

mmmm

*Yazar Nnnnn Ccc*

---

**Gönderim Tarihi:** 27-Eki-2022 12:12PM (UTC+0300)

**Gönderim Numarası:** 1936733496

**Dosya adı:** Cansu\_AKG\_L,\_Nuray\_CAN.docx (296.57K)

**Kelime sayısı:** 8375

**Karakter sayısı:** 48469

# MICROALGAES AS A SUSTAINABLE AND FUNCTIONAL FOOD SOURCE AGAINST CLIMATE CHANGE

Cansu AKGÜL<sup>1</sup>, Nuray CAN<sup>1</sup>

<sup>1</sup>Istanbul Aydın University Anadolu BİL Vocational School, Food Processing  
Department, Food Quality Control and Analysis Program

**Corresponding Author:** cansuakgul@aydin.edu.tr

*The excessive increase in the world population, the harmful effect of traditional agricultural products and livestock farming on the environment, climate change, decrease in drinkable water and declining arable land, resources lead researchers to seek alternative sustainable food. Environmentally friendly features of microalgae such as CO<sub>2</sub> consumption and rich nutrient content, the no need for drinking water and land make microalgae encouraging alternative food resource.*

*They are photosynthetic microorganisms that produce energy and biomass using carbon dioxide and light. There are 16 classes of microalgae, including cyanobacteria, green algae and diatoms, which are biotechnologically important.*

*Microalgae contains sustainable ingredients for high quality staple food such as polyunsaturated fatty acids, proteins, amino acids, lipids and, bioactive components as well as phytochemicals, essential vitamins, and minerals. Microalgae biomass has high levels of essential nutrients and functional compounds used in various industries. Chlorella and Spirulina which contain high amounts of protein have been commercialized as food supplements. Carotenoid group color pigments are isolated from Dunaliella and Haematococcus microalgae and used as food additives. In addition, polyunsaturated fatty acids were isolated from microalgae and presented to the market as a food supplement. In recent years, functional food products such as some microalgal-based biscuits and crackers, soft drinks, pizza and chocolate have also been produced due to their rich nutritional content.*

*This study aims to explain the chemical composition of microalgae and its current applications in the food industry as a functional food ingredient and its potential as a sustainable alternative food source.*

**Key words:** microalgae, sustainability, food, climate change.

## 1. INTRODUCTION

The increasing of the world population increases the global food demand. In a study prepared by FAO, et al. in 2021, it was reported that the number of people affected by hunger in the world will reach approximately 660 million by 2030 (Chichaibelu et al., 2022). In addition, the COVID-19 pandemic significantly affects the food supply system. The traditional food supply system needs a transformation to meet the increasing global food demand. The adverse effects of traditional foods on environmental such as climate change, scarcity of agricultural plantations, decrease in potable water resources, increasing greenhouse gas emissions, using pesticide and increased carbon emissions from livestock farming have led food suppliers to seek new sustainable food.

Algae are a resistant species. They can live in a variety of habitats, adapting to harsh living conditions. (Levasseur, et al., 2020). Algae are divided into two according to their size; macro and microalgae. Microalgae usually consist of a single cell or a collection of single cells. The organisms with the highest photosynthetic efficiency are microalgae. They perform photosynthesis using light and nutrients such as carbon dioxide (CO<sub>2</sub>), nitrogen, phosphorus and potassium. Cyanobacteria, green algae and diatoms are important microalgae due to their potential for biotech applications, apart from 16 different microalgae classes. (Hosseinkhani et al., 2022). In the last years, the use of a functional component in the nutritional content of microalgae by adding to foods or processing directly into the food product has attracted more and more attention. In the study of Chen et al., (2022), the number of publications on microalgae is given in Figure 1 by years

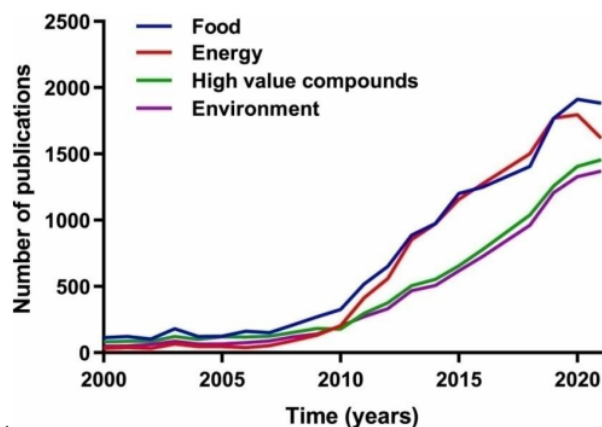


Figure 1. Number of publications by years of different microalgae applications (Chen et al., 2022)

