Chapter 10
Recent Developments on Algae as a Nutritional Supplement

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10.1 Introduction

The increasing population and life threatening diseases are major growing concern of today's world. To meet the nutritional demand of the rising population, researchers are looking for alternative sources for food which are easy to cultivate, cost effective and produce large amount of bioactive compounds useful to prevent major diseases. Cultivation of algae is advantageous over other plant crops. Algae cultivation requires less water and terrestrial land. Furthermore, algae can be cultured using brackish or marine water resources. Algae are the source of many essential nutrients. They are a diverse group of autotrophic organisms ranging from unicellular to multicellular forms. Some of the algae are recognized as balance foods which offer sufficient quantity of proteins, carbohydrates, vitamins, and minerals for normal functioning of human body. Blue green algae, red algae and green algae are reported to have higher contents of dietary fibre.

The marine forms of algae are commonly called as seaweeds. They have been used as food and medicine for many centuries. The algal extracts are used as supplements in many food, dairy, and pharmaceutical industries. Algae are used as one of important medicinal sources due to its antioxidant, anticancer and antimicrobial properties.

In last few decades functional foods have emerged rapidly due to high market demands and promising health benefits. The new trend of research is inclined in development of algal fortified functional food items consumed popularly like pasta (Fradique et al., 2010), salad dressing (Gouveia et al., 2006), mayonnaises and

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gelled desserts (Batista et al., 2012). Incorporation of algae to food products serves various purposes like natural food colour and also as a source of high value bioactive compounds. Different species of microalgae are used for natural compounds for food industry. Apart from food, algae have various other applications in feed, pharmaceutical and production of biofuel. The bioactive compounds present in algae include carotenoids, sulphated polysaccharides, essential fatty acids, polypeptides, amino acids, vitamins and minerals (Gouveia et al., 2006). Microalgal pigments are an excellent source of natural food colours which can replace synthetic food colours used in industry. European Commission has recently committed to replace 46 synthetic food colours as these are allergic and showing hyperactivity in children (McCann et al., 2007).

10.2 Major Nutritional Components of Algae

10.2.1 Lipids and Fatty Acids

Glycolipids are major lipids present in algal cell. The other lipids present in lesser quantities are neutral and phospholipids. Lipids present in microalgae are in monogalactosyl, diacylgylerols, digalactosyl and phosphatidyl glycorel form and exhibit anti-inflammatory and anti-thrombotic activity (Antonopoulou et al., 2005). Microalgae are rich sources of long chain fatty acids like linoleic (C18:2), α-linolenic acids (C18:3) and palmitic acid (C16:0) than vegetable oils like soya or sunflower oil (Draaisma et al., 2013). The most interesting fact of marine algae is that it contains large amount of ω-3 polyunsaturated fatty acids (PUFAs) of eicosapentaenoic acids (EPA, 20:5) and docossahexaenoic acid (DHA, 22:6). These functional fatty acids are traditionally extracted from marine fishes mainly from Salmon, Cod and Tuna. Marine algal oil rich in PUFA are an excellent alternative source of nutrition for vegetarian population. An EPA content of 39 % of total fatty acids is documented in *Phaeodactylum tricornutun* and *Nannochlorpsis sp* (Adarme-Vega et al., 2012). Docosahexaenoic acid (DHA) extracted from *Crypthecodinium cohnii* or *Schizochytrium* sp. for formulation of infant food are marketed by Martek Biosciences (Kyle et al., 1995).

The fatty acid profiling of *Spirulina platensis* reveals that it is a rich and active source of lauric, palmitoleic and oleic acids. The super critical extract of same algae does not possess a significant amount of γ-linoleic acid (GLA) in the fatty acid extracts (Mendiola et al., 2007). The marine seaweeds are also a very good source of ω-3 and ω-6 fatty acids. According to the studies conducted by MacArtain et al., *Palmaria* and *Sargassum* species have well balanced ω-3/ω-6 ratio along with highest lipid content of 3.8 % and 3.9 % respectively. Another polyunsaturated fatty acid known as oleic acid are present abundantly in *Gracilaria* sp., *Ulva* sp. and *Fucus* sp. (Ortiz et al., 2006).

