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FROM OCEAN TO PLATE: EMBRACING ALGAE AS A HEALTHY AND SUSTAINABLE FOOD SOURCE: A REVIEW

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ABSTRACT

Algae are aquatic photosynthetic organisms that grow by consuming carbon dioxide, light, nutrients and include organisms that range in diversity from giant kelp and seaweed (Macroalgae) to microscopic single-cellular algae (Microalgae) (Kovac *et al.*, 2023). As a result of their remarkable resource efficiency, algae have emerged as a promising source of nutrient-rich biomass that has the potential to alleviate a number of the present problems associated with food production (Jyoti *et al.*, 2022). Algae are rich in energy and a good supply of macro- and microelements, proteins, lipids, carbohydrates and other physiologically active compounds. Additionally, they include high levels of proteins, amino acids, halogenated chemicals, polysaccharides, polyphenols, carotenoids, sterols, steroids, lectins, polyketides, alkaloids and carrageenans (Babich *et al.*, 2022). Given the food industry's need for constant innovation, algae provide intriguing options as novel food sources and for developing new food items to match changing customer tastes and provide them with a good and healthful diet (Wells *et al.*, 2021). Algal-derived substances, like algal oils and flours, contribute to the creation of tasty and nutritious food products. Including algae in regular meals promotes a more ethical and sustainable food system while also broadening the variety of food options available. It is so exciting to see what more study, instruction, and culinary innovation will be required to properly incorporate algae into world cuisine cultures. Embracing algae from ocean to plate represents a paradigm shift towards a healthier, more sustainable, and environmentally conscious approach to food production and consumption.

Key words : Algae, Seaweed, Food, Ingredients, Nutrition, Sustainability, Environmental Impact.

Introduction

Climate change and the world's growing population are putting tremendous strain on current agricultural and food production methods. With an estimated 9.7 billion people on the planet by 2050, there will be a huge demand for protein from both plant and animal-based sources, including fruits, vegetables, grains, nuts and seeds, as well as meat, poultry, fish and dairy products. This has prompted researchers to look into more sustainable and novel food sources. One such innovative and ecological production method that is being researched more and more as a food, food ingredient and food additive is algae. Algae are a large and diverse group of autotrophic eukaryotic and photosynthetic organisms. As per

Blazencic (2007), algae are the most abundant primary producers, although some can be heterotrophic. In biological sense, the term algae implies more divisions of lower plants which contain chlorophyll in cells and are typical in habitants of aquatic biotopes. They proliferate quickly and are able to photosynthesize. While the cellular structure and reproduction of algae and plants varies, their physiological characteristics are comparable. They have a greater ability to use solar energy, which makes them more suitable for increasing the nutritional value of food and feed. They also have a well acknowledged potential for producing useful chemicals or biomass. Microalgae have a combination of higher plant-typical characteristics and microbial cell-specific biotechnology.



Fig. 1 : Edible algae sea weed, *Spirulina* and *Chlorella*.

Or, to put it another way, they have the ability to multiply quickly in a liquid media while having extremely basic nutritional needs (unlike fungi and bacteria, they do not need an organic carbon source) and metabolizing. Algae are rich in nutrients that are beneficial to human health as they contain bioactive antioxidants, soluble dietary fibers, minerals, phytochemicals and polyunsaturated fatty acid, which are low in calories. Edible algae like *Spirulina* and *Chlorella* are rich in B vitamins, especially B₁₂ and proteins, which make them a popular choice among plant-based eaters.

Algal foods hold great potential as a source of ingredients for the creation of innovative culinary products. While thousands of species of algae exist, only some are actually consumable which include: *Spirulina*, *Chlorella*, Seaweed (nori, dulse, kelps) and Sea moss. Proteins, minerals, vitamins, amino acids, lipids, fatty acids, polysaccharides, nucleic acid and carotenoids can all be found in algae metabolites. According to Jyoti *et al.* (2022), algal metabolites are excellent sources of extra nutrients. Algae-derived ingredients, such as algal oils and flours, add to the development of nutritious and tasty food products. The integration of algae into mainstream diets not only diversifies food options but also aligns with the principles of a sustainable and ethical food system.

Algae: A package of Nutrients

Seaweeds and other edible algae are full of different nutrients and can be a great complement to a balanced diet. Depending on the kind of algae, the nutritional value might vary, but in general, edible algae are recognized for having a high vitamin, mineral, protein, and other health-promoting content and a low calorie and fat content.

1. Rich Source of Micronutrients: Edible algae are packed with essential vitamins and minerals crucial for maintaining overall health. Vitamin A, known for its role in vision and immune function, is present in significant amounts, as is vitamin C, a powerful antioxidant and vitamin B complex, play crucial roles in various physiological functions within the body.

These algae are also a notable source of vitamin K, essential for blood clotting and various minerals like iodine, calcium, iron, magnesium, and potassium, all vital for various physiological functions.

