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MICROALGAE - MACROALGAE BASED NUTRACEUTICALS AND THEIR BENEFITS

Hilal Kargın [1]*, Murat Bilgüven [2]

[1] Mersin University Faculty of Fisheries,
Basic Sciences Department, Yenişehir Campus, C-Block, 33169 Yenişehir, Mersin, Turkey
[2] Mersin University Faculty of Fisheries,
Department of Aquaculture, Yenişehir Campus, C-Block, 33169 Yenişehir, Mersin, Turkey

Abstract
Algae produce some substances that have a positive effect on human health. Algae are known as sources suitable for use in food and foods with the bioactive components they produce at a high rate. These ingredients are called nutraceuticals. Nutraceuticals are products that have physiological benefits and are protective against chronic diseases and are generally recommended to be used as medicines. Bioactive nutraceuticals from aquaculture; fish oil (ω-3), seal blubber oil, algae oil, shark liver oil, shark cartilage, chitin, chitosan as well as enzymes, peptides and their components, vitamins (vitamin A,D,E, β carotene), macroalgae and its components, protein hydrolysates and other products. It is known that these high-value components in algae regulate immunity, prevent diabetes, oxidation, inflammation, high cholesterol and cardiovascular diseases, and have positive effects against obesity and unbalanced nutrition. In this review, information is given about micro and macroalgae-based nutraceuticals, their application areas and potential health benefits.

Keywords: Microalgae, Macroalgae, Nutraceuticals, Functional food, Bioactive components.

1. INTRODUCTION

It is known that algae produce some substances that have a positive effect on human health. Algae come to the forefront as suitable sources for use in food and foods because of their high content of components such as protein, polysaccharide, carbohydrate, lipid, vitamin, mineral, amino acid, fatty acid, carotenoid and the bioactive components they produce. Algae contain many bioactive components with wide biological activities such as antioxidant, antibacterial, antiviral, and anticarcinogenic, these components are called nutraceuticals. Phycocolloids, which are used as active and auxiliary substances in pharmacy, are obtained from marine algae. In addition, antioxidant compounds in algae have an important place in the fight against free radicals, which are formed during the functioning of the metabolism and are the initiator of some chronic diseases (Ranga Rao and Ravishankar, 2018).

Macroalgae are plant organisms that form the feeding, shelter, and breeding environment for aquatic organisms (Ak, 2015). Macro-microalgae are classified under very large groups according to their cell structure, the pigments they form and the cell materials they store, and they have been used for many years as human food due to their nutraceutical properties or in the production of

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

important food additives such as alginates and carrageenan. Commonly known as "seaweeds" or "sea vegetables", macroalgae have been used by humans for generations as food, soil conditioner or fertilizer. While seaweed is considered a nutrient due to its high nutritional content and low caloric value in many Asian countries, especially in China, Japan and Korea, it is traditionally used as a source of phycocolloid and animal feed in western countries (Paiva et al., 2016; Paiva et al., 2017). Today, macroalgae are used as food, fertilizer, phycocolloid and cosmetic components, the main market of which is in Asia. Despite this, the industrial production of macroalgae is not at the expected levels (Milledge and Harvey, 2016; Barka and Blecker, 2016). The fact that they are very rich in terms of nutrients has made macroalgae to be considered the food additive of the century (Kılınç et al., 2013). In addition to their nutritional values, macroalgae attract attention as "functional food" (De Quirós et al., 2010; Wells et al., 2017). Although they contain high levels of mono and polyunsaturated fatty acids, macroalgae with very low-fat content are known as healthy food sources that are very rich in carbohydrates and protein. Macroalgae differ greatly from land-grown vegetables by containing all essential amino acids, vitamins A, C, E and B complex, and mineral substances such as Na, Mg, P, K, I, Fe, Zn. (Circuncisão et al., 2018). Macroalgae are important sources for many cultures, especially East Asia, and can be used in products such as soup, salad, stew, and sushi. It is stated that some species of the 32.4 million tons of seaweed grown in the world in 2018 are primarily grown as direct human food. Examples of these are *Undaria pinnatifida*, *Porphyra* spp., *Caulerpa* spp. (FAO, 2018; FAO, 2020). Today, it is reported that the most consumed species among macroalgae are brown (66.5%), red (33%) and green (5%) algae, respectively (Afonso et al., 2019). The brown seaweed *Laminaria* sp. (kombu), *Undaria* sp. (wakame), *Hizikia fusiforme* (hiziki) are important sources especially for Asian countries such as China and Japan. Laminaria has been used in Japan, while Undaria has been used in Japan, China and Korea for many years. *Cladosiphon okamuranus* (mozuku) is used as a salad in Japan, *Sargassum* sp. is consumed as a soup in Korea or used with soy sauce after processing (Kılınç et al., 2013). Fucus vesiculosus finds application as a functional ingredient in many foods in order to prevent oxidative deterioration due to the fluorotannin and antioxidant compounds it contains (Afonso et al., 2019). *F. vesiculosus* was added to apple juice (Poveda-Castillo et al., 2018) to control unwanted microorganisms due to fucoidan compound, which has bacteriostatic and bactericidal effects, and to wheat flour (Arufe et al., 2018) to improve the rheological properties of bread dough. positive results have been obtained. *Laminaria sp.* is one of the most economically important algae species and is used as a raw material in alginate production worldwide. Fucoxanthin, a carotenoid obtained from brown macroalgae and diatoms, is industrially extracted mostly from *U. pinnatifida* (Abu Ghannam and Shannon, 2017). Brown algae extracts can be used as emulsifiers in dairy products such as ice cream and cheese and bakery products due to the phycocolloids they contain (Sudhakar et al., 2018). It was determined that the addition of *U. pinnatifida* to pasta improves the biofunctional properties of pasta, increases the interaction between starch and protein matrix and improves the quality of pasta. Green seaweed, *Ulva sp.*, *Enteromorpha sp.*, *Monostroma* sp., *Caulerpa sp.*, *Codium sp*., is generally consumed as a direct food source, especially in Asian countries, they are consumed raw, dried or cooked (Kılınç et al., 2013). *Caulerpa lentillifera*, known as "sea currant" or "green caviar", is considered as food (Gomez-Zavaglia et al., 2019). *Ulva* species are traditionally consumed in the form of "aonori" in Japan. Aonori is a mixed type crop that also includes green algae such as *Monostroma latissimum* and *Enteromorpha prolifera*. *Ulva lactuca*, known as "sea lettuce" or "green laver", is used in salads and soups in Europe (Yu-Qing et al., 2016). Since ulvan, a hydrocolloid obtained from *Ulva*