One reason why microalgae are promising as an alternative food source is their strong carbon sequestration ability. Compared to traditional livestock and traditional agricultural products, the using of land by microalgae is very small. While herbicides and pesticides are used in traditional agricultural products, there is no need for herbicides or pesticides in the production of microalgae. Their production is not limited to the seasons. Compared to traditional food sources, it is predicted that microalgae will be an important source in meeting the nutritional needs due to their ability to increase their weight 2-3 times in a day under suitable conditions, their easy and economical production, and no side effects (Uzuner and Haznedar, 2020). Microalgae have various bioactive compounds such as polyunsaturated fatty acids (EPA and DHA), polyphenols, phycobiliproteins (pigment-protein complexes) and phytosterols, protein (bioactive peptides and essential amino acids), pigments (carotenoids, chlorophylls), vitamins, polysaccharides (Levasseur et al., 2020; Matos, et al., 2017; Kumar et al., 2022). Balboa et al. (2013) found that methanolic and ethanolic algae extracts have antimicrobial effects against food-borne bacteria in meat and bakery products.

The use of microalgae in food has been accepted as safe by national authorities. Nostoc flagelliforme is traditional in Chinese diet and Spirulina has also been traditionally consumed in Mexico and Africa since the 1900s. The last years, use of microalgae-based foods, food additives and food supplements has increased. For example, docosahexaenoic acid (DHA) is used in some beverages like milk and juices for infants and children (Singh et al., 2020).

In recent years, it has been reported that 13,090 new food products based on microalgae have been introduced to the world market. 21% of these new food products are beverages and 79% are food (Boukid et al., 2021).

Considering the increasing trend of microalgae in the food market, this review aims to present a new approach for microalgae-based functional food ingredients and foods, to present the promising properties of microalgae as a sustainable alternative food source and the potential for application in the food industry. In addition, a discussion of the environmental problems and challenges that may be encountered in microalgae-based food applications is also included.

## 2. NUTRITIONAL COMPOSITION of MICROALGAE

Many nutritional and functional components that can be processed into food products contain microalgae. While carbohydrates and proteins constitute the basic nutritional components, polyunsaturated fatty acids, color pigments, vitamins and minerals constitute functional components that can be obtained from microalgae. The nutritional components found in microalgae are shown in Figure 3. The ratios of nutrient components that can be obtained from the best known microalgae species are summarized in the Table 1 made by Kusmayadi et al. (2021).

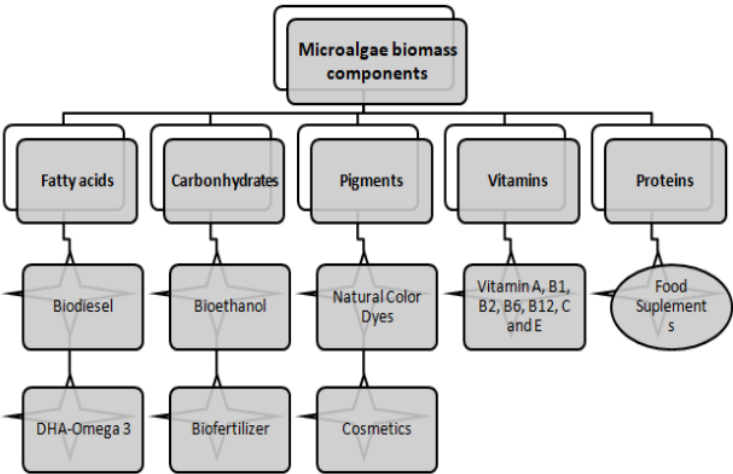


Figure 2. Bioproducts from microalgae biomass and their applications

Table 1 Nutritional composition of different microalgae species (Kusmayadi et al., 2021)				
Microalgae species	Compounds (%)			References
	Lipids	Proteins	Carbohydrates	
Botryococcus braunii	33	39.61	2.38	Sydney ve ark..(2010)