10.2.2 Sugars and Polysaccharides

Algal cell wall has rigid structure due to accumulation of various sugars and polysaccharides. Algal cells are highly efficient for photo conversion and can accumulate upto 50 % carbohydrate in dry weight basis. Polysaccharides deposited in cell walls act as a shield to sustain in tides and ocean currents. Different algal species synthesize different sugars and polysaccharides as a storing material. In cyanobacteria, glycogens are produced whereas in green algae amylopectins are present in the cell wall.

Seaweeds contain sulphated polysaccharides, fucoidan, polyelectrolytes like alginates, carrageenans, agarans etc. The species rich in polysaccharides mainly belong to brown algae or pheophycea family and are prevalent in coastal area. *Ascophyllum*, *Porphyra* and *Palmaria* are few brown algal species which contain very high amount of hetero polysaccharides. The green seaweed *Ulva* also contains huge amount of hetero polysaccharides (65 % on dry weight basis). The nutrient availability and stress factors like light, pH and salinity around the residing environment of macro algae mostly determine the sugar content present in the algal cell wall. Macro algae contain large amount of fucose, mannose, galactose, glucose and uronic acid. *Sargassum vulgare* contains upto 70 % carbohydrates in dry weight basis. The polysaccharides present in *Sargassum* sp. exhibits potential antiviral action as it contains alginic acid, xylofucans and fucans.

Seaweeds are rich sources of dietary fibres. According to literature the dietary content in edible seaweed varies from 33 % to 62 % of the total fibres on dry weight basis. There are two varieties of dietary fibres present in seaweeds namely soluble and insoluble dietary fibres. The soluble dietary fibres include laminarin, porphyran, furonan and alginic acids. The insoluble dietary fibre include cellulose, hemicelluloses, mannans and xylans. Highest amount of total dietary fibres are present in Undaria (58 %) followed by Fucus (50 %), Porphyra (30 %) and Saccharina (29 %).

Another interesting species of microalgae is *Phorphiridium* sp. It is encapsulated with sulphated polysaccharides and composed of 10 different sugars. The prominent sugars present in these algae are xylose, glucose and galactose. Mannose, methylated galactose and pentoses are present in small quantities. The glucoronic acid and sulphur ester groups present in the cell of *Phohiridium* species negatively charge the cell wall.

10.2.3 Proteins and Essential Amino Acids

Microalgae are richest source of single cell proteins. *Spirulina* sp. which is the most investigated microalgae till date contains protein up to 70 % in dry weight basis (González-Benito et al., 2009). The amino acid present in *Spirulina* species also has high percentage of protein digestibility (Habib, 2008). The other high protein containing species are *Chlorella vulgaris* (55 %) and *Dunaliella* sp. (57 %). Samarakoon and Jeon (2012) did a comparative analysis of defatted soyabean flour and microalgal powder of *Nannochloropsis* spp., *Porphyridium cruentum* and *Phaeodactylum tricornutun* and found that the former two species are rich in hydrophobic and hydrophilic amino acid than soya flour.

Phycobiliproteins are the accessory pigment present in microalgal strains in enormous quantity. These proteins are derived during photosynthesis. *Spirulina platensis* contains a significant amount of phycobiliproteins in their cell matrix. The other pigments attached with phycobiliproteins are phycocyanin giving blue green colour to cyanobacteria: phycoerithrin and allophycocyanin (Viskari and Colyer, 2003). The phycobilin proteins have important pharmacological benefits to human health. It acts as therapeutic medicine to various cancer cells specially leukaemia treatment (Subhashini et al., 2004). The purified form of phycobilin proteins are used in cosmetic industry, natural food colour and as fluorescent labels in analytical chemistry (Kronick, 1986).

10.2.4 Vitamins

Both micro and macro algae accumulates essential vitamins and minerals due to their autotrophic nature. The algal biomass is richer in depositing water soluble vitamins (B_1, B_2, B_6, B_{12}, C) than Baker yeast and meat. Microalgae accumulates vitamin in larger quantities as compared to soyabeans and cereals. The rhodophycean and chlorophycean group of algae do not synthesize vitamin B_{12} but can derive it from other bacteria grown together with the algae (Becker, 2004). The brown seaweed species of *Ascophyllum*, *Fucaceae*, *Fucus* sp. contain large amount of α, β and γ tocopherol or vitamin E. Total 200–600 mg kg^{-1} of vitamin E is available in the above mentioned brown seaweed species in dry weight basis. The green algae contains only α-tocopherol. Vitamin E has high antioxidative capacity and prevents oxidation of algal lipids (Jayashree & Kamat, 1985).