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

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species, can replace gelatin with its rheological and gelling properties, it is stated that this component can be used in meat-derived products (Vázquez-Rodríguez and Âmâya-Guerra, 2016). The red macroalgae *Porphyra* is the most widely consumed seaweed in the world and is sold in markets as dried, thin leaves to prepare sushi. As a result of the re-evaluation of the *Porphyra* genus, some species belonging to this genus were transferred to the *Pyropia* genus. Therefore, in some sources *Porphyra* spp. (laver), *Pyropia* spp. (nori) expressions can be encountered. In general, it is stated that laverine is obtained from the red algae *Porphyra* and *Pyropia* genus (Cho and Rhee, 2020). Nori, which is consumed in Japan, China, Korea and other Asian and Western Pacific societies, is also used as a complement in rice, soups and salads (Jibril et al., 2016). Porphyra species are also known to be traditionally used in the production of "laver bread" in Wales (Fitzgerald et al., 2011).
Nutraceutical additives are products that are obtained by isolating or purifying from foods, have physiological benefits and protect against chronic diseases, and are generally recommended to be used as medicine-like products. Foods gain functional quality by enriching them in terms of components that have a positive effect on certain functions of metabolism in order to live healthier or to protect against various diseases (Eyyüboğlu, 2000). Nutraceuticals represented as functional foods or functional food ingredients; they are nutritional supplements that have been found to provide many health benefits, including the prevention and treatment of disease (Alasalvar et al., 2002). Microalgae-based nutraceuticals offer a wide range of applications and usage alternatives for human nutrition, from antioxidants to anti-aging.
Bioactive nutraceuticals from aquaculture; animal oil (ω3 polyunsaturated fatty acids), seal blubber oil, algae oil, shark liver oil, shark animal tissue, chitin, chitosan furthermore as enzymes, peptides and their parts, vitamins (vitamin A, β-carotene, vitamin D, vitamin E), alga (macroalgae) and their parts, supermolecule hydrolysates and alternative product (Fleurence, 1999; Boydreau, 2000).

2. FOOD IMPORTANT MICROALGAE

Biotechnological and nutraceutical applications of microalgae are particularly focused on four main microalgae: *Spirulina* (*Arthrospira*), *Chlorella*, *Dunaliella salina* and *Haematococcus pluvialis* (Walker et al., 2005).
Spirulina (Arthrospira) has high protein content and nutritional value (Alçay et al. 2017) and has gained worldwide popularity as a food supplement. *Spirulina* also has an amino acid content of 62% and is a rich natural source of phytopigments including vitamins A, B_1, B_2, B_{12}, carotenoids and xanthophyll. *Spirulina* is one of the richest sources of algae containing γ-linolenic acid (GLA). GLA is a polyunsaturated fatty acid and a powerful nutraceutical Spirulina is an excellent source of phycobiliprotein. Due to their high free radical scavenging capacity, these compounds are also used as potential antitumor and anticancer supplements (Sajilata et al., 2008).
The largest industrial producers of spirulina square measure within the USA, Thailand, India, Taiwan, China, Bangladesh, Pakistan, Asian country (Myanmar), Balkan nation and Chile. Spirulina is understood worldwide principally for its potential organic process price. it's one in every of the rare edible microorganism because it has minimal risk of acid accumulation within the body because of its low purine concentration (Sjors and Alessvero, 2010). The food business classifies A. platensis as a living thing supermolecule. In different words, it's Associate in Nursing edible eubacteria with high organic process price. true bacteria square measure of nice importance for humans and animals in terms of the proteins, carbohydrates, lipids, vitamins, enzymes and different bioactive compounds (antibiotics, algicides, toxins, pharmaceutically active compounds

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

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and plant growth regulators) they synthesize. it's made in vitamins, minerals, β-carotene, essential fatty acids and antioxidants, all of that have expedited its industrial production as human food supplements over the past decade (Kelman et al., 2012). Spirulina additionally has Associate in Nursing organic compound content of sixty two and may be a made supply of vitamins A, B_1, B_2, B_{12}, yet as phytopigments like carotenides and xanthophylls. Spirulina is one in every of the richest sources of protoctist containing γ-linolenic acid (GLA). GLA may be a unsaturated carboxylic acid and a potent nutraceutical substance (Sajilata et al., 2008). Spirulina is a wonderful supply of phycobiliprotein. because of their high radical scavenging capability, these compounds are used as potential antitumour and antineoplastic supplements. it's been determined that spirulina consumption has positive effects on the circulatory system and reduces pressure level and sterol. Given its anti-carcinogenic properties, it's been accustomed treat syndrome in individuals suffering from the 1986 city nuclear accident (Hernveez-Ledesma and Herrero, 2014).