<i>Chlorella vulgaris</i>	14–22	51–58	12–17	<u>Wolkers ve ark.,(2011)</u>
<i>Haematococcus pluvialis</i>	15	48	27	<u>Bleakley ve Hayes (2017)</u>
<i>Isochrysis galbana</i>	12–14	50–56	10–17	<u>Milledge (2011)</u>
<i>Nannochloropsis</i> sp.	22–31	33–44	8–14	<u>Xu ve ark., (2004)</u>
<i>Porphyridium cruentum</i>	5.78-7.55	27.7-40.8	22.8–39.3	<u>Fuentes ve ark., (2000)</u>
<i>Scenedesmus quadricauda</i>	1.9	47	21–52	<u>VanKrimpen ve ark., (2013)</u>
<i>Spirulina maxima</i>	6–7	60–71	13–16	<u>Milledge (2011)</u>
<i>Synechococcus</i> sp.	11	63	15	<u>Becker (1994)</u>
<i>Tetraselmis maculata</i>	3	52	15	<u>VanKrimpen ve ark.,(2013)</u>

## 2.1 Pigments

Pigments attract attention as natural color dyes in the food industry. Microalgae pigments are grouped into 3 classes; phycobiliproteins (such as water-soluble phycocyanin), carotenoids (such as oil-soluble xanthophylls and carotenes), and chlorophylls (fat-soluble) (Sasa et al., 2020). The best known strain (approximately 14% w/w in dry matter) for  $\beta$ -carotene production is *Dunaliella salina*. Microalgae produce different color pigments under different nutritional conditions. For example, Lv et al., (2016), in their study, investigated the cell morphology and carotenoid accumulation of microalgae culture in *Dunaliella salina* under conditions of nutrient deprivation (sulfur, phosphorus and nitrogen) and combined use of nutrients. It has been reported to form different color pigments under different conditions.

Astaxanthin (bright red color pigment) is produced at a high rate by *Haematococcus pluvialis*.(Hosseinkhani et al., 2021). One of the color pigments used in the food industry and beneficial for health is fucoxanthin. (Peng et al., 2011). *Phaeodactylum tricornutum*, also known as the sea diatom, contains high amounts of fucoxanthin, which draws attention as a functional food due to its anti-obesity properties. Microalgae also have higher carotenoid content than macroalgae. For example, some microalgae have up to 15 times higher fucoxanthin (18.23 mg/g) than the dominant producer seaweed (Gomez et al., 2016).

Another commercially important pigment is phycocyanin, a protein-pigment complex that gives blue color. The phycocyanin color pigment is most commercially obtained from *Spirulina*, with 7% to 20% of its protein content being phycocyanin. The extracted phycocyanin is used in soft drinks, candies, chewing gums and jellies.

Color pigments produced by microalgae have health benefits such as anti-inflammatory, neuroprotective and antioxidant properties. For example, carotenes have the feature of being both a free radical scavenger and a precursor to vitamin A for eye health.

1

## 2.2 Fatty acids

Polyunsaturated fatty acids (PUFAs) are essential, meaning they must be obtained through diet. Considering the health benefit of PUFA's, they are attracting attention by microalgae producers.

Omega 3 and omega 6 fatty acids are included in PUFAs. Alpha linolenic acid (ALA) Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are in the omega 3 fatty acid class, while arachidonic acid (ARA) and  $\gamma$ -linolenic acid (GLA) are in the omega 6 fatty acid class of immune, cardiovascular, nervous PUFAs are important areas that provide health benefits on their systems and play role in hormone synthesis. Lipids produced by microalgae contain higher PUFA than fish oil. Especially in heterotrophic conditions, as well as less chemical contamination. 39% of the lipids produced by *Phaeodactylum tricornutum* and *Nannochloropsis* sp microalgae are EPA, and 30-40% of the lipids produced by *Thraustochytrium* and *Schizochytrium limacinum* microalgae are DHA.

Higher plants, fungi and bacteria can be used for the industrial manufacturing of EPA and DHA but fungi need carbon of organic origin for PUFA synthesis and biomass growth will be very slow. Plants must be genetically modified for PUFA synthesis (Ursin, 2003).