10.3 Functional Properties of Algae

10.3.1 Antioxidant Activity

Antioxidant activities have been recognized in various forms of algae, especially from the marine origin like red algae, green algae and brown algae. Various forms of anti-oxidant assays, like 1,1-diphenyl-2-picrylhydrazyl (DPPH), superoxide anion (O_2), hydroxyl radical ($OH^{•}$) and peroxyl radical (ROO•), were conducted by many researchers on different algal species to prove its antioxidant potential. Radical scavenging activity using DPPH have revealed antioxidant effects of a methanol extract of the blue-green algae *Anabaena* species. Ascorbate, iron and

H_2O_2 assays have also revealed antioxidant effects of phycobiliprotein phycocyanin in *Spirulina platensis* extract. The potent antioxidant properties of *Ulva lactuca* is associated mainly with its flavonoids contents. Radical scavenging activity of the green algae *Ulva fasciata* Delile was found to be associated mainly with its sesquiterpenoids. Animal studies of hot water extract of *Ulva reticulate* found it to reduce hepatic oxidative stress (Rao et al., 2004).

Sometimes, the antioxidant properties of algal extract are showing more specific reaction. For example, studies on methanol extracts of *Fucus vesiculosus* and *F. serratus* have shown to protect DNA damage of human epithelial colorectal adenocarcinoma cells (Caco-2) induced by H_2O_2. However, the same extract fails to protect DNA damage induced by tert-butyl hydroperoxide. A similar study conducted by O'Sullivan et al. (2011) using methanolic extracts of *Pelvetia canaliculata* reported that the extract have inhibited H_2O_2 induced superoxide dismutase depletion in Caco-2 cells. Solvent extracts from red algal species also showed antioxidant properties. Ethanol extracts of *Callophyllis japonica* suppressed H_2O_2 induced cellular apoptosis (Kang et al., 2005). Phlorotannins compounds from brown algae like *Eisenia bicyclis*, *Ecklonia cava* and *Ecklonia kurome* showed DPPH radical scavenging activities (Shibata et al., 2008).

10.3.2 Anti-Cancer Activity

Algal species are possessing variety of intra cellular compounds which showed anticancer properties. Various studies on algae showed that the polysaccharides are the major components that exhibit anti-cancer properties. *Spirulina platensis* extracts showed chemo preventive effect against carcinogenesis induced by dibutyl nitrosamine. The extract from the *Spirulina maxima* suppressed the expression of Bcl2 in A549 cells and inhibited viability of other human cancer cells. de Jesus Raposo et al. (2013) stated that polysaccharides from red microalgal species showed anticancer properties in two human tumour cell lines MCF-7 and HeLa. Cancer preventive action of the polysaccharides from the microalga *Porphyridium cruentum* was also reported by Gardeva et al. (2009). Sulphated polysaccharides from tropical green algae showed promising anticancer activities. Up to 58 % inhibition of HeLa cell proliferation was shown by sulphated polysaccharides isolated from *Caulerpa prolifera*. Two polysaccharide fractions obtained from the green alga *Caulerpa racemosa* showed anticancer properties against H22 tumour transplanted in mice. At a dose of 100 mg kg^{-1} d^{-1} these two fractions showed anti-tumour activity up to 84 % and 54 % in 48 h and 14 h, respectively (Ji et al., 2008).

Among marine algae, brown and red algae have been studied more as the sources of polysaccharides with anti-cancer and anti-tumour properties than green algae. The anti-cancer and anti-tumour properties of these marine algae are mainly associated with a specific group of polysaccharides called ulvans. Ulvans are water soluble sulphated polysaccharides normally found in the cell walls of marine green algae. These ulvans are characteristic of the plants, belonging to the genera *Ulva*, *Enteromorpha, Monostroma, Caulerpa* etc. Water-soluble sulphated polysaccharide fractions of *Enteromorpha prolifera* showed *in vivo* and *in vitro* stimulation of immunity by significantly increasing ConA-induced splenocyte proliferation and induced the production of various cytokines via up-regulated m-RNA expression. Double the response was found with ulvan obtained from *Ulva rigida*. Increase in the expression of cytokines stimulated the activity of macrophages as well as induced an increase in COX-2 and NOS-2 expressions (Leiro et al., 2007). Ulvans from *Ulva pertusa* showed significant enhancement of immunity and cytokine production. They had little cytotoxicity against tumour cells. There are also several studies conducted on the antioxidant activities of ulvans in experimental rats against hepatitis.

