceutical products due to their concentrated health benefits and ease of consumption.

Tablets and Capsules: These are convenient forms for delivering algae extracts like Spirulina, Chlorella, or astaxanthin. They target specific health benefits, such as boosting immunity, enhancing energy, or supporting cardiovascular health (Olaniran et al., 2023).

Powders: Algae powders are versatile and can be added to smoothies, juices, or recipes. Spirulina and Chlorella powders are commonly marketed for their high protein, vitamin, and mineral content, appealing to fitness enthusiasts and those seeking a detox solution (Sikka, 2019).

2. Functional Foods: Functional foods incorporate algae to deliver health benefits beyond basic nutrition.

Algae-Infused Snacks: Products like seaweed chips or algae-enriched protein bars are increasingly popular as healthy, on-the-go snacks.

Drinks and Smoothies: Spirulina or chlorella-based green smoothies are a staple in the health food sector (Wu et al., 2023).

3. Fortified Products: Fortification with algae enhances traditional foods, making them functional and nutrient-dense.

Algae-Enriched Bread and Cereals: Adding algae flour or extracts to bread, pasta, or cereals increases their protein and micronutrient content, appealing to health-conscious consumers (Wu et al., 2023).

Dairy Alternatives: Algae-based nutrients are incorporated into plant-based milk, cheese, and yogurts to improve their omega-3 and vitamin content, making them competitive with traditional dairy (Jareonsin et al., 2024).

4. Beverages: Algae-based beverages target hydration, energy, and nutrition.

Protein Shakes: These are popular among athletes and fitness enthusiasts, offering a plant-based protein source combined with essential amino acids and micronutrients (Arenas-Jal et al., 2020).

Energy Drinks: Algae extracts like Spirulina or Chlorella is used to create natural energy drinks with antioxidant properties and fewer synthetic additives (Ayaz et al., 2024).

Herbal Teas: Seaweed or algae-infused teas provide a calming and detoxifying option.

5. Cosmetics with Nutraceutical Benefits: Algae's bioactive compounds are also utilized in cosmetic products with health-enhancing properties, bridging the gap between beauty and wellness.

Anti-Aging Creams and Serums: Products enriched with algae-derived antioxidants like astaxanthin and fucoidan combat oxidative stress, reduce wrinkles, and improve skin elasticity (Parikh et al., 2024).

Moisturizers and Masks: Algae-based skincare products are rich in vitamins and minerals, providing hydration, nourishment, and skin renewal properties (Mago et al., 2023).

By leveraging algae's bioactive properties, these products meet diverse consumer demands, from health supplements to functional foods and wellness-oriented cosmetics. The versatility and sustainability of algae make it a key player in the nutraceutical market.

7.5 Challenges in Algae Nutraceuticals:

The development of algae-based nutraceuticals involves numerous hurdles. One of the main challenges is the scalability of manufacturing and its accompanying expenses.

While algae farming and processing technologies have advanced, large-scale cultivation often requires significant investments in infrastructure, energy, and resources, making it expensive. Furthermore, regulatory and safety concerns pose

hurdles as stringent quality standards, labelling requirements, and approvals are necessary to ensure product safety and efficacy, especially for human consumption. Another challenge is consumer acceptance and awareness; despite the health benefits, many consumers remain unfamiliar with algae-based products or are hesitant due to taste, odor, or misconceptions.

7.6 Conclusion:

Algae, with their exceptional nutritional profile and bioactive compounds, have proven to be a powerful resource in the field of nutraceuticals. From boosting immunity and improving cardiovascular health to aiding in disease prevention and promoting overall vitality, algae offer an impressive range of health benefits. Their application in dietary supplements, functional foods, cosmetics, and even pharmaceuticals underscore their versatility and importance in enhancing human well-being. Beyond their health benefits, algae stand out as a sustainable solution to global challenges, offering eco-friendly alternatives to conventional agricultural and industrial practices. Their ability to grow rapidly with minimal resources, coupled with their role in carbon sequestration and water purification, positions them as a critical component in the push for a healthier planet. To fully realize the potential of algae, further research and innovation are essential. Advancing cultivation methods, reducing production costs, and exploring novel applications will be crucial for expanding their accessibility and acceptance. Algae's promise as a nutraceutical powerhouse and a sustainable health solution offers immense opportunities for scientists, industries, and policymakers to collaborate in harnessing this incredible resource for the betterment of both human health and the environment.