## 2.3 Proteins

Proteins are an important source of nutrients in human nutrition, consisting of amino acids. The protein content of microalgae is higher than traditional protein sources. (chickpea 18%, soy 35%; beef 50% and turkey 63%). The protein content of microalgae is in the range of 40-60% in dry matter. (Bleakley and Hayes, 2017; Geada et al., 2021). Another reason microalgae are gaining attention is because they are more economical and ecological friendly. Because of microalgae have high growth rates, photosynthetic efficiency and also carbon neutralization properties.

Christaki et al. (2011) reported that *Arthrospira*, *C. vulgaris*, and *Spirulina* contained 70% (w/w), 51-58% (w/w) and 60-71% (w/w) protein respectively. Microalgae also can be genetically modified to synthesize high-efficiency protein. The ability of microalgae to synthesize all amino acids makes them superior to conventional protein foods (Kusmayadi et al., 2021).

Phenylalanine, isoleucine, leucine, lysine, methionine, valine, histidine, arginine and threonine which is called essential amino acids (EAAs) must be supplied outside. Some foods of animal origin contain all of the EAAs, while plant foods do not fully compensate the EAAs. For this reason, EAAs that are insufficient in vegan nutrition have the potential to be met through microalgal proteins (Barka and Blecker, 2016).

## 2.4 Vitamins and Minerals

Microalgae contain pro A ( $\beta$ -carotene), vitamins B, C and E also *Isochrysis galbana* contains vitamins A, group B and E also *Euglena gracilis* contains pro A and vitamins C and E (Zhou et al., 2022; Del Mondo et al., 2020). In the study of Tarento et al., (2018), it was determined that *Anabaena cylindrica*, whose biotechnological production process has been developed for vitamin K1, has 200 $\mu$ g-1 vitamin K1 content, can be provided up to two to three times the daily adult need, and even by optimizing the process, the efficiency has been increased up to four times. In addition, *Chlorella* strains have the ability to synthesize significant levels (9-18%) of

vitamin B12. B12 cannot be synthesized from higher plants, but can be obtained from bacteria in the digestive system of animals or from animal foods. Vitamin B12 deficiency, which can be encountered in a vegetarian diet, can be obtained from microalgal sources. Megaloblastic anemia can occur in vitamin B12 deficiency. *Chlorella* sp has high vitamin B content. B group vitamins are important in fatty acid synthesis, electron transfer and DNA repair. (Edelmann et al., 2019). In addition, *Spirulina* is used as a source of vitamins A, B, E and K (Carmona et al., 2009). *Eisenia arborea* contains a similar amount of vitamin C to citrus fruits. Vitamin C has an antioxidant effect and a role in the immune system, tissue growth and repair. *Spirulina* also contains vitamin E, which has antioxidant properties, and B1 vitamins, which have anti-inflammatory properties (Chew et al., 2017; Edelman et al., 2019). The effects of microalgal vitamins on human metabolism vary due to solubility and structure differences. In vivo and in vitro digestion model trials should be performed to determine metabolic effects.

In addition to vitamins, microalgae contain minerals such as phosphorus, calcium, potassium, sulfur, sodium and magnesium in their structure. One of the things to consider is that high sodium consumption is not recommended as some microalgae species may contain high levels of sodium and may increase blood pressure and cardiovascular ailments (Aburto et al., 2013). The micromineral composition of different microalgae species, such as copper, iron, manganese, selenium and zinc, also differs.

## 2.5 Carbohydrates

Carbohydrates are the main product of photosynthesis, and under suitable conditions, microalgae can be used as a source of carbohydrates with antioxidant, hypolipidemic and hypoglycemic activities. A storage carbohydrate can be defined as a set of polysaccharides found inside the cell. In microalgae, carbohydrates are mainly present as polysaccharides. Storage carbohydrates (simple sugars, starch, cellulose, etc.) in microalgae are found in the chloroplast and cytosol. It is possible to accumulate carbohydrates up to 50% in dry weight (w/w) with a high photosynthesis rate (Markou et al., 2012).

Carbohydrate metabolism and composition differ according to microalgae species. For example, in dry matter, *Porphyridium cruentum* (w/w) contains 40-57%, *Prymnesium parvum* (w/w) 25-33%, *Scenedesmus quadricauda* (w/w) 21-52% carbohydrates. (Van Krimpenet et al., 2013). Carbohydrate production efficiency and composition in microalgae are affected by temperature, growing system and presence of light, salt stress, nutrients, etc. It can be managed with environmental parameters. In addition, the metabolic process and the kind of carbon source affect the carbohydrate composition formed after photosynthesis in microalgae. (Kusmayadi et al., 2021).