In case of brown algae, extensive research on its crude extracts against different cancer cell lines showed promising anticancer potential. The *in vivo* studies on antitumour activity of brown algae showed the importance of these seaweeds for cancer therapy. The enzymatic extract as well as crude polyphenolic and polysaccharide fractions of *Ecklonia cava* showed antiproliferative activity against murine colon cancer cell line (CT-26), human leukemia (THP-1), mouse melanoma (B-16), and human leukemia (U-937) cells. The nuclear staining experiment showed that activity against CT-26 cells was due to apoptotic cell demise. The remarkable anticancer and antitumour properties of various brown algae are due to the presence of sulphated polysaccharide of fucoidan and carotenoid of fucoxanthin. They were found to be the most important active metabolites of brown algae as potential chemotherapeutic or chemopreventive agents. Some of the studies on brown algae that showed anti-cancer properties are listed in Table 10.1. In addition to fucoidan and fucoxanthin, alginic acid in brown algae also showed some cancer preventive properties. The alginic acid is an anionic polysaccharide distributed widely in the cell walls of brown algae. They have the ability to neutralize toxins and heavy metals by binding them in intestines and convert into a chemical which is less detrimental to human. Apart from brown algae, red algae also showed anti-cancer properties in research studies. Several well known polysaccharides from red algae have wide application in microbiology, biotechnology and food technology due to their gelling properties. Carrageenans are the best examples. Carrageenans indirectly showed anti-cancer properties by increasing antioxidant, antiviral and antitumour immunity.

10.3.3 Anti-Microbial Activity

Most of the studies on algal species showed that they are the actual producers of many biologically active secondary metabolites which are having antimicrobial effect. Some of this secondary metabolite includes polysaccharides, quinines, alkaloids, cyclic peptide, phlorotannins, diterpenoids and sterols. Several researchers made efforts to bring out these bioactive substances from algae using different methods. Screening of different classes of algae for their antibiotic value is recorded in many literatures.

Table 10.1 Some selected studies on brown algae that showed anti-cancer properties

Cell-lines showing positive response	Algal species used	Sample used for studies	Reference
Ehrlich carcinoma	*Sargassum ringgoldianum,*	Powdered tissue	Shevchenko et al. (2007)
	Lonicera japonica,		
	Lessonia nigrescens,		
	Scytosiphon lomentaria		
Mammary tumour cells	*Undaria pinnatifida*	Aqueous extract	Thinh et al. (2013)
Breast cancer,	*Undaria pinnatifida*	Aqueous extract	Synytsya et al. (2010)
Mammary carcinogenesis			
Human breast adenocarcinoma,	*Padina pavonica,*	Methanolic extract	Li et al. (2006)
Human prostate cancer cells	*Cystoseira mediterranea*		
Human leukaemic T cell lymphoblast,	*Sargassaceae sp.,*	Aqueous extract	Chizhov et al. (1999)
Human Burkitt's lymphoma,	*Dictyota dichotoma,*		
Human chronic myelogenous leukaemia	*Desmarestia ligulata*		

Of all classes of algae, seaweeds take up an important place as a source of antimicrobial compounds. Apart from antimicrobial properties, the biomolecules from seaweeds are also reported to have anticoagulant and antifouling properties (Marechal et al., 2004). Some of the antimicrobial compounds derived from algae are acrylin acid, chlorellin, aliphatic compounds, phenolic inhibitors, sesquiterpenes, diterpernoids, etc.

The aqueous extract of selected macroalgae (*Ulva fasciata, Gracilaria corticata, Sargassum wightii* and *Padina tetrastromatica*) from south-west coast of India showed significantly higher anti-bacterial activity. Gram negative bacterial species are highly sensitive than Gram positive bacterial species. The maximum zone of inhibition was noted with *G. corticata* against *Proteus mirabilis* and *P. tetrastromatica* against *Staphylococcus aureus* and *Vibrio harveyi*. The green algal extract of *Cladophora fascicularis* when tested against three pathogens viz. *Staphylococcus aureus*, *Escherichia coli* and *Bacillus subtilis* showed significant inhibitory effect which was due to an ether containing compound present in the extract. Dubber and Harder (2007) in their studies showed that methanolic and hexane extract from three different macroalgal species (*Mastocarpus stellatus, Laminaria digitata* and *Ceramium rubrum*) have anti-microbial activity against 12 fish pathogens.