7.7 References:

1. Ahmed, N., Sheikh, M. A., Ubaid, M., Chauhan, P., Kumar, K., & Choudhary, S. (2024). Comprehensive exploration of marine algae diversity, bioactive compounds, health benefits, regulatory issues, and food and drug applications. *Measurement: Food*, 100163.
2. Alves, C., Silva, J., Pinteus, S., Gaspar, H., Alpoim, M. C., Botana, L. M., & Pedrosa, R. (2018). From marine origin to therapeutics: The antitumor potential of marine algae-derived compounds. *Frontiers in pharmacology*, *9*, 777.
3. Ankita, A. R., & Gagandeep Singh, S. (2024). Exploring the Potential of Microalgae as Food Supplements: A Comprehensive Review. *Journal of Scientific & Industrial Research*, *83*, 688-702.

4. Anwar, H., Hussain, G., & Mustafa, I. (2018). Antioxidants from natural sources. *Antioxidants in foods and its applications*, *3*.
5. Arenas-Jal, M., Suñé-Negre, J., Pérez-Lozano, P., & García-Montoya, E. (2020). Trends in the food and sports nutrition industry: A review. *Critical Reviews in Food Science and Nutrition*, *60*(14), 2405-2421.
6. Ariede, M. B., Candido, T. M., Jacome, A. L. M., Velasco, M. V. R., de Carvalho, J. C. M., & Baby, A. R. (2017). Cosmetic attributes of algae-A review. *Algal Research*, *25*, 483-487.
7. Ayaz, A., Zaman, W., Radák, Z., & Gu, Y. (2024). Harmony in Motion: Unraveling the Nexus of Sports, Plant-Based Nutrition, and Antioxidants for Peak Performance. *Antioxidants*, *13*(4), 437.
8. Balta, I., Stef, L., Pet, I., Iancu, T., Stef, D., & Corcionivoschi, N. (2021). Essential fatty acids as biomedicines in cardiac health. *Biomedicines*, *9*(10), 1466.
9. Carbone, D. A., Pellone, P., Lubritto, C., & Ciniglia, C. (2021). Evaluation of microalgae antiviral activity and their bioactive compounds. *Antibiotics*, *10*(6), 746.
10. Cardoso, S. M., Pereira, O. R., Seca, A. M., Pinto, D. C., & Silva, A. M. (2015). Seaweeds as preventive agents for cardiovascular diseases: From nutrients to functional foods. *Marine Drugs*, *13*(11), 6838-6865.
11. El-Saadony, M. T., Zabermawi, N. M., Zabermawi, N. M., Burollus, M. A., Shafi, M. E., Alagawany, M., Yehia, N., Askar, A. M., Alsafy, S. A., & Noreldin, A. E. (2023). Nutritional aspects and health benefits of bioactive plant compounds against infectious diseases: a review. *Food Reviews International*, *39*(4), 2138-2160.
12. ElFar, O. A., Chang, C.-K., Leong, H. Y., Peter, A. P., Chew, K. W., & Show, P. L. (2021). Prospects of Industry 5.0 in algae: Customization of production and new advance technology for clean bioenergy generation. *Energy Conversion and Management: X*, *10*, 100048.
13. Fekete, M., Lehoczki, A., Tarantini, S., Fazekas-Pongor, V., Csípő, T., Csizmadia, Z., & Varga, J. T. (2023). Improving cognitive function with nutritional supplements in aging: a comprehensive narrative review of clinical studies investigating the effects of vitamins, minerals, antioxidants, and other dietary supplements. *Nutrients*, *15*(24), 5116.
14. Ferdous, U. T., & Yusof, Z. N. B. (2021). Medicinal prospects of antioxidants from algal sources in cancer therapy. *Frontiers in pharmacology*, *12*, 593116.