Today it's utilized in dietary supplements, in pill or powder type, alone or together with alternative protoctist or plant extracts for human and animal use. Spirulina is taken into account an honest supply of vitamins and essential amino acids. It conjointly contains a terribly high macromolecule content with a balanced composition, that makes it even additional fascinating as a dietary supplement (Batista et al., 2013). though dried spirulina utilized in dietary supplements contains lower amounts of essential amino acid and essential amino acid than meat, eggs and milk, it's a composition wealthy all told essential amino acids and contains on the average hr (51-71%) macromolecule (Heidarpour et al., 2011). there's conjointly a motivating discussion concerning B complex. Most edible blue-green algae, like spirulina, don't naturally contain B complex, however principally pseudovitamin B12, that is inactive in humans. It conjointly contains a fat content of concerning seven-membered and attracts attention with its α-linolenic acid (ALA), linolic acid (LA), stearidonic acid (SDA), omega-3 (EPA), omega-3 fatty acid (DHA) and arachidonic acid (AA) content.). it's thought of to be complete relating to its content in vitamins like blood type and hydrocarbons. Spirulina is additionally a supply of vitamins E and C (Batista et al., 2013).

Although it is stated that the commercially important microalgae are *Spirulina*, *Chlorella*, *Haematococcus, Dunaliella, Botryococcus, Phaeodactylum, Porphyridium, Chaetoceros, Crypthecodinium, Isochrysis, Nannochloris*, *Nitzschia*, *Schizochytrium, Tetraselmis* and *Skeletonemayes*, among the microalgae, the most evaluated for human consumption are *Arthrospira*, *Chlorella* and *Aphanizomenon*, which are rich in essential components and protein, and *Dunaliella* and *Haematococcus* species, which are rich in antioxidant carotenoids (Niccolai et al., 2019). Especially *Spirulina* and *Chlorella* are produced on a large scale worldwide and they are added to many products (such as salad dressing, beverages, bakery products) and/or sold as protein supplements (Wells et al., 2017). It is stated that when *Spirulina* is added to the growth medium of lactic acid bacteria, it consumes the nitrogen in the environment and secretes carbohydrates and some other substances, thus promoting the development of lactic acid bacteria and showing a prebiotic effect. In addition, it is stated that *Chlorella pyrenoidosa* inhibits the development of *Candida albicans* and *Listeria monocytogenes* (Gupta et al., 2017). *Spirulina* and other microalgae have been the material of many studies and have been added to different foods for many different purposes such as increasing the nutrient content, improving their functional, textural properties and antioxidant activity.

Spirulina, one of the cyanobacteria, is claimed to be a sustainable food source with the potential to end starvation problem of the world and it is reported that it can be used successfully in the treatment of many diseases. The recommended daily dose is 3-5 g. Microalgae, which have long

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

been part of the human diet, are not a new food source. For this purpose, it is known that *Nostoc* is used in Asia and *Spirulina* is used in Africa. In recent years, microalgae biomass has been used in healthy foods. Microalgae most used in the food industry are *Cyanophyceae* (blue-green algae), *Chlorophyceae* (Green algae), *Bacillariophyceae* (diatoms), *Chrysophyceae* (Golden algae) (Chacon-Lee and Gonzalez-Marino, 2010).

Chlorella could be a microscopic living thing marine plant that belongs to the chlorophyte (Chlorophyta). The characteristic inexperienced pigmentation is thanks to the presence of the 2 chlorophylls a and b, that also are identical in land plants. It will be simply grownup in straightforward conditions, and massive amounts of biomass will be made terribly} very short time. It solely wants water, CO_2, lightweight and alittle range of minerals. Considering the number of macromolecule, amino acids, minerals, vitamins and pigments, it ought to be seen as a perfect food. additionally, elements of alga vulgaris, alga pyrenoidosa species that exceed five hundredth of their cell mass, conjointly contain macromolecule. Proteins isolated from alternative alga species Anabeana, Dunaliella, Phaeodactylum, Arthrospira platensis and protozoan that square measure proverbial to own high macromolecule content, might have sturdy inhibitor and anti inflammatory activity (Ngo et al., 2010).

Chlorella algae; It is widely produced and marketed in many countries, including China, Japan, Europe and the USA. Used as a range of nutrients widely used in health foods (e.g. carotenoids, vitamins, minerals), chlorella is considered a broad potential source as a feed in the food market as well as in animal and aquaculture. *Chlorella* cells contain β-1,3-glucan, which is an active immunostimulator (acting as a scavenger of free radicals and reducing blood fats). Polysaccharides in *Chlorella* are associated with the antitumor effect. Effects of *Chlorella* on human health; It prevents the proliferation of cancer cells and treats various types of cancer, supports the immune system, increases resistance to some infections, facilitates digestion in the intestines, lowers blood sugar and cholesterol levels, regulates hypertension, stomach disorders such as ulcers and gastritis, and prevents the liver from being adversely affected by toxic components. It has been determined that the treatment of skin diseases, regeneration of the skin, prevents the development of pathogenic microorganisms with the natural component called "chlorellin" (Mello-Sampayo et al., 2013).

