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Editorial

Algae and Cyanobacteria as Next-Generation Sustainable Nutritional Resources

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Nutritional potential

Algae and cyanobacteria are becoming more widely acknowledged as prospective sources for functional foods, alternative proteins, nutraceuticals, and sustainable nutrition. Their capacity to produce proteins, vital amino acids, polyunsaturated fatty acids (PUFAs), carbohydrates, pigments, vitamins, minerals, and other physiologically important substances on relatively little arable land accounts for their significance [1]. Because of their high biomass productivity and the potential for growing under conditions that lessen reliance on conventional agricultural land and freshwater resources, microalgae have been highlighted in recent literature as potential contributors to future food systems. One of the most crucial nutritional elements of algal biomass is protein. Although the concentration varies greatly depending on the species, cultivation conditions, and processing, species from genera including *Arthrospira platensis*, *Chlorella, Scenedesmus*, and *Nannochloropsis* can contain significant levels of protein. Because some species have comparatively balanced necessary amino acid profiles, microalgal proteins are especially appealing. Although digestibility differs among animals and can be enhanced by proper processing and cell wall breakdown, recent study suggests that microalgal protein may be accessible to humans [2]. As a food organism that is high in protein (Single cell protein/SCP), the cyanobacterium *Arthrospira platensis* is particularly significant. It is a multipurpose nutritional component that includes proteins, vital amino acids, lipids, carbs, minerals, and dietary fiber. The evaluation of *Arthrospira* as a vegan protein source that can support a sustained human diet is still ongoing [3]. Lipids that are vital for nutrition can be found in algae, especially PUFAs. Algae biomass can include α-linolenic acid (ALA), arachidonic acid (ARA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), depending on the species. Because they can directly create EPA and DHA and can be grown without using marine fish resources. Microalgae are being researched more and more as potential substitutes for omega-3 oils derived from fish [4]. A wide range of micronutrients, including minerals and numerous vitamins, can be obtained from algal biomass. As concentrated nutritional supplements, *Chlorella* and *Arthrospira* are especially well-known. According to recent reviews, *Chlorella* contains minerals, proteins, vitamins, PUFAs, pigments, and phenolic compounds [5]. Structural and storage polysaccharides, and soluble bioactive polysaccharides are examples of algal carbohydrates [6]. These may contribute to food's texture, water-holding capacity, dietary fiber, and other functional qualities, depending on the organism. According to recent assessments, microalgal polysaccharides may have a significant role in gastrointestinal digestion, nutrient absorption, and technical processes like thickening and stability [7]. Alginates, agar, and carrageenan's-structurally varied polysaccharides with uses as food hydrocolloids and dietary fiber- are especially abundant in macroalgae. Algal carbohydrates are therefore important for both nutrition and technology. Algae produce bioactive pigments, which is one of their unique nutritional benefits. These consist of phycobiliproteins like C-phycocyanin, carotenoids including β-carotene, lutein, astaxanthin, and chlorophylls. These substances

have potential uses as natural food coloring and nutraceutical additives, as well as antioxidant properties. In particular, cyanobacteria like *Arthrospira* have C-phycocyanin. According to recent research, it is a bioactive protein with purported anti-inflammatory and antioxidant qualities as well as a naturally occurring blue food hue [8].

Functional foods and nutraceuticals

Algae are appealing for the development of functional foods, nutraceuticals, nutritional supplements, and fortified foods due to their combination of macronutrients and bioactive chemicals. The use of microalgal biomass as a component in drinks, baked goods, snacks, protein formulations, and meat or seafood substitutes has been studied. Because microalgae's proteins, PUFAs, colors, vitamins, and minerals can provide both nutritional and sensory qualities, recent study also emphasizes the use of microalgae in plant-based seafood products [9]. Furthermore, substances including carotenoids, polyphenols, and omega-3 fatty acids found in microalgae may have an impact on biomarkers related to metabolic health, according to systematic research. However, before establishing therapeutic claims, more robust human clinical evidence is needed, as a large portion of the evidence for disease-preventive benefits is still preclinical [10].

Health benefits

- **Anti-inflammatory activity:** In experimental models, a number of algae compounds have shown the capacity to alter inflammatory pathways. Their possible use in diets intended to promote long-term metabolic and inflammatory health has drawn attention as a result [11].
- **Antioxidant activity:** Peptides, phenolic compounds, carotenoids, phycobiliproteins, and other metabolites can scavenge reactive species or take part in antioxidant defense mechanisms. Prominent examples are phycocyanin obtained from *Arthrospira* and astaxanthin derived from *Haematococcus* [12,13].
- **Immunomodulatory effects:** In experiments, algal proteins, polysaccharides, pigments, and peptides have demonstrated immunomodulatory action. For this reason, the use of algal biomass and extracts in nutraceutical research is growing [9].
- **Cardiometabolic activity:** The effects of algae-derived omega-3 fatty acids, peptides, pigments, and polysaccharides on lipid metabolism, glucose control, and cardiovascular risk factors are being studied. Although the strength of the evidence varies significantly between specific chemicals and species [11].
- **Prebiotic potential and gut health:** Some algal polysaccharides may have prebiotic-like qualities and interact with the intestinal bacteria. This is a new field that links algal foods to the gut-microbiome-health axis [14].

Sustainable advantages

Compared to many traditional agricultural systems, algae production gives a significant extra benefit. Depending on the production strategy, microalgae can be grown with great productivity on comparatively little arable areas. While integrated systems may make use of nutrient-rich waste streams, their cultivation can also help trap carbon. Algae are fascinating for creating circular and sustainable food production systems because of their qualities [10].

Future prospects

The future of algae and cyanobacteria as functional foods and nutraceuticals lies at the intersection of nutrition, biotechnology, and sustainability. They are essential resources for creating healthier and more resilient food systems because of their exceptional nutritional diversity, quick biomass yield, and minimal environmental impact. The commercialization of scientifically proven algae nutraceuticals and functional food items will be accelerated by ongoing developments in cultivation technology, bioprocessing, omics-based research, and clinical validation.

Conclusion

A versatile source for next-generation foods and nutraceuticals is algae and cyanobacteria. Both nutritional and functional benefits are provided by their blend of premium proteins, PUFAs, vitamins, minerals, colors, polysaccharides, and bioactive peptides. Among the most promising organisms for use in food and nutraceutical applications are *Arthrospira, Chlorella, Dunaliella, Haematococcus*, and *Nannochloropsis*. Significant antioxidant, anti-inflammatory, immunomodulatory, and metabolic-health potential is currently supported by research; however, the strength of the evidence differs among species, compounds, and health outcomes. Therefore, bioavailability, clinical validation, standardized

cultivation and extraction, safety evaluation, sensory enhancement, and sustainable large-scale production should be the main areas of future development.

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