Ulva lactuca, commonly called as Sea lettuce, was reported to have antimicrobial activity. These green algae have long been used as traditional food to treat helminthic infections and urinary diseases. Its antimicrobial activity is due to the presence of acrylic acid. Apart from *Ulva lactuca*, three different seaweeds which include *Padina gymnospora, Sargassum wightii* and *Gracilaria edulis* were also shown to have severe antimicrobial activity against common human bacterial pathogen. Methanolic extracts of 32 different macroalgae isolated from Atlantic and Mediterranean coastal area of Morocco were found to have antibacterial property against *S. aureus*, *E. coli*, *Enterococcus faecalis* and *Klebsiella pneumonia* (Ibtissam et al., 2009). Aqueous extract of *Dictyota dichotoma* and *Padina gymnosora* from Indian waters were effectual against *Bacillus megatherium* and *S. aureus*. Green algal extract of *Caulepra prolifera* showed significant anti-microbial activity against common marine bacterial strains. *Zandariania prototypus*, *Cystoseria sricata* and *Cymbula compressa* when extracted with ethanol showed inhibitory effect against bacteria and fungi. Similarly, El-Naggar (1987) reported that extracts of marine algae, *Dictyota dichotoma*, *Dilophus fasciola* and *Cystoseria barbata* isolated from Egyptian water were found to have significant antibacterial activities against common human pathogens.

In vitro studies on selected human upper respiratory tract pathogens treated with extracts of seaweeds showed significant positive effect. Various seaweed species belonging to the family *Chlorophyceae, Phaeophyceae* and *Rhodophyceae* that were isolated from coastal region of South Africa showed strong antibacterial activity. The level of antimicrobial activity of various marine algal extracts varies with the season during which it was isolated for studies at the same location. Another group of compounds that are more frequently reported for its anti-microbial properties is bromophenol compounds. They are found widely in many marine species of red and brown algae, and especially rich in the red algae of family *Rhodomaceae* (Oh et al., 2008). These bromophenol compounds are exhibiting a wide spectrum of pharmacological properties which includes enzyme inhibition, cytotoxic, antioxidant, antinflammatory and antimicrobial activities.

Al-Saif et al. (2013) studied antimicrobial activity of various solvent extracts of five different algal species (*Caulerpa occidentalis*, *Cladophora socialis*, *Dictyota ciliolata, Gracilaria dendroides* and *Ulva reticulata*) isolated from Red Sea coastal area in Saudi Arabia. The extracts obtained from the red alga *G. dendroides* showed better action against the tested common pathogens of human (*Escherichia coli, Enterococcus faecalis, Pseudomonas aeruginosa* and *Stapylococcus aureus*) followed by the green alga *U. reticulata*, and brown algae *D. ciliolata*. The reason for the better activity of *G. dendroides* was revealed by analyzing its chemical composition, where it showed highest percentages of fats, proteins and other flavonoid groups. Out of the four different extracts obtained from four different solvents (chloroform, ethanol, petroleum ether and water), chloroform extract showed significant antibacterial activity followed by ethanolic extract.

10.3.4 Anti-Inflammatory Activity

Oxidative stress plays a major role in the development of cancer, endothelial dysfunction, lung diseases, gastrointestinal disorder and atherosclerosis. All these diseases involve inflammatory reactions. Many naturally occurring food materials are

Table 10.2 Bioactive compounds from various algal sources (anti-inflammatory property)