15. Ghosh, S., Sarkar, T., Pati, S., Kari, Z. A., Edinur, H. A., & Chakraborty, R. (2022). Novel bioactive compounds from marine sources as a tool for functional food development. *Frontiers in Marine Science*, *9*, 832957.
16. Ito, N., Seki, S., & Ueda, F. (2018). The protective role of astaxanthin for UV-induced skin deterioration in healthy people—A randomized, double-blind, placebo-controlled trial. *Nutrients*, *10*(7), 817.
17. Jacquier, E. F., Kassis, A., Marcu, D., Contractor, N., Hong, J., Hu, C., Kuehn, M., Lenderink, C., & Rajgopal, A. (2024). Phytonutrients in the promotion of healthspan: a new perspective. *Frontiers in Nutrition*, *11*, 1409339.
18. Jareonsin, S., Pumas, C., Jaitiang, D., & Uttarotai, T. (2024). Green Fusion Proteins: An Approach to Sustainable Nutrition Blending Plant and Algae-Based Proteins for a Circular Food System. *Future Foods*, 100415.
19. Kesharwani, R. K., Kumar, P., & Keservani, R. K. (2025). *The Nature of Nutraceuticals: History, Properties, Sources, and Nanotechnology*. CRC Press.
20. Mago, Y., Sharma, Y., Thakran, Y., Mishra, A., Tewari, S., & Kataria, N. (2023). Next-generation organic beauty products obtained from algal secondary metabolites: a sustainable development in cosmeceutical industries. *Molecular Biotechnology*, 1-21.
21. Mallik, B., Mishra, T., Dubey, P., Kesheri, M., & Kanchan, S. (2024). Exploring the Secrets of Microbes: Unveiling the Hidden World Through Microbial Omics in Environment and Health. In *Microbial Omics in Environment and Health* (pp. 269-294). Springer.
22. Mata, T. M., Martins, A. A., & Caetano, N. S. (2010). Microalgae for biodiesel production and other applications: a review. *Renewable and Sustainable Energy Reviews*, *14*(1), 217-232.
23. Mironiuk, M., & Chojnacka, K. (2018). The environmental benefits arising from the use of algae biomass in industry. *Algae biomass: characteristics and applications: towards algae-based products*, 7-16.
24. Mišurcová, L., Škrovánková, S., Samek, D., Ambrožová, J., & Machů, L. (2012). Health benefits of algal polysaccharides in human nutrition. *Advances in food and nutrition research*, *66*, 75-145.
25. Montuori, E., de Pascale, D., & Lauritano, C. (2022). Recent discoveries on marine organism immunomodulatory activities. *Marine Drugs*, *20*(7), 422.
26. Motshekga, S. C., Temane, L. T., Orasugh, J. T., & Ray, S. S. (2023). Marine Algae and Their Importance. *Current Status of Marine Water Microbiology*, 67-124.

27. Naik, B., Mishra, R., Kumar, V., Mishra, S., Gupta, U., Rustagi, S., Gupta, A. K., Preet, M. S., Bhatt, S. C., & Rizwanuddin, S. (2024). Micro-algae: Revolutionizing food production for a healthy and sustainable future. *Journal of Agriculture and Food Research*, *15*, 100939.
28. Narula, P., Mahajan, A., Gurnani, C., Kumar, V., & Mukhija, S. (2015). Microalgae as an indispensable tool against heavy metals toxicity to plants: a review. *Int. J. Pharm. Sci. Rev. Res*, *31*(1), 180.
29. Olaniran, A. F., Folorunsho, J. O., Akinsanola, B. A., Taiwo, A. E., Iranloye, Y. M., Okonkwo, C. E., & Osemwegie, O. O. (2023). Application of Astaxanthin and Carotenoids Derived from Algae for the Production of Nutraceuticals, Pharmaceuticals, Additives, Food Supplement and Feed. *Next-Generation Algae*, *2*, 95-124.
30. Osuala, O., & Ezemba, C. C. (2022). Algae, a hope for sustainable living. *Ezemba, C. C and Osuala, OJ (2022). Algae, a hope for sustainable living. Asian journal of research in botany*, *7*(4), 16-25.
31. Parikh, H. S., Singh, P. K., & Tiwari, A. (2024). Algal biorefinery: focus on cosmeceuticals. *Systems Microbiology and Biomanufacturing*, 1-23.
32. Patel, A. K., Singhania, R. R., Awasthi, M. K., Varjani, S., Bhatia, S. K., Tsai, M.-L., Hsieh, S.-L., Chen, C.-W., & Dong, C.-D. (2021). Emerging prospects of macro-and microalgae as prebiotic. *Microbial Cell Factories*, *20*(1), 112.
33. Pradhan, B., Nayak, R., Patra, S., Jit, B. P., Ragusa, A., & Jena, M. (2020). Bioactive metabolites from marine algae as potent pharmacophores against oxidative stress-associated human diseases: A comprehensive review. *Molecules*, *26*(1), 37.
34. Rao, N. R. H., Tamburic, B., Doan, Y. T. T., Nguyen, B. D., & Henderson, R. K. (2021). Algal biotechnology in Australia and Vietnam: Opportunities and challenges. *Algal Research*, *56*, 102335.
35. Saidaiah, P., Banu, Z., Khan, A. A., Geetha, A., & Somraj, B. (2024). A comprehensive review of Omega-3 fatty acids: Sources, industrial applications, and health benefits. *Annals of Phytomedicine*, *13*(1), 209-225.
36. Saini, K. C., Rani, A., Gupta, S. K., & Sharma, P. (2024). Algae a Potential Source in Cosmetics: Current Status, Challenges, and Economic Implications. *Indian Journal of Microbiology*, 1-16.
37. Saini, R. K., Prasad, P., Sreedhar, R. V., Akhilender Naidu, K., Shang, X., & Keum, Y.-S. (2021). Omega− 3 polyunsaturated fatty acids (PUFAs): Emerging plant and microbial sources, oxidative stability, bioavailability, and health benefits—A review. *Antioxidants*, *10*(10), 1627.