Dunaliella has the capacity to produce particularly high concentrations of β-carotene. Other carotenoids produced by *Dunaliella* include lutein, neoxanthin, zeaxanthin, violaxanthin, α-carotene, and cryptoxanthin. These applications include nutritional supplements for human health, such as nutrient mixtures, tablets, capsules, animal feed, natural pigments and dyes. Red to orange *Dunaliella* powder contains 1-3% β-carotene. The oil-based β-carotene extract is used to color margarine and beverages (Hamed et al., 2015).

Haematococcus pluvialis has been identified as the organism that accumulates the highest level of astaxanthin (1.5-3.0% by dry weight) in nature. Astaxanthin which is Commonly found in crustaceans and fish, is a very useful red carotenoid used for pigmentation of fish in aquaculture. *H.pluvialis* is consumed as a nutritional supplement in the USA, Japan and a few European countries and is used as a coloring agent in salmon feeds. Also, *H.pluvialis* is a very good candidate for biorefining strain with a fatty acid content of 30-60% dry weight in red cell-containing astaxanthin (Solovchenko, 2015).

3. BIOACTIVE COMPOUNDS CONTAINED BY ALGAE

Microalgae produce useful bioproducts such as β-carotene, astaxanthin, docosahexaenoic acid (DHA, C22:6n-3), and eicosapentaenoic acid (EPA), bioactive and functional pigments, natural

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

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dyes, polysaccharides, antioxidants (Tablo 1) (Hemantkumar and Rahimbhai, 2019). It is known that these high-value components in algae regulate immunity, prevent diabetes, oxidation, inflammation, high cholesterol and cardiovascular diseases, and have positive effects on obesity and unbalanced nutrition (Akyıl et al., 2016).

It has superior nutritional profiles and bioactive peptides, dietary fiber, polysaccharides, PUFA, vitamins, minerals, polyphenol etc. As a result of being rich in bioactive components, macroalgae are known to have beneficial effects on health (Paiva et al., 2016; Circuncisão et al., 2018). Since the intake of protein, fiber, minerals, vitamins, essential amino acids and PUFAs will increase with the consumption of macroalgae, it is stated that the formation of some chronic diseases may decrease like diabetes, obesity, heart diseases, cancer, etc. caused by low fiber diet, which is especially associated with western societies (Ranga Rao and Ravishankar, 2018).

Table 1. Bioactive compounds found in different microalgae species and their health benefits **(Hemantkumar and Rahimbhai, 2019)**

Microalgae species	Bioactive compounds	Benefits
C.vulgaris	Santaxanthin	Color agent and antioxidant
	Lutein	Antioxidant, anticancer, prevent heart ailments
	Sulfonated polysaccharide	Antiviral, Anticancer, antioxidant
	EPA	Nutritional supplement
	Glycoprotein	Anti-inflammatory
	Vitamin C	Prevents heart ailments.
H.pluvialis	Astaxanthin	Strong antioxidant property, anti-inflammatory effect, anticancer
Dunaliella spp.	β-carotene	Food colorant, Antioxidant property, anti cancer
	Glutathione	Antioxidant, heart attack reducing effect, anticancer activity, anti Parkinson's disease
Spirulina spp.	γ-linolenic acid (GLA)	Nutritional supplement
	Phycocyanin	Natural food coloring, antioxidant

3.1. Nutraceutical lipids and their benefits

Algae have an important place in the production of ω series fatty acids, which are essential in a commercially healthy diet. Algae species living in the seas form fatty acids with longer chains and more than two double bonds compared to fresh water ones. It is divided into two groups as polar lipids (lipids; phospholipids, glycolipids and sphingolips) produced by microalgae and non-polar lipids such as (triacylglycerol, sterol, free fatty acids) (Chen et al., 2018; Aratboni et al., 2019). The lipid content of microalgae, which is generally 20-50% on a dry matter basis, is at higher levels than plants with a higher chain length and unsaturation degree (Villarruel-López et al., 2017). Microalgae, especially ω3 series, are considered alternative products to fish oil because they contain high amounts of essential nutrients such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are long-chain polyunsaturated fatty acids (PUFA). Microalgae such as *Arthospira, Chlorella, Dunaliella, Haematococcus, Schizochytrium, Porphyridium cruentum* and *Crypthecodinium cohnii* are known as important sources of ω3 polyunsaturated fatty acids (Caporgno and Mathys, 2018). The chain lengths of fatty acids in algae are usually between C14 and C22. Microalgae draw attention with the compositions of the lipids they contain, rich in 18, 20 and 22-C PUFAs. Their total lipid content varies between 7-62%. As in all other microorganisms, the lipid amount of algae can be increased by limiting the amount of usable nitrogen in the

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environment, but the same is not true for the amount of biomass. PUFAs are divided into two groups as ω3 and ω6. A (C18:2), GINA (C18:3) and ARA (C20:4) are the most important ω6 fatty acids, while ALNA (C18:3) and its metabolites EPA (C20:5) and DHA (C22:6) is from the ω3 fatty acid group. Long-chain polyunsaturated fatty acids such as ω3 series, namely eicosapentaenoic acid (EPA, C20:5n-3) derived from microalgae and docosahexaenoic acid (DHA, C22:6ω3) are important products used in the food and feed industry today. Since these polyunsaturated fatty acids cannot be synthesized by humans and animals, they must be taken into the daily diet. Increasing demand for ω3 fatty acids also increases the need for PUFA to be obtained from alternative sources due to the overexploitation of global fish stocks in the food market. For this reason, algae-based nutritional formulations rich in these fatty acids are becoming increasingly important (Koller et al., 2014).

