Chapter

Microalgae and Its Use in Nutraceuticals and Food Supplements

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Abstract

Microalgae are a large diverse group of microorganisms comprising photoautotrophic protists and prokaryotic cyanobacteria—also called as blue-green algae. These microalgae form the source of the food chain for more than 70% of the world's biomass. It contains higher nutritional values, with rapid growth characteristics. Microalgae are autotrophic organisms and extensively desired for use in nutraceuticals and as supplement in diet. Many microalgal species are documented for health benefits, by strengthening immune system and by increasing the nutritional constitution of body. In this chapter the major economically important species like *Spirulina*, *Chlorella*, *Haematococcus*, and *Aphanizomenon* are described with reference to its importance as nutraceuticals and food.

Keywords: microalgae, *Spirulina*, *Chlorella*, nutraceuticals, food supplements

1. Introduction

Microalgae are a large diverse group of microorganisms comprising photoautotrophic protists and prokaryotic cyanobacteria—also called as blue-green algae. These microalgae form the source of the food chain for more than 70% of the world's biomass [1]. Microalgae are single-celled, microscopic photosynthetic organisms, found in freshwater and marine environment. They produce compounds such as protein, carbohydrates, and lipids. Mostly, microalgae are photosynthetic microorganisms; it does not contain cell organelles unlike land plants. They use the carbon from air for energy production.

Microalgae can be cultivated photosynthetically using CO_2, solar energy, and water. It can be cultivated in shallow lagoons, marginal ponds, raceway ponds, or artificial tanks. The use of plastic tubes/reactors in pond system can achieve up to seven times the production efficiency compared to open culture system [2].

There are more than 300,000 species of microalgae, out of which around 30,000 are documented. They live in complex natural habitats and can adapt rapidly in extreme conditions (in variation of extreme weather conditions). This ability makes them capable to produce secondary metabolites, with novel structure and biologically active functions.

Microalgae produce some useful bio-products including β-carotene, astaxanthin, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), bioactive and functional pigments, natural dyes, polysaccharides, antioxidants, and algal extracts.

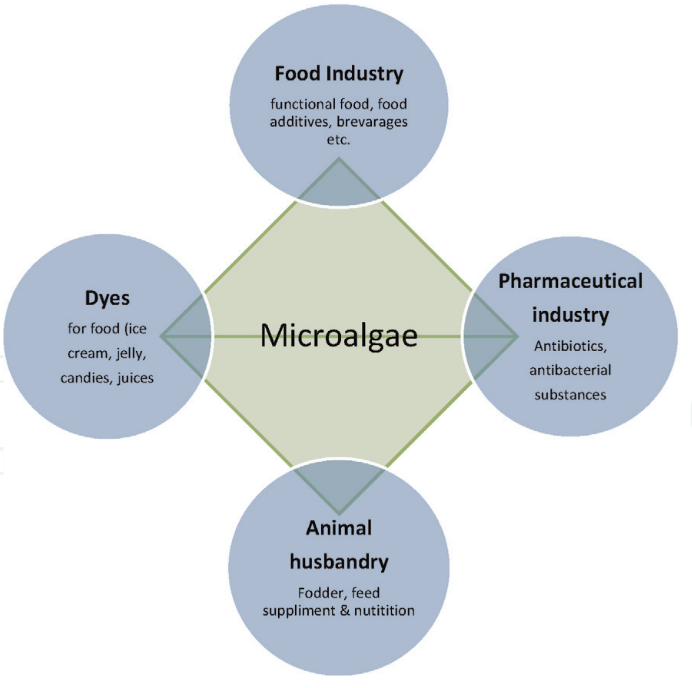

Figure 1.
Application of microalgae in various fields.

The first commercial cultivation of *Chlorella* was started in 1960 in Japan for nutraceuticals. Microalgae grow fast and produce large biomass with high protein content and consist the source of "single cell protein" [3] (**Figure 1**).

Algae are classified into many major groups, based on pigment composition, storage compound, and diversity in features of its ultrastructure. However, advance molecular biology-based techniques are nowadays used to check the relation between taxonomic groups and families of the specific class.