Sulphated polysaccharides from microalgae polysaccharides have received special attention due to their bioactivity (Matos 2017). Sulphated polysaccharides are produced from the culture of *Porphyridium cruentum*. Sulphated polysaccharides can be used in food and vaccine applications. One of the sulphated polysaccharides  $\beta$ 1-3 glucan, has effects on health, stimulating the immune system and reducing blood cholesterol. Sulfated polysaccharides are used for their emulsifier, thickener and stabilizer properties in food industry (Matos, 2017; Ruocco et al., 2016). For example, carrageenan is used as a suspension stabilizer in cocoa milk. (Ruocco et al., 2016).

## 3. MICROALGAE APPLICATIONS as HUMAN FOOD

Algae have been used as food and fodder for centuries. For example, it is stated that the use of Nostoc microalgae by some tribes in Africa and *Spirulina* microalgae in Asia is quite old. People are accustomed to the use of microalgae as food. The reason this source has only had commercial use for a few decades is the focus on a possible inadequate protein provision due to the fast growth of the world's population in the mid-1900s. In the 1950s, the use of algae was proposed as an alternative protein source to meet the global food request. Japan began the first industrial scale production of the microalgae species *Chlorella* for human consumption in the 1960s. Large scale algae production plants were built in Australia, Asia, Israel, India and the USA in the 1980s (Chacón-Lee and González-Mariño, 2010: 656; Vigani et al., 2015: 81; Wells et al., 2017: 949).

Food products containing microalgae can be classified into two major groups that containing all microalgae biomass and containing a microalgae-derived compound. Microalgae biomass can be used to color foods and benefit from their nutritional or functional properties (Lafarga, 2019: 2).

*Arthrospira*, *Chlorella*, *Dunaliella salina*, *Aphanizomenon flos-aquae*, *Haematococcus* and *Spirulina* are the most commonly used microalgae for human consumption. One of the reasons for this is that *Arthrospira*, *Chlorella*, *Spirulina* and *Aphanizomenon* have a rich composition of protein and essential elements, while *Dunaliella* and *Haematococcus* have carotenoids with antioxidant activity (Spolaore et al., 2006: 88; Niccolai et al., 2019: 1).

Various foods produced with the addition of microalgae are offered for sale in Asia and North America, especially in European countries including Italy, Germany, Spain and France. These include pasta, cookies, biscuits, crackers, cakes, rusks, cereal bars, fruit bars, ice cream, smoothies, organic algae drinks, candies, vegetable juice and chocolate (Lafarga, 2019: 2).

However, the addition of microalgae biomass to some cereals and dairy products continues to be the subject of various studies. Aydemir and Öner (2020: 553) investigated the effects of 0.25%, 0.50, 0.75 and 1% *Spirulina platensis* additions on the microbiological, chemical, physical, and sensory properties of yoghurts during the storage period. It was determined that the addition of *Spirulina platensis* increased the total phenolic substance content, total antioxidant capacity value and protein amount of yoghurts. The addition of *Spirulina platensis*, did not change statistically *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* numbers. It was determined that the most liked samples from the sensory point of view were control yoghurt and yoghurt with 0.25% *Spirulina platensis* addition, respectively. Szmejd et al. (2018: 44) investigated the effect of *Spirulina platensis* use on antioxidant capacity in the production of dairy, pistachio and mint ice cream. According to the results of the antioxidant activity tests surveyed by the free radical scavenging potential, the researcher determined that all ice creams enriched with microalgae extract had a significantly higher antioxidant potential. The addition of *Spirulina* improved the ability for quenching free radicals about by 8% in dairy ice cream and the lowest parameters were determined this product. Çelekli et al. (2019: 4) investigated the growth of probiotic bacteria in buttermilk produced by adding 0.25%, 0.5%, and 1% *S. platensis* and using probiotic culture before and after fermentation and on days 7, 14, and 21 of storage. The addition of *S. platensis* remarkably increased the development of probiotics after fermentation and during storage, and the highest total dry matter and protein values were achieved with the use of *S. platensis* at the rate of 1%. Tohamy et al. (2018: 347) investigated the effect of the use of *Chlorella vulgaris* on some properties of cheese. It has been

reported that the use of *Chlorella vulgaris* enriches Se, Zn, Fe, Mg and K and increases its antioxidant activity.