The presence of comparatively giant amounts of LC ω3-PUFA (EPA and DHA) in food and marine oils is chargeable for its useful effects on health (Nettleton, 1995). independent agency and DHA have medicinal drug properties. independent agency and DHA ar synthesized by each living thing and cellular marine protoctist like plant and macroalgae (Pigott and Tucker, 1987). Lipids obtained from marine microalgae have a large vary of applications, particularly within the larval stage of cultivation for enrichment of fish feed. additionally, they exhibit numerous properties like medicinal drug, antiallergic, antiviral and therapeutic. The broad spectrum of properties is thanks to the presence of assorted parts like PUFA, HUFA and alternative substances. numerous microalgae-derived macromolecule - fatty acids and their activities ar given in Table a pair of (Raposo et al., 2013).

The oil content of microalgae varies greatly according to the microalgae species, and the average oil content of the most commonly known algae reaches up to 20-50% of the dry matter. Microalgae oil can also be used in biofuel production as a renewable energy source that provides higher energy efficiency per hectare than oilseeds such as sunflower and rapeseed (Solovchenko, 2015).

Microalgae ar thought-about to be a very important renewable supply of bioactive lipids because of their high content of PUFAs, that ar effective within the hindrance and treatment of varied diseases. PUFAs like like (ALA, C18:3 ω-3), eicosapentanoic acid (EPA), docosapentanoic acid (DPA, C22:5 ω-3) and DHA ar related to vessel, cancer, sort a pair of polygenic disorder, kidney disease, it's been shown to be effective within the hindrance or treatment of varied diseases like asthma attack (Matos, 2017). particularly independent agency and DHA play a very important role on human metabolism. These fatty acids scale back the number of steroid alcohol, acylglycerol, beta-lipoprotein and extremely beta-lipoprotein and increase the HDL content. DHA is employed as a nutritionary supplement in foods and beverages for the event of the system, vessel health and therefore the healthy functioning of alternative organs. Isochrysis galbana offers hope to the food business because of its considerably high fat content (24%) containing a valuable supply of ω-3 PUFAs (EPA and DHA). Therefore, microalgae ar seen as an alternate to fish oils in terms of containing sterols, tocopherols, and coloring pigments. Crypthecodinium cohnii ω3 may be a species wealthy in DHA, one amongst the unsaturated fatty acids. C. cohnii contains two hundredth of the whole biomass and it's noted that the DHA magnitude relation in total fatty acids is 30-50%. Phospholipids, sterols, triacylglycerols, wax esters and their metabolic merchandise represent the fundamental composition of marine lipids. tiny amounts of lipids like glycerin esters, glycolipids, sulfolipids and hydrocarbons are found in marine lipids (Nakagawa et al., 2007). The sterols found within the natural structure of microalgae increase the nutritionary price of the merchandise they're further to. In distinction to higher plants, alga contain numerous sterols of various nature. Major

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

protoctist sterols ar steroid alcohol, fucosterol, isofucosterol, clionosterol and stigmasterol. whereas humans will synthesize steroid alcohol, they can't synthesize phytosterol. that is why they need to require from the skin. though higher plants ar called the most industrial supply of phytosterol, it's conjointly found in high amounts in alga species like class Chlorophyceae, class and class. These phytosterols have health edges like inhibiting polygenic disorder, oxidation, inflammation, and high steroid alcohol (Hernveez-Ledesma et al., 2014).

Table 2. Microalgae lipid-fatty acid activities **(Raposo et al., 2013).**

Lipid-fatty acids	Activity
Eicosapentaenoic acid (EPA)	Nutraceutical, antimicrobial and anti-inflammatory
y-linoleik asit (GLA)	Tissue integrity and anti-aging
Arachidonic acid (ARA)	Aggregative and vasoconstrictive of platelets
Docosahexaeonic acid (DHA)	Nutraceutical and effective in brain development
Brassicasterol and stigmasterol	hypercholesterolemic
y-amino-butyric acid (GABA)	Neurotransmitter, antioxidant and anti-inflammatory
Okadaic acid	Effective in promoting the secretion of antifungal and nerve growth factor
Microcholine-A	Immunosuppressive

Although the lipid content of macroalgae is low (approximately 5-10% on dry matter basis), the polyunsaturated fatty acid content is equal or higher than that of land plants. Macro- and microalgae can also be used in biofuel production due to their oil content (Maghraby and Fakhry, 2015; Aratboni et al., 2019).

The effects of polyunsaturated fatty acids on health are briefly; Treatment of coronary heart diseases, adjustment of blood lipid level, lowering of blood pressure and treatment of hypertension, Effective in the treatment of atomic eczema and some skin diseases, Lowering LDL level and increasing HDL ratio, prevention and treatment of immune system diseases, some cancer risks (breast, prostate, colon, colon) Reducing and treating the rates of cancer (such as cancer) and increasing the tendency of blood clotting by reducing blood platelet aggregation, prevention of thrombosis, healthy and balanced nutrition of fetuses and newborns, development of brain and nerve tissues and prevention of visual disturbances, rigidity observed in muscle ligaments with symptoms of rheumatoid arthritis and It can be summarized as the prevention of tissue pain (Newton, 1997).