The global market value of microalgae is estimated to be around US$ 6.5 billion, out of which about US$ 2.5 billion is generated by the health food sector, US$ 1.5 billion by the production of DHA, and US$ 700 million by aquaculture. The annual production of microalgae is approximately 7.5 million tons.

2. Microalgal diversity

The diversity of microalgae is vast and represents an intact resource. The scientific literature indicates the existence of 200,000 to several million species of microalgae when compared to about 250,000 species of higher plants [4].

Green microalgae usually grow in freshwater and seawater, whereas several other species of microalgae grow in extremely saline environments, such as the Great Salt Lake in UT, USA, and the Dead Sea in Israel. Within these aqueous habitats, some algae grow inside the deeper waters, others populate the subsurface water column, and a few grow at the limits of the photic zone, 200–300 m below the water surface [5–8]. The microalgae are small in size (mostly 5–50 μm) and characterized by a simple morphology, usually unicellular. Accordingly, most of the species are not observed as an individual cell/specimen but become noticeable only when it generates large colony, specially in the form of green, black, red, or brown patches on the water surface. Coastlines between 45 and 30°N are suitable regions for algal farming, in particular in those territories at the south of the Mediterranean that experience warmer climates and whose temperature does not go too much below 15°C throughout the year [2]. This type of warmer climate of the Mediterranean region can facilitate the algal growth in the open or closed pond system.

The environmental parameters favorable for mass scale culture are explored by many counties. For example, Israel and few Mediterranean countries have explored specific parameters for each economically important alga and cultivating it by maintaining them artificially for mass scale production. Few advance countries have started culturing several microalgal strains of biofuel production, while countries like Libya, Cyprus, and Turkey also have plenty of marginal lands to harvest algae. For these countries a limited water resource is not a constraint as they are using recycled brackish or saline water. With the high temperatures in the Mediterranean region, the open or closed pond system would probably be the most efficient and suitable to grow algae.

Terrestrial microalgae belong primarily to three diverse evolutionary pedigrees: the blue-green algae (Cyanobacteria), the green algae (Chlorophyta and Streptophyta), and the diatoms (Bacillariophyceae, Ochrophyta) [9]. However, the species of green and blue-green algal group are the majorly studied group, taxonomically as well as with economical perspective. Nevertheless, the understanding of the patterns of geographical distribution in terrestrial algae is inadequate, mainly due to poor understanding of the diversity of these organisms [10].

3. Microalgae: uses as nutraceuticals and food

Microalgae have a wide range of industrial applications, in food industries, wastewater purification, and pharmaceutical formulations [11]. Microalgae can also be used for high-value food, health food for human, polysaccharides, food and fodder additives, cosmetics, antioxidants, anti-inflammatory objects, dyes and feed for aquaculture, and preparation of biofilms [3, 12, 13].

The most widely used microalgae include Cyanophyceae (blue-green algae), Chlorophyceae (green algae), Bacillariophyceae (including diatoms), and Chrysophyceae (including golden algae). **Table 1** highlights some major microalgal species, products, and their application.

Since the last 20 years, biotechnological and nutraceutical application of microalgae has focused specifically on four major microalgae: (a) *Spirulina* (*Arthrospira*), (b) *Chlorella,* (c) *Dunaliella salina*, and (d) *Haematococcus pluvialis*.

3.1 *Spirulina*

Spirulina is a prokaryotic cyanobacterium that has been commercially produced for over 30 years for uses including fish food, vitamin supplements, food dyes, aquaculture, pharmaceuticals, and nutraceuticals [15, 16]. *Spirulina* is manufactured by many pharmaceutical companies. This alga is thought of as a super food and is widely cultured, primarily in specifically designed raceway ponds and photobioreactors, to meet the current demand.

Spirulina is one of the algae studied for large-scale commercial culture. It grows best at a high pH (9–11) and high bicarbonate concentrations. Generally raceway ponds are used to culture *Spirulina*. The water depth in the pond is generally 300–500 mm depending on the physical–chemical parameters and density of microalgae. The depth is also dependent on pond size, water flow velocity, and light absorption by the algal culture. Water temperature and pH have a large effect on the productivity of this species. It grows well between the temperatures of 35 and 37°C [17]. *Spirulina* is a filamentous microalga; hence, its harvesting is relatively easy.