Bioactive compounds	Organism	References
C-phycocyanin	*Spirulina platensis*	Shih et al. (2009)
Sulphated galactofucan	*Lobophora variegata*	Medeiros et al. (2008)
Alginic acid	*Sargassum wightii*	Sarithakumari et al. (2013)
Galactan	*Gelidium crinale*	Silva et al. (2010)
Methanol extract	*Neorhodomela aculeata*	Lim et al. (2006)
Fucans	*Lobophora variegate*	Siqueira et al. (2011)
Lectin	*Pterocladiella capillacea*	Silva et al. (2010)
Methanol extract	*Bryothamnion triquetrum*	Cavalcante-Silva et al. (2012)
Sulphated polysaccharide fraction	*Gracilaria caudate*	Chave et al. (2013)
Mucin-binding agglutinin	*Hypnea cervicornis*	Silva et al. (2010)

having variety of antioxidants that play a major role in anti-inflammatory activity. Algal species are the major sources of naturally occurring antioxidant, especially the marine algal species. Bowel inflammation are caused due to various reasons, one among them is increased formation of acetic acid, especially during fasting. Animal studies using rats showed that the acetic acid induced inflammation. This is effectively reduced by the crude extract of *Dunaliella bardawil*, a green algae rich in beta-carotene. Lycopene from *Chlorella marina* showed the anti-inflammatory activity against arthritis in rat model studies. Similarly, in a sheep model study conducted by Caroprese et al. (2012), extracts rich in phytosterols obtained from *Dunaliella tertiolecta* showed significant anti-inflammatory effects. The various bioactive compounds from different algal sources showing anti-inflammatory property are listed in Table 10.2.

10.4 Algal Nutraceuticals and Its Safety Issues

Algae are a diverse group of photo autotrophs that have ability to grow quickly by using light, CO_2, and produce more biomass per acre than plants. When referred to food supplement, microalgae plays an important role as a best source. Some of the important genus in microalgae that are more prevalent in food supplements are *Spirulina, Chlorella, Dunaliella, Nostoc, Botryococcus, Anabaena, Chlamydomonas, Scenedesmus* etc. Most of the microalgal groups are having almost balanced nutrient content which include vitamins, minerals, essential amino acids and fatty acids. Growing concern among consumers on proper nourishment along with increasing population, easy and cost-effective sources of food supplement are in demand. Due to plentiful production of beneficial compounds and easy for cultivation, the market for algal-based nutraceuticals are coming up with very profitable outcome. Since microalgae are commonly used as food and feed supplements, some of the microalgae of commercial importance are described in this chapter. Bishop and Zubeck (2012) report very well described the use of microalgae especially *Spirulina, Chlorella, Dunaliella, Haematococcus* and *Aphanizomenon*, as nutritional supplements and also explained about their challenges.

Spirulina is a rich source of vitamins, pigments, antioxidants and essential fatty acids along with numerous minerals. The major issue with consumption of *Spirulina* was its digestibility index and bioavailability of selected nutrients like vitamin B_{12}. This issue was also sorted out by using efficient post-harvest processing steps that improve the digestibility index and bioavailability of *Spirulina* biomass. Another issue is the identification of toxins called microcystin in the biomass. This microcystin was reported to cause liver cancer and other diseases. However, the traces of the toxin microcystin in biomass were due to invasion of other algae like *Microcystis* sp. in the *Spirulina* cultivation area. *Spirulina* as such was devoid of any toxin that is harmful for human consumption. Also *Spirulina* was reported to accumulate heavy metals in their biomass. But again this issue arises only in the species that was obtained from uncontrolled environment. Usually those species are employed for biofuel production and not for food purposes. In spite of the production of *Spirulina* sp. from the controlled environment there are some side effects viz. diarrhea, nausea and vomiting that were reported with the use of *Spirulina* products. The exact reason for that is still not clear.

Like *Spirulina*, the green algae *Chlorella* is also one of the nutrition-rich microalgae used as food supplement worldwide. It contains approximately 60 % protein along with other essential minerals and vitamins. The protein of *Chlorella* contains all essential amino acids required for the nutrition of heterotrophic organisms. Lutein and xanthophylls are also found abundantly in the *Chlorella* sp. *Chlorella* extracts were shown to have various properties like antitumor, antioxidant, anti-inflammatory, antimicrobial activities etc. It was also reported to control blood pressure, lower cholesterol levels, and enhance the immune system. Though benefits of *Chlorella* sp. are enormous, some investigations were also carried out to find out the possible side effects of *Chlorella* sp. Sometimes *Chlorella* products are labeled and sold in the market as low allergen which may be of clinical significance to certain types of people. Some consumers have reported few side effects after consumption of *Chlorella* biomass tablets and capsules which include low digestibility, nausea, vomiting, and other gastrointestinal related problems (Tiberg et al., 1995). This may be due to the improper processing of biomass before consumption. *Chlorella* tablets have been reported to cause acute tubule-interstitial nephritis often resulting in renal failure. Apart from some negative effects of *Chlorella* products, cultivation of *Chlorella* is also more challenging as well. Unlike *Spirulina*, *Chlorella* cultivation systems are expensive and often become contaminated by other algae.