3.2. Algae-Based Proteins, Polysaccharides and Algal Products

Microalgae contain essential amino acids that cannot be synthesised by humans or animals. Due to the high protein content of various microalgae species such as Spirulina platensis, C. vulgaris and I. galbana, the use of microalgae as a protein source is of great interest. The protein content of spirulina varies between 60-70% on a dry matter basis (Hamed et al., 2015). Arthrospira and Chlorella, rich in proteins and amino acid profiles, are used as dietary supplements or as functional compounds to prevent cellular (tissue) damage in some diseases (Raposo et al., 2013). It has also been reported that *Spirulina* contains vitamins, minerals and many active biological substances. The cell wall is composed of polysaccharides with 86% digestibility and easily absorbed by the human

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body. *Spirulina* is used as a dietary supplement in the form of tablets, flakes and powders in foods It is also used in the aquaculture, aquarium and poultry industries (Sjors and Alessvero, 2010). In addition, parts of the cell mass of *Chlorella vulgaris, Scenedesmus obliquus* and *Chlorella pyrenoidosa* species exceeding 50% also contain protein. Proteins isolated from other algae species *Anabeana, Dunaliella, Phaeodactylum, Arthrospira platensis* and *Euglena*, which are known to have high protein content, may have strong antioxidant and anti-inflammatory activity. The high protein content of algae contributes to increasing its market value. The enzymes (superoxide dismutase and carbonic anhydrase) obtained from *Dunaliella, Porphyridium, Anabaena, Isochrysis galbana* and *Amphidinium carterae* can also play an important role in the regulation of metabolic waste (CO_2) (Muralidhar et al., 2017).
In general, the carbohydrate content of microalgae on a dry weight basis is approximately 10%. The most abundant carbohydrate monomers in microalgae are glucose, rhamnose, xylose and mannose. Microalgae such as *Arthrospira*, *Chlorella*, *Nannochloropsis*, *Dunaliella* are also considered as potential prebiotics thanks to the oligo- and polysaccharides they contain. Recently, Spirulina products have gained importance due to their cholesterol-lowering, anticancer and immune system enhancing effects (Ragonese et al., 2014).

3.3. Macroalgae Protein, Polysaccharides and Its Benefits

Since macroalgae are thought to be an excellent source of protein, it is expected that macroalgae will replace animal and vegetable protein sources over time in meeting protein needs (Øverland et al., 2019). It has been reported that the protein ratios of macro and microalgae are very close to the protein ratio in traditional protein sources such as meat, milk, egg and soy (Bleakley and Hayes, 2017), and even Spirulina platensis, Chlorella species may be higher (Wells et al., 2017; Kazir et al., 2019). While the protein content of brown macroalgae is generally low (less than 15% on a dry matter basis), the protein content of green and especially red algae (eg *Porphyra* spp., *Pyropia* spp., *Palmaria palmata*, *Ulva* spp.) is reported to be higher (Wells et al., 2017; Øverland et al., 2019). It has also been reported that the essential amino acid contents of macro-and microalgae are comparable to, or even superior to, conventional sources (Wells et al., 2017; Øverland et al., 2019).
On the other hand, macroalgae are very rich in polysaccharides and can contain polysaccharides ranging from 4-76% on a dry matter basis. *Ascophyllum spp., Porphyra spp., Palmaria spp.* and *Ulva spp.* are the species with the highest polysaccharide content (Stiger-Pouvreau et al., 2018). Hydrocolloids such as agar, alginate, agarose and carrageenan, known as algal polysaccharides, are added to various beverages, meat and dairy products as additives, and used in fields such as pharmacy and cosmetics (Wells et al., 2017; Stiger-Pouvreau et al., 2018). Polysaccharides are widely used in the food industry as gelling and/or thickeners. Macroalgae; agar contains large amounts of polysaccharides such as alginate and carrageenan. These; are called phycocolloids or hydrocolloids. Polysaccharides such as agar, alginate and carrageenan used commercially are extracted from macroalgae (especially *Laminaria*, *Gracilaria*, *Macrocystis*). On the other hand, the most promising microalgae for commercial purposes is *Porphyridium cruentum*, single-celled red algae that produce sulfated galactan exopolysaccharide instead of carrageenan in many applications. *Porphyridium cruentum* can synthesize valuable bioactive substances such as extracellular polysaccharides and polyunsaturated fatty acids (Lu et al., 2020). In addition, this red color is associated with phycobiliproteins, phycocyanin, allophycocyanin and phycoerythrin (Raposo et al., 2013).

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

In addition to phycocolloids; Algae are sources of biologically active phytochemicals such as carotenoids, phycobilins, fatty acids, vitamins, sterols, tocopherols, phycococines and others. Seaweed, which is rich in fiber, exhibits anticarcinogenic and antioxidant properties, reducing the absorption of toxins. Studies have shown that agar is harmless for health and the metabolism can digest this compound at a rate of 1/3. It is used medically in the treatment of constipation (Muralidhar et al., 2017).

Green macroalgae contain sulfated polysaccharide, sulfated galactan and xylan; brown algae contain alginic acid, fucoidan and laminaran; red algae contain agar, carrageenan, xylan, floridean-starch, water-soluble sulfated galactan and porphyran (StigerPouvreau et al., 2018). In addition, it is stated that algae improve the intestinal microflora by showing a prebiotic effect due to the oligo- and polysaccharides they contain, and in this respect, fucoidan, laminarin and alginate contained in brown seaweeds have a special importance (Gupta et al., 2017).