38. Samoraj, M., Çalış, D., Trzaska, K., Mironiuk, M., & Chojnacka, K. (2024). Advancements in algal biorefineries for sustainable agriculture: Biofuels, high-value products, and environmental solutions. *Biocatalysis and Agricultural Biotechnology*, *58*, 103224.
39. Sharma, P., & Sharma, N. (2017). Industrial and biotechnological applications of algae: a review. *Journal of Advances in plant biology*, *1*(1), 01-25.
40. Sikka, T. (2019). The contradictions of a superfood consumerism in a postfeminist, neoliberal world. *Food, Culture & Society*, *22*(3), 354-375.
41. Singh, R. P., Bhaiyya, R., Khandare, K., & Tingirikari, J. M. R. (2022). Macroalgal dietary glycans: potential source for human gut bacteria and enhancing immune system for better health. *Critical Reviews in Food Science and Nutrition*, *62*(6), 1674-1695.
42. Sun, N., Tan, B., Sun, B., Zhang, J., Li, C., & Yang, W. (2022). Evaluation of protein digestibility and iodine bioavailability in raw and cooked Sargassum fusiforme (Harvey) Setchell using in vitro methods. *British Food Journal*, *124*(9), 2722-2739.
43. Thiyagarasaiyar, K., Goh, B.-H., Jeon, Y.-J., & Yow, Y.-Y. (2020). Algae metabolites in cosmeceutical: An overview of current applications and challenges. *Marine Drugs*, *18*(6), 323.
44. Valko, M., Leibfritz, D., Moncol, J., Cronin, M. T., Mazur, M., & Telser, J. (2007). Free radicals and antioxidants in normal physiological functions and human disease. *The international journal of biochemistry & cell biology*, *39*(1), 44-84.
45. Vlaicu, P. A., Untea, A. E., Varzaru, I., Saracila, M., & Oancea, A. G. (2023). Designing nutrition for health—Incorporating dietary by-products into poultry feeds to create functional foods with insights into health benefits, risks, bioactive compounds, food component functionality and safety regulations. *Foods*, *12*(21), 4001.
46. Wang, H.-M. D., Chen, C.-C., Huynh, P., & Chang, J.-S. (2015). Exploring the potential of using algae in cosmetics. *Bioresource technology*, *184*, 355-362.
47. Wu, J. Y., Tso, R., Teo, H. S., & Haldar, S. (2023). The utility of algae as sources of high value nutritional ingredients, particularly for alternative/complementary proteins to improve human health. *Frontiers in Nutrition*, *10*, 1277343.
48. Yadav, D. K., Singh, A., Agrawal, V., & Yadav, N. (2021). Algal Biomass: A Natural Resource of High-Value Biomolecules. *Bioprospecting of Plant Biodiversity for Industrial Molecules*, 303-334.

49. Yang, S., Fan, Y., Cao, Y., Wang, Y., Mou, H., & Sun, H. (2024). Technological readiness of commercial microalgae species for foods. *Critical Reviews in Food Science and Nutrition*, *64*(22), 7993-8017.
50. Yu, Z., Hong, Y., Xie, K., & Fan, Q. (2022). Research progresses on the physiological and pharmacological benefits of microalgae-derived biomolecules. *Foods*, *11*(18), 2806.
51. Zheng, L.-X., Chen, X.-Q., & Cheong, K.-L. (2020). Current trends in marine algae polysaccharides: The digestive tract, microbial catabolism, and prebiotic potential. *International Journal of Biological Macromolecules*, *151*, 344-354.
52. Zou, Y., Zeng, Q., Li, H., Liu, H., & Lu, Q. (2021). Emerging technologies of algae-based wastewater remediation for bio-fertilizer production: a promising pathway to sustainable agriculture. *Journal of Chemical Technology & Biotechnology*, *96*(3), 551-563.