Spirulina contains 60–70% protein by weight (including many amino acids) and contains up to 10 times more beta-carotene than carrots per unit mass [18]. *Spirulina* is rich in nutrients such as B vitamins, phycocyanin, chlorophyll, vitamin E,

Group/species	Extract	Use/application
Arthrospira (*Spirulina*) *platensis*	Phycocyanin, biomass	Health food, cosmetics
Arthrospira (*Spirulina*)	Protein, vitamin B12	Antioxidant capsule, immune system
Aphanizomenon flos-aquae	Protein, essential fatty acids, β-carotene	Health food, food supplement
Chlorella spp.	Biomass, carbohydrate extract	Animal nutrition, health drinks, food supplement
Dunaliella salina	Carotenoids, β-carotene	Health food, food supplement, feeds
Haematococcus pluvialis	Carotenoids, astaxanthin	Health food, food supplement, feeds
Odontella aurita	Fatty acids, EPA	Pharmaceuticals, cosmetics, anti-inflammatory
Porphyridium cruentum	Polysaccharides	Pharmaceuticals, cosmetics
Isochrysis galbana	Fatty acids	Animal nutrition
Phaeodactylum triconutum	Lipids, fatty acids	Nutrition, fuel production
Lyngbya majuscule	Immune modulators	Pharmaceuticals, nutrition
Schizochytrium sp.	DHA and EPA	Food, beverage, and food supplement
Crypthecodinium cohnii	DHA	Brain development, infant health and nutrition
Nannochloropsis oculata	Biomass	Food for larval and juvenile marine fish

Adopted from [14].

Table 1.
The major microalgal species, products, and application.

omega 6 fatty acids, and many minerals [19]. *Spirulina* is used for weight loss [20], diabetes [21], high blood pressure, and hypertension [22]. It has documented antiviral [23, 24] and anticancer properties [25]. *Spirulina* positively affects cholesterol metabolism by increasing HDL levels, which can lead to healthy cardiovascular functions [26]. Romay et al. [27] described the antioxidant and anti-inflammatory properties of C-phycocyanin, which is a prevalent pigment in *Spirulina*. Essential amino acids like leucine, isoleucine, and valine are significantly present in *Spirulina*. *Spirulina* contains fatty acids like linolenic and γ-linolenic acid and ω-3 and ω-6 polyunsaturated fatty acids. *Spirulina platensis* is a natural source of DHA accounting up to 9.1% of the total fatty acids. The mineral content of *Spirulina* depends on the water in which it was grown, and its content of iron, calcium, and magnesium provides high nutritional value [16]. Belay et al. [18] reported that *Spirulina* powder contains provitamin A (2.330×10^3 IU/kg), β-carotene (140 mg 100/g), vitamin E (100 mg 100/g), thiamin B1 (3.5 mg 100/g), riboflavin B2 (4.0 mg 100/g), niacin B3 (14.0 mg 100/g), vitamin B6 (0.8 mg 100/g), inositol (64 mg 100/g), vitamin B12 (0.32 mg 100/g), biotin (0.005 mg 100/g), folic acid (0.01 mg 100/g), pantothenic acid (0.1 mg 100/g), and vitamin K (2.2 mg 100/g). The amino acid composition of *Spirulina* is given in **Table 2**.

3.2 *Chlorella*

Chlorella is a single-cell, spherical shaped (2–10 μm in diameter), and photoautotrophic green microalga with no flagella. It multiplies rapidly requiring only CO_2, water, sunlight, and a small amount of minerals. *Chlorella* has been grown commercially cultured in photobioreactors [28] and harvested by centrifugation or

Amino acids (g kg^{-1})	*Spirulina*	*Chlorella*
Alanine	47	48
Arginine	43	36
Aspartic acid	61	52
Cysteine	6	4
Glutamic acid	91	63
Glycine	32	34
Histidine	10	13
Isoleucine	35	26
Leucine	54	53
Lysine	29	35
Methionine	14	15
Phenylalanine	28	31
Proline	27	29
Serine	32	28
Threonine	32	27
Tryptophan	9	6
Tyrosine	30	21
Valine	40	36
Adapted from [16].		