3.4. Natural Pigments and Benefits

Pigments are colored chemical compounds. These substances reflect certain wavelengths of visible light. They participate in the photosynthetic system due to the absorption of light energy by microalgae. Apart from chlorophyll, the most important photosynthetic pigment, microalgae also contain phycobiliproteins and a variety of carotenoids. These natural pigments help absorb sunlight and protect the microalgae from the harmful effects of sunlight. Chlorophyll, the primary photosynthetic pigment of all algae, is present in 0.5-1.5% of the dry matter of microalgae and is used in foods and medicines for its wound-healing and anti-inflammatory properties. Chlorophyll is one of the valuable pigments produced by microalgae. It is generally preferred as a natural colorant. In addition, it is widely used in pharmacological products because it accelerates the cell renewal and healing process of wounds. Chlorophyll is also used in ulcer treatment and oral sepsis. Chlorophyll a is in all photosynthetic organisms; chlorophyll b in plants and green algae; chlorophyll c, mainly in dinoflagellates; chlorophyll d in red algae; chlorophyll f is found in cyanobacteria. *Chlorella, Spirulina, Dunaliella, Scenedesmus, Haematococcus, Botryococcus* and *Diatom* are the most used microalgae species in industrial applications for the production of carotenoids (Pérez-Legaspi *et al.*, 2019). Phycobilins are divided into four groups: phycocyanin, allophycocyanin, phycoerythrin, and phycoerythrocyanin. Phycocyanins are obtained from blue-green algae, and phycoerythrin is obtained from red microalgae (Alam et al., 2018). The pigments found in macroalgae are chlorophyll, carotenoids and phycobilins (Vimala and Poonghuzhali, 2015).

While carotenoids are found in most algae species, chlorophylls are found in higher plants and photosynthetic algae, and phycobilins are found only in cyanobacteria and some red algae (Koller et al., 2014). Carotenoids are natural pigments that have the ability to act as provitamin A and are present at 0.1-0.2% in dry matter in microalgae. While carotenoids and chlorophylls are fat-soluble pigments; Phycobilins are photosynthetic pigments surrounded by water-soluble proteins known as phycobiliproteins. Phycobiliproteins are mostly found in cyanobacteria, but are also found in some red algae and cryptomonads. Studies have shown that a carotenoid-rich diet can reduce the risk of diseases involving free radicals, such as atherosclerosis and cancer. β-carotene is used as a food pigment in cheese, oil and margarine. *Dunaliella* species responsible for β-carotene production produce more than 14% of their dry weight of β-carotene. It is used as a food colorant, vitamin A precursor and antioxidant, and is added to cosmetic products (Yaakob et al., 2014).

The most important carotenoids produced by microalgae are β-carotene, produced by D. salina, and astaxanthin, produced by H. pluvialis. Astaxanthin is a ketocarotenoid known for its strong

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

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antioxidant properties. Astaxanthin, a natural pigment, is a powerful antioxidant that is more effective than other carotenoids such as vitamins C and E or β-carotene, lycopene, lutein and zeaxanthin. This pigment has many benefits, such as immune-boosting properties. Furthermore, this pigment is mainly used in salmon feed. Astaxanthin occurs naturally in Haematococcus pluvialis (H. pluvialis), Chlorella zofingiensis and *Chlorococcum sp.* (Tanaka et al., 2012). The main microalgae that produces commercial astaxanthin is *H. pluvialis*. Astaxanthin is used in the prevention and treatment of chronic inflammatory diseases, eye diseases, skin diseases, cardiovascular diseases, cancer, neurodegenerative diseases, liver diseases, metabolic syndrome, diabetes, diabetic nephropathy and gastrointestinal diseases. *Haematococcus pluvialis* is defined as the organism that produces the most astaxanthin (1.5–3.0% in dry weight) in nature (Batista et al., 2013).

Phycobiliproteins are dark, water-soluble and fluorescent pigments. Microorganisms responsible for the production of phycobiliproteins are Spirulina (*Arthrospira*) and *Porphyridium*, a red alga. (Román et al., 2002). It is used in clinical diagnostics as a sensitive fluorescent indicator, in cosmetics and nutrition as a natural dye or in foods such as chewing gum, confectionery, dairy products and ice cream. Blue-coloured phycocyanins are an economically important type of phycobiliprotein found in large quantities in cyanobacteria. Phycocyanin is found in cyanobacteria such as *Spiruluna* and *A.flos-aquae*. C-PC is commercially produced from the phototrophic cyanobacterium *Arthrospira plantensis* (*S.platensis*). C-PC is used as a colorant in many food products such as fermented milk products, ice cream, soft drinks, desserts, chewing gums. Phycobiliproteins are used as fluorescent agents in the pharmaceutical industry. Phycobiliproteins with pharmacological potential contain antioxidant, anti-inflammatory, nerve cell and liver protective substances. Due to its stability, phycocyanin is also used in cosmetics and as a food colorant. In addition, the pigments of red algae are recommended for food and cosmetic ingredients.

Fucoxanthin is a member of the carotenoid family and is a brown-orange pigment found in brown seaweeds, which, together with chlorophyll, acquires a brown or olive green color. It has been determined that fucoxanthin is also effective in anticancer, antihypertensive, antipyretic, high antioxidant activity and antiobesity (Heo et al., 2010). Fucoxanthin is used as a debilitating drug. In addition, fucoxanthin protects the blood vessels of the liver, brain, bone, skin and eyes (Kelman et al., 2012).

Lutein, one of the carotenoids, is a yellow pigment that is beneficial to human health and used as a functional food. *Chlorella*, *Spirulina*, *Dunaliella*, *Scenedesmus*, *Haematococcus*, *Botryococcus* and Diatom are the most used microalgae species in industrial applications for carotenoid production. *Chlorella pyrenoidosa* and *Scenedesmus obliquus* species are microalgae that produce high amounts of lutein. Lutein reduces the risk of eye diseases such as cataracts and retinitis pigmentosa. Zeaxanthin, a stereoisomer of lutein, often coexists with lutein. Zeaxanthin is synthesized by green microalgae. Zeaxanthin is produced by the *Chlorella ellipsoidea* species. Lutein and zeaxanthin are used for chicken skin color, pet foods, animal and fish feed, and for pharmaceutical purposes (Pérez-Legaspi et al., 2019).