- 2. Protein Powerhouse:** Algae, particularly *Spirulina* and *Chlorella* are excellent sources of plant-based proteins. These proteins are not only rich in amino acids but also easily digestible, making them an ideal supplement for those following vegetarian or vegan diets. *Spirulina* contains 63 per cent of protein while *Chlorella* holds 60 per cent protein of its dry weight, including all the essential amino acids.
- 3. Omega-3 Fatty Acids:** Certain types of algae, especially microalgae, are unique in their ability to produce omega-3 fatty acids like DHA (docosahexaenoic acid), GLA (gamma linolenic acid) and EPA (eicosapentaenoic acid). These essential fats, commonly found in fish, play a crucial role in heart health and cognitive function. Incorporating algae into the diet provides a sustainable and plant-based alternative for those seeking omega-3 fatty acids.
- 4. Fiber for Digestive Health:** Edible algae, such as seaweeds, are rich in dietary fiber. Fiber is essential for promoting healthy digestion, regulating blood sugar levels and supporting a feeling of fullness.
- 5. Antioxidants and Bioactive Compounds:** Algae are packed with antioxidants that help neutralize free radicals, protecting cells from oxidative stress. Additionally, certain bioactive compounds found in algae have demonstrated anti-inflammatory and anti-cancer properties in research studies, suggesting potential health benefits beyond basic nutrition.

Applicability of algae

Algae, often overlooked as simple aquatic organisms, have emerged as versatile bioresources with applications spanning various industries. From addressing nutritional needs to serving as eco-friendly solutions in energy, agriculture and beyond, algae showcase a wealth of potential applications.

1. Food and Nutrition

- **Human Consumption:** Algae, such as seaweeds, *Spirulina* and *Chlorella*, are edible and rich in nutrients. They are used in various cuisines and as dietary supplements, providing essential vitamins, minerals, proteins, and omega-3 fatty acids.

2. Biotechnology

- **Biofuel Production:** Algae are being explored as a sustainable source for biofuel production. They have the potential to generate biofuels like biodiesel and bioethanol more efficiently than traditional crops.
- **Bioplastics:** Algae-derived materials are being researched for the production of biodegradable plastics, contributing to efforts to reduce plastic pollution.

3. Pharmaceuticals

- **Nutraceuticals:** Algae are a source of bioactive compounds with potential health benefits. Extracts from certain algae may be used in the development of nutraceuticals or dietary supplements.
- **Drug Production:** Some algae are used in pharmaceutical research for the production of bioactive compounds with antibacterial, antiviral, and anticancer properties.

4. Cosmetics and Personal Care

- **Skincare Products:** Algae extracts are commonly used in cosmetics and skincare products due to their moisturizing, antioxidant, and anti-inflammatory properties.
- **Hair Care:** Algae-based ingredients may be included in hair care products for their nourishing and conditioning effects.

5. Agriculture

- **Soil Amendment:** Algae-based products can be used as soil conditioners, improving soil structure and nutrient content.
- **Fertilizers:** Algae-based fertilizers provide plants with essential nutrients and organic matter, contributing to sustainable agriculture practices.

6. Water Treatment

- **Wastewater Treatment:** Certain types of algae can absorb and remove pollutants from wastewater, contributing to water purification processes.

- **Algal Turf Scrubbers:** Algal turf scrubbers use algae to absorb nutrients from water, aiding in the mitigation of excess nutrients in aquatic ecosystems.

7. Environmental Monitoring

- **Bio-indicators:** Algae can serve as bio-indicators in environmental monitoring programs. Changes in algae populations can indicate shifts in water quality and ecosystem health.

8. Textile Industry

- **Dye Production:** Some algae species like *Chlorella* (green algae) and dulse (red algae) produce natural pigments that can be used as eco-friendly dyes in the textile industry.

9. Animal Feed

- **Aquaculture and Livestock Feed:** Certain algae can be used as a nutritious feed supplement in aquaculture and livestock farming, providing essential nutrients for growth and health.

Culinary Applications of Algae

The culinary world is increasingly embracing the diverse and unique flavors of algae, expanding the scope of gastronomic possibilities. Seaweeds, such as nori, dulse, and kelp, are integral components of various cuisines, adding umami richness, subtle brininess, and unique textures to dishes.

1. **Seaweed in Salads and Wraps:** Various types of edible seaweeds, such as nori, dulse, and wakame, can be used in salads and wraps. Nori is commonly used to wrap sushi, while dulse and wakame can be added to salads for a unique taste and nutritional boost.
2. **Agar-Agar as a Gelatin Substitute:** Agar-agar, derived from certain types of red algae, is often used as a vegetarian alternative to gelatin. It is used to set desserts, jellies and other culinary creations.
3. **Algae Powders in Smoothies and Baking:** Algae powders, such as spirulina and chlorella are rich in nutrients and can be added to smoothies, juices, or baked goods for a nutritional boost and a vibrant green color.
4. **Algae Oil in Cooking:** Algae oil, extracted from certain algae species, is a plant-based oil rich in omega-3 fatty acids. It can be used as cooking oil or added to dressings and sauces.
5. **Algae Snacks:** Companies are developing algae-based snacks, such as seaweed chips and algae-based crackers. These snacks offer a unique taste, a source of vitamins and minerals, and are often considered a