Table 2.
Amino acid profile of Spirulina *and* Chlorella *microalgae (in mg kg^{-1}).*

autoflocculation. After harvesting the biomass is spray-dried, and the cell powder is sold directly. *Chlorella* contains 11–58% protein, 12–28% carbohydrate, and 2–46% lipids of its dry weight [29]. *It also* contains various vitamins such as β-carotene (180 mg 100/g), provitamin A (55,500 IU/kg), thiamin B1 (1.5 mg 100/g), vitamin E (<1 mg 100/g), riboflavin B2 (4.8 mg 100/g), niacin B3 (23.8 mg 100/g), vitamin B6 (1.7 mg 100/g), inositol (165.0 mg 100/g), vitamin B12 (125.9 mg 100/g), biotin (191.6 mg 100/g), folic acid (26.9 mg 100/g), and pantothenic acid (1.3 mg 100/g) [18, 30]. The amino acid composition of *Chlorella* is shown in **Table 2**.

Chlorella is able to decrease blood pressure, lower cholesterol levels, and enhance the immune system [16]. It also has the potential to relieve fibromyalgia, hypertension, or ulcerative colitis [31, 32]. The presence of aortic atheromatous lesions was significantly inhibited, and low-density lipoprotein (LDL) cholesterol levels were greatly suppressed upon consumption of *Chlorella* [33]. Some *Chlorella* consumers have mentioned a potential correlation between some brands of *Chlorella* tablets and nausea, vomiting, and other gastrointestinal issues. *Chlorella* has been labeled as a weak allergen and may be of clinical significance to certain types of people [34].

3.3 *Dunaliella*

Dunaliella (*D. salina)* is a unicellular green alga which contains large amounts of β-carotene, glycerol, and protein that can easily be extracted through its thin cell wall. *Dunaliella* does not required waters appropriate for agricultural and domestic uses and can be cultured in brackish water, marine water, and highly saline water. Global production of *Dunaliella* is estimated to be 1200 tons dry weight per year [16]. The dominant companies that produce *Dunaliella*, mainly for beta-carotene production, are located in Israel, China, the USA, and Australia and include Betatene, Western Biotechnology, AquaCarotene Ltd., Cyanotech Corp., and Nature Beta Technologies [35].

Dunaliella produces many carotenoid pigments with the dominant being beta-carotene and smaller amounts of lutein and lycopene [36]. Some strains of *Dunaliella* contain up to 14% of beta-carotene on dry weight basis. The total carotenoid content of *Dunaliella* varies with the physicochemical parameters and growth conditions. In optimal environmental condition, it can yield around 400 mg beta-carotene/m^2 of cultivation area [37]. Carotenoids from *Dunaliella* are potent free radical scavengers that reduce levels of lipid peroxidation and enzyme inactivation, thereby restoring enzyme activity. Research has shown beta-carotene to prevent cancer of various organs like the lungs, cervix, pancreas, colon, rectum, breast, prostate, and ovary by means of antioxidant activity [36]. It has also been shown to promote regression of certain types of cancer. Supplements of *Dunaliella* have also shown excellent hepatoprotective effects and reduced the occurrence of liver lesions [38].

3.4 *Haematococcus pluvialis*

Haematococcus pluvialis (*H. pluvialis*) is unicellular biflagellate freshwater green microalga. This species is known for its ability to accumulate large quantities of

Composition content (% of DW)	Green stage	Red stage
Proteins	29–45	17–25
Lipids (% of total)	20–25	32–37
Neutral lipids	59	51.9–53.5
Phospholipids	23.7	20.6–21.1
Glycolipids	11.5	25.7–26.5
Carbohydrates	15–17	36–40
Carotenoids (% of total)	0.5	2–5
Neoxanthin	8.3	n.d
Violaxanthin	12.5	n.d
β-carotene	16.7	1
Lutein	56.3	0.5
Zeaxanthin	6.3	n.d
Astaxanthin (including esters)	n.d	81.2
Adonixanthin	n.d	0.4
Adonirubin	n.d	0.6
Canthaxanthin	n.d	5.1
Echinenone	n.d	0.2
Chlorophylls	1.5	2 0

Adapted from [16].