Natural pigments of seaweeds provide food and pigmentation by photosynthesis. In addition, natural pigments have also been found to have health benefits that make them important marine nutraceuticals. Phycobilins are divided into four groups: phycocyanin, allophycocyanin, phycoerythrin, and phycoerythrocyanin. Phycocyanins are obtained from blue-green algae, and phycoerythrin is obtained from red microalgae (Alam et al., 2018). The pigments found in macroalgae are chlorophyll, carotenoids and phycobilins (Vimala and Poonghuzhali, 2015).

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

3.5. Chitin and Chitosan Derivatives and Their Benefits

Chitosan is a natural polymer derived from chitin and is the second most abundant polysaccharide after cellulose. As it is non-toxic, it is used in pharmaceuticals, biomedicine, the food industry, healthcare and agriculture. This encapsulation is used as a vehicle for nutraceutical and pharmacological agents. Chitosan derivatives (N,O-carboxymethyl chitosan, N,O-carboxymethyl chitosan lactate, N,O-carboxymethyl chitosan acetate and N,O-carboxymethyl chitosan prolidin) also show antioxidant activity (Muralidhar et al., 2017).

Chitin and chitosan are nutraceutical components due to their antimicrobial activity, their ability to bind bile salts and their cholesterol-lowering properties. Since chitin and chitosan are natural components, they do not show toxic properties, and by being reduced by bacteria, they show bifido bacteria (a bacteria that helps digestion that lives in the intestinal flora) and probiotic properties, preventing the development of bacteria that spoil foods. They reduce blood serum cholesterol level. Due to their stated properties, these products find a wide area of use in the food industry, especially in the regeneration of biomass used in cheese production, in the preparation of edible films or coatings, in the production of aroma and as a stabilizer or enzyme-supporting agent. Chitin and chitosan, which are used as solvents for tablets and other drugs in the pharmaceutical industry, are used in surgical applications, vascular grafts, blood coagulation and as an artificial kidney membrane. Since chitin accelerates the regeneration of tissues, it is used as a protective and restorative film in skin injuries such as cuts and burns. If chitosans prepared in different viscosities are used as coatings, they prevent oxidation and microbial spoilage in both raw and cooked fish (Kamil et al., 2002).

3.6. Vitamins and Their Benefits

Microalgae; they are important sources of A, B_1, B_2, B_3, B_6, B_{12}, C, E, biotin, niacine, folic acid and pantothenic acid. When evaluated in terms of mineral matter, microalgae have a balanced content in terms of Na, K, Ca, Mg, Fe, Zn and trace elements. Microalgae rich in B_{12} and Fe, such as *Spirulina*, are important alternatives for vegetarians. Vitamins have wide applications in the food and health industry. Species such as *Dunaliella tertiolecta*, *Nannochloropsis oculata*, *Spirulina platensis*, *Tetraselmis suecica* and *Euglena gracilis* are sources of vitamins E and C. Microalgae such as *Arthrospira galbana*, *P. cruentum* and *Tetraselmis* have strong antioxidant activity. The fat-soluble vitamin K isolated from *Pavlova* helps blood clotting and coagulation. The role of antioxidant vitamins in health and disease control is important. These antioxidants are substances that prevent and delay oxidation in oils and fats (Muralidhar et al., 2017).

Products such as alginic acid, agar, sodium alginate, carrageenan produced from macroalgae are used as thickeners and emulsifiers in food processing. Seaweed and algae products are used as a special diet product in some countries. Various vitamins, DHA and mucopolysaccharides and mineral substances have been produced from these creatures. The mineral content of macroalgae is 10-100 times higher than that of terrestrial plants. Green algae are rich in Mg and Fe, red algae are rich in Mn, and brown algae are rich in I. The Na, K and Zn content of red and brown algae is higher than green algae (Circuncisão et al., 2018).

4. CONCLUSIONS

Algae; It contains many bioactive components called nutraceuticals. Phycocolloids, which are used as active and auxiliary substances in pharmacy, are obtained from algae-based nutraceuticals.

*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr

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Macroalgae are used as food, fertilizer, phycocolloid and cosmetic components. The nutritional richness of macroalgae has made them the food additive of the century. In addition to their nutritional values, macroalgae attract attention as "functional food". In addition, microalgae-based nutraceuticals are antioxidants for human nutrition and provide a wide range of applications and uses, from anti-aging. For this reason, the use of natural bioactive components in micro and macroalgae in the field of health and for nutritional purposes is increasing the importance of algae-based nutraceuticals, which are auxiliary active substances in the prevention and treatment of many diseases.

As a result, while algae are used as nutraceuticals in functional foods, they reduce the risk in chronic diseases; It is a key nutritional supplement for a healthy life. For this reason, algae are increasing in importance with their protective properties for human health. Today, many people with high economic power prefer to consume healthy natural foods. Algae-based nutraceuticals will provide many benefits to the aquaculture industry as a result of having more beneficial effects on health, meeting the demands of natural nutrition, fishing industry and consumers, and increasing the demand for micro and macroalgae will cause it to be the focus.

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*Corresponding author, E-mail address: hkrgylmz@mersin.edu.tr