Güroy (2020) produced muffins using 0.4%, 0.6 and 0.8% fresh or dried *Spirulina* and examined the impact of *Spirulina* addition on some properties of muffins. It was defined that muffins containing 0.6% and 0.8% fresh *Spirulina* contained higher phycocyanin and scored higher sensory point than muffins containing 0.8% dried *Spirulina*. Onacık Gür et al. (2018: 7) examined the effect of adding 1, 2, 3% *Spirulina platensis* powder on whole grain cookies. Moisture content and hardness of the cookies decreased due to the addition of microalgae powder, and even the addition of 1% microalgae changed the color of the cookies to intense green. Singh et al. (2015: 1394) was carried out biscuit production with the addition of *Spirulina platensis* powder. The addition of spirulina powder to the biscuit improved its protein and antioxidant potential proportionally with the added amount of spirulina powder. Ak et al. (2016: 30) carried out chemical, microbiological and sensory analysis in the bread they produced by adding 10% *Spirulina*. The use of *Spirulina* enabled the bread to be enriched in terms of protein, Ca, Mg and Fe and had a positive impact on the prevention of mold growth in bread stored at room conditions. Although the algae aroma was perceived, the sensory evaluation of the bread was found to be satisfactory. Based on these results, the researcher reported that the use of microalgae can improve the nutritional quality without having a negative effect on the shelf-life. In a study investigating the effect of using *Dunaliella salina* microalgae on some properties of pasta, El-Baz et al. (2017: 45) stated that in terms of cooking quality, the volume and weight of pasta increased, and cooking losses also increased. The increase in the amount of microalgae used increased the amount of Fe, Ca, Mg, K minerals and chlorophyll A, chlorophyll B and carotene phytochemicals. Sensory evaluation showed that the mouthfeel and overall acceptability of pasta enriched with 1% and 2% algae were not significantly affected compared to the control sample, while the flavor was not significantly affected in pasta containing 1% algae.

As mentioned before, in addition to microalgae biomass, some components produced by microalgae can be used in various foods. Pigments such as phycobiliproteins, polyunsaturated fatty acids and carotenoids are the main components obtained using microalgae (Spolaore et al., 2006: 88). The effect of the use of these components obtained from microalgae on the properties of foods attracts the attention of researchers. It is reported that biscuits produced using phycocyanin extracted from *Spirulina platensis* are acceptable in terms of sensory properties such as color, odour/aroma, taste, texture, general taste and general acceptability. It is also stated that the addition of phycocyanin can increase the oxidative stability of biscuits during storage (Abd El Baky et al., 2015: 236).

With a regulation made in 2015, the commercialization of foods containing oil rich in EPA and DHA extracted from the microalgae *Schizochytrium* sp. was allowed in the European Union. Astaxanthin is accepted by the FDA as GRAS, which is the acronym for "generally recognized as safe". This product is produced from *Haematococcus pluvialis* and is another example of microalgae derived compounds commercialized for food applications (Lafarga, 2019: 2).

The use of microalgae in human nutrition is not limited to the use of all microalgae mass or the components it produces in foods. Microalgae can be found on the market in different forms such as liquids, capsules and tablets. Microalgal tablets are preferred by consumers because they are rich in protein, vitamins, polysaccharides, polyunsaturated fatty acids, microelements and edible fiber and are believed to improve health, prevent diseases and aid weight loss (Lianget al.,

2004: 45). However, there is no commercialized product prepared with the addition of microalgae in Turkey. However, vitamin supplements and fishmeal with spirulina, and spirulina in powder and capsule form are available in the market (Sasa et al., 2020: 103).

#### 4. SUSTAINABILITY of ALGAL-BASED FOODS

Many people in the world face hunger. It is reported that 828 million people are affected by hunger in 2021 and this number corresponds to 9.8% of the world population (FAO, IFAD, UNICEF, WFP, WHO, 2021). On the other hand, it is stated that the world population exceeded 7.8 billion in 2021 and it is expected to exceed 9.3 billion by 2050 (TUIK, 2013; TUIK, 2022). As a result of the increasing world population, it is inevitable that the demand for food will increase (Ahmad et al., 2020: 6). On the other hand, growing world population, increasing consumption of persons, technological developments, ease of intercommunicate and rising translocation of the people have caused limited natural resources and revived environmental problems (Özdemir and Güçer 2018: 281). Therefore, while meeting the increasing food demand, the limited resources such as water and soil should be regarded, and the effects of food production on the ecosystem should be considered (FAO, 2017). It emerges as the need to feed the ever-increasing human population with more and more limited natural resources. This is considered one of the most important challenges faced in the 21st century (Torres-Tiji et al., 2020: 1). This has resulted in an increased interest in sustainable food (Ifeanyichukwu et al., 2020: 33).