Table 3.
Composition of H. pluvialis *biomass in green and red cultivation stages.*

strong antioxidant astaxanthin (up to 2–3% on dry weight) under any conditions. The principal commercial astaxanthin-producing microalga is *H. pluvialis* [9, 26]. Astaxanthin is used as a nutritional supplement and anti-inflammatory and anti-cancer agent for cardiovascular diseases and is recently recorded to prevent diabetes and neurodegenerative disorders and stimulates immunization. It also has anti-inflammatory properties and is used for various commercial applications in the dosage forms as biomass, capsules, creams, granulated powders, oils, soft gels, syrups, and tablets [39].

Photoautotrophic culture of *H. pluvialis* is mainly carried out in open raceway ponds or closed photobioreactors. The accumulation of astaxanthin is affected by environmental factors such as light, temperature, pH, salt concentration, and nutritional stresses. The cellular composition of *H. pluvialis* varies notably between its "green" and "red" stages of cultivation [40]. Specific biochemical characters of green and red stage of *H. pluvialis* are described in **Table 3**. The table shows that carbohydrate content in the green stage is approximately half of the red stage. *H. pluvialis* can accumulate approximately 5% DW of astaxanthin which is considered as a natural source of this high-value carotenoid protein [37].

3.5 *Aphanizomenon*

Aphanizomenon is a prokaryotic cyanobacterium commonly found in freshwater systems. There are approximately 500 tons of dried *Aphanizomenon* produced annually for use in food and pharmaceutical industries [41]. The dominant production source of *Aphanizomenon* in North America is Upper Klamath Lake and Klamath Falls, Oregon, and currently constitutes a significant part of the health food supplement industry throughout North America. *Aphanizomenon* contains a significant amount of C-phycocyanin, a light-harvesting pigment. It has antioxidant and anti-inflammatory properties [42]. *Aphanizomenon* also exhibits high

Component	*Spirulina*	*Dunaliella*	*Haematococcus*	*Chlorella*	*Aphanizomenon*
Protein	63	7.4	23.6	64.5	1.0
Fat	4.3	7.0	13.8	10.0	3.0
Carbohydrate	17.8	29.7	38.0	15.0	23.0
Chlorophyll	1.15	2.2	0.4 (red) 1.1 (green)	5.0	1.8
Magnesium	0.319	4.59	1.14	0.264	0.2
B-carotene	0.12	1.6	0.054	0.086	0.42
Vitamin B1 (thiamin)	0.001	0.0009	0.00047	0.0023	0.004
Vitamin B2 (riboflavin)	0.0045	0.0009	0.0017	0.005	0.0006
Vitamin B3 (niacin)	0.0149	0.001	0.0066	0.025	0.025
Vitamin B5 (pantothenic acid)	0.0013	0.0005	0.0014	0.0019	0.0008
Vitamin B6 (pyridoxine)	0.00096	0.0004	0.00036	0.0025	0.0013
Vitamin B9 (folic acid)	0.000027	0.00004	0.00029	0.0006	0.0001
Vitamin B12 (cobalamine)	0.00016	0.000004	0.00012	0.000008	0.0006

Adopted from [16].

Table 4.
Summary of referenced biochemical constitutions of average nutritional compositions (g per 100 g DW).

hypo-cholesterolemic activity, significantly greater than soybean oil, which decreases blood cholesterol and triglyceride levels [43–45]. It also produces polyunsaturated fatty acids (i.e., omega 3 and omega 6), a deficiency of which has been linked to immunosuppression, arthritis, cardiovascular diseases, mental health issues, and dermatological problems [16]. A summary on biochemical characters of all these economically important species is described in **Table 4**.

4. Summary

As the human population continues to increase, the demand for nutritive food and health products increases concomitantly. The sources of nutritive biomass that can meet this demand are pursued rampantly. Their wide diversity, fast growth, and diverse uses make them easily accepted for commercial culture. Microalgae require much fewer resources as compared to other crops. The role of algae in human health and nutrition will continually increase with additional research in the areas of health benefits and culturing. The usage of currently produced algae primarily includes food, food additives, aquaculture, colorants, cosmetics, pharmaceuticals, and nutraceuticals. Very few algal species are being cultivated for human use. There are likely more species of algae that have not been identified than ones that have and those still numbers in the thousands. Therefore, the potential for algal use in the realms of food consumption, health supplements, energy production, and many more is likely to intensify in the years to come.

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