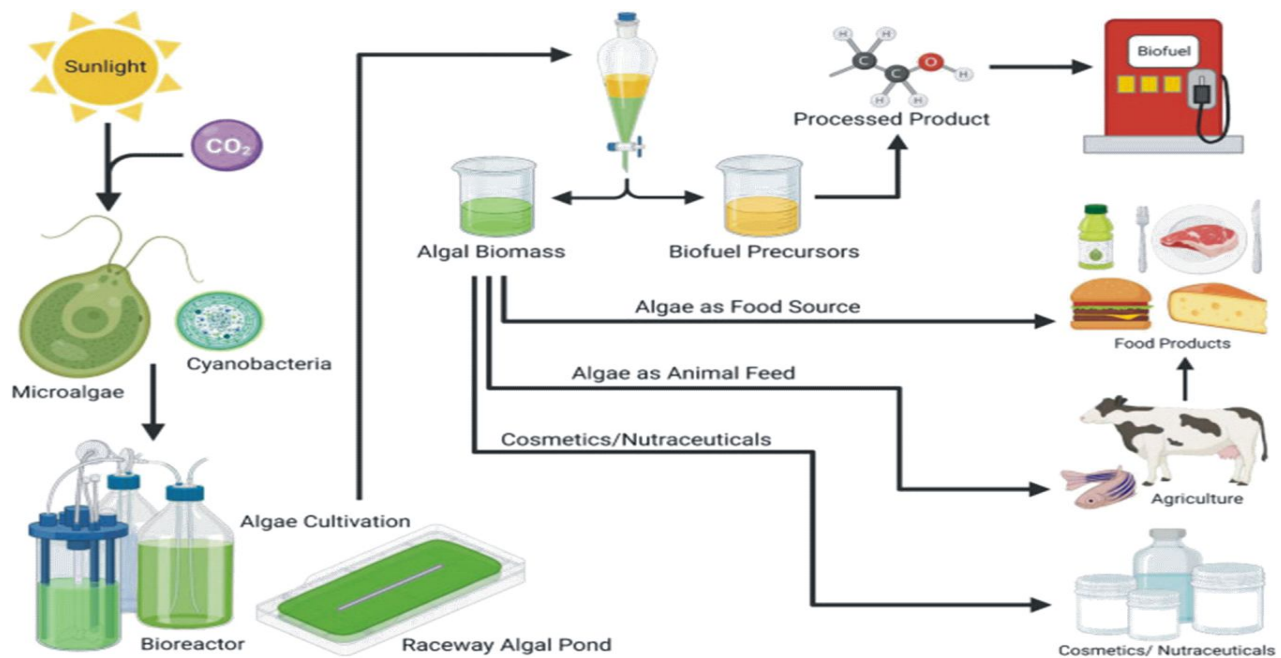


Fig. 2 : Versatile markets for algae products (adapted from Diaz *et al.*, 2023).

more sustainable option than traditional snacks.

- 6. Algae-Based Sauces and Condiments:** Algae extracts can be used to enhance the umami flavor in sauces and condiments. Alginate, derived from brown algae, is often used as a thickening or gelling agent in sauces.

Sustainability and environmental impact

Algae are the future of sustainability. Algae offer several sustainability benefits and minimal environment impact. Considering the fact that Algae are poorly explored, their cultivation can be independent of external conditions, more efficient convert solar energy and in comparison with higher plants, they do not require fertile soil, produce a wide range of substances, can be used for different applications and some species reproduce very fast, so that these organisms present a really remarkable source of biomass and certain compounds. Algae stand as exemplars of sustainability, playing a pivotal role in mitigating environmental challenges. Cultivating and harnessing algae for various applications offers a sustainable alternative to conventional practices with lower ecological footprints. In bio-fuel production, algae outshine traditional crops, requiring less land and water while absorbing carbon dioxide during growth. The use of algae-derived materials in bio-plastics aligns with the ethos of sustainability, as these biodegradable alternatives contribute to reducing the persistence of plastic waste in the environment. Furthermore, algae's proficiency in wastewater treatment serves as a natural solution for purifying water bodies, addressing pollution concerns. As

sources of nutrition and nutraceuticals, algae offer sustainable options for food security without the environmental burdens associated with intensive agriculture.

Conclusion

The journey from ocean to plate presents an exciting narrative of embracing algae as a viable, healthy and sustainable food source. This comprehensive review underscores the immense potential of algae, not only as a nutrient-rich super food but also as a solution to various environmental challenges. Algae's exceptional nutritional profile, containing essential vitamins, minerals, antioxidants, and omega-3 fatty acids, positions it as a promising alternative to conventional food sources. Moreover, its cultivation requires minimal resources—less land, water, and fertilizers—making it an environmentally friendly choice that aligns with the principles of sustainability. The versatility of algae, seen in its various forms such as seaweed, microalgae and macro algae, offers a wide range of culinary applications, appealing to diverse tastes and dietary preferences. However, to fully realize the potential of algae as a mainstream food source, continued research, technological advancements, and increased public awareness are pivotal. Overcoming challenges related to taste preferences, scalability and market accessibility will be crucial in integrating algae into global food systems.

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