Dunaliella is well known for its pigment beta-carotene, which accounts for up to 14 % of its dry weight. An ideal growth condition can yield up to 400 mg beta-carotene m^{-2} using *Dunaliella* sp. The other major pigment includes alpha-carotene, lutein and lycopene.

Dunaliella carotenoids are having potent antioxidant properties that reduce levels of lipid peroxidation and enzyme inactivation. Studies have shown beta-carotene of *Dunaliella* can prevent cancer of various organs like lungs, stomach, colon, rectum, breast, prostate and ovary by means of its antioxidant activity. Despite the advancement in the production of beta-carotene from natural sources like *Dunaliella*, more than 90 % of commercialized beta-carotene is produced synthetically which pose a challenge for extraction of beta-carotene from *Dunaliella* sp. However, natural beta-carotene has a higher bioavailability as compared to synthetically manufactured beta-carotene. Further, the activity and amount of the antioxidant enzymes were significantly greater in *Dunaliella* as compared to synthetic. In case of *Dunaliella* only little data are there to show its negative effects. Multigenerational studies with rats that consumes up to 10 % *Dunaliella* in their diets also showed no significant negative effects. Thus it was indicative on the safety of *Dunaliella* for the human consumption.

Haematococcus sp. is a green alga that has wide applications in nutraceuticals, pharmaceuticals, cosmetics and aquaculture industries. The major pigment produced by *Haematococcus* sp. is the red coloured astaxanthin, which makes *Haematococcus* cells to appear red. United States, India and Israel are said to produce approximately 300 tons dry weight of *Haematococcus*. Astaxanthin is sold in the market at $2500 per kilogram dry weight with an annual worldwide market estimated at $200 million. However, 95 % of this market is covered by synthetically derived astaxanthin (Lorenz and Cysewski, 2000). *Haematococcus* is cultivated commercially in large-scale outdoor systems and controlled photobioreactors, predominantly for astaxanthin. Some of the major players worldwide in the production of *Haematococcus* include Cynotech Corporation, Parry Nutraceuticals, BioReal, Inc., Alga Technologies, Fuji Health Science, Valensa International, and Aquasearch Inc. So far none of the reports showed its negative consequences upon ingestion (Marazzi et al., 2011). Animal studies also showed no adverse effects of consuming 5 to 18 g/kg. *Haematococcus* algal extract containing astaxanthin was also tested on humans for adverse clinical parameters which showed no evidence of adverse effects even upto 20 mg/day for four weeks (Satoh et al., 2009). Food and Drug Administration (FDA) has approved for the selling of *Haematococcus pluvialis* as a new dietary ingredient in the United States.

Aphanizomenon is a blue-green alga commonly found in freshwater systems. Approximately 500 tons of dried *Aphanizomenon* is estimated to be produced annually for use in food and pharmaceutical products. The major players in this field of Aphanizomenon production for food supplements are Cell Tech International Inc., Life Enthusiast Co-op, AquaSource and Klamath Valley Botanicals, Inc. *Aphanizomenon* sp. also showed no major side effects. Aphanizomenon flos-aquae, the dominant species used in production has not been shown to produce hepatotoxins (Carmichael et al., 2000).

10.5 Future Scope and Conclusion

Demand for nutritive food and health products increases parallel with the increase in human population. Algae are one of the best sources to meet nutritive demands due to their fast growth and better health benefits. The role of algae in human health and nutrition will increase with more research in this area. Currently algae are produced for food, aquaculture, colorants, cosmetics, pharmaceuticals and nutraceuticals purposes. But usage wise only small fraction is used for human food. Many algal species are still unexploited for its use as food and nutraceuticals purposes. So, there are more chances to enhance algal production and its usage. If the ability to use algae as functional food is developed by consumers on regular basis, undoubtedly there will be a continual interest on its value addition by researchers and manufacturers.

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