Sustainable food is defined as food that is protective and sensitive to biodiversity and ecosystems, culturally acceptable, accessible, affordable, nutritionally adequate, safe and healthy (Baş et al., 2021: 1). One of the promising feedstock in terms of sustainability is microalgae (Draaisma et al., 2013: 169). Because microalgae have high productivity per unit area. They can also be grown on land that is not suitable for agriculture. In addition, it can be grown in non-drinking waters and salty waters (Torres-Tiji et al., 2020: 1).

Microalgae don't have particular support and seminal structures. It can change carbon dioxide and all of the light energy into biomass. It converts 6% of the radiation into biomass. This rate is much lower in terrestrial crops. Therefore, it has higher surface area efficiency and photosynthetic activity compared to terrestrial crop plants. Sugarcane is one of the plants with the highest photosynthetic conversion efficiency. It has a photosynthetic activity of 3.5% to 4%. For industrial production, microalgae are suitable. Because they have simple growth requirements such as inorganic salts, wide environmental compatibility, and higher growth rate, (Kumar et al., 2022: 2).

Another advantage of microalgae is that they can be grown in all climatic conditions (Kumar et al., 2022: 2). Climatic conditions suitable for microalgal productivity are in areas with high temperature, low precipitation and high annual sunshine. These areas are considered unsuitable for agriculture. Currently, some microalgae production facilities are semi-desert areas with little rainfall and more sunlight. Examples of these are Eilat (Israel), Hutt Lagoon (Western Australia), and Whyalla (South Australia) (Randhir et al., 2020: 3).

Food production has some environmental impacts on terrestrial and aquatic environments. Agricultural activities, which are part of the food production process, are one of the main actors in the depletion of resources, as they use about one-third of arable land, almost three-quarters of global water resources and one-fifth of energy. Animal production requires a large amount of land to raise animals and produce their feed, approximately half of all of all agricultural activities. Agriculture negatively affects lands by causing pollution and weakening of soil health

due to excessive chemical input. It is emphasized that clearing more land to meet the increasing demand for food, especially meat, poses a danger to ecosystems. It is stated that this land clearing, also called deforestation, makes an indirect but major contribution to the impact of agriculture on the environment, including loss of biodiversity (Meyer and Reguant-Closa, 2017: 2).

Although animal foods come to the forefront as a protein source, plant products such as grains and pulses are recommended to protect natural resources such as water and soil and to provide more affordable protein supply (Ismail et al., 2020: 57). However, although their protein content is close to animal protein sources, it is thought that causes such as desertification of agricultural lands, becoming water resources are limited and climate change may make difficult the production of grains and pulses. This has enabled microalgae, whose production is relatively less dependent on climate and water, to come to the fore as a protein source (Can et al., 2021: 1148). It is reported that microalgae-based proteins have several advantages compared to other currently used protein sources and can contribute significantly to meeting the protein needs of the world population. Microalgae-based proteins have low land needs (<2.5 m<sup>2</sup> per kg protein) compared to animal-based proteins such as pork (47-64 m<sup>2</sup>), chicken (42-52 m<sup>2</sup>) and beef (144-258 m<sup>2</sup>). Also microalgae have less soil requirements compared to some vegetable protein sources. For example, pea protein meal, soybean meal and others (Caporgno and Mathys, 2018: 2). Microalgae have higher protein yield per unit area compared to terrestrial crops. This value is 4-15 tons/Ha/year for microalgae, 0.6-1.2 tons/Ha/year for soybean, 1-2 tons/Ha/year for pulse legumes, and 1.1 tons/Ha/year for wheat (Bleakley and Hayes, 2017: 2).

Similarly, the estimated land area required to produce algal sterols is notably less than that required by crops such as canola or maize. For instance, the rapeseed plant uses 12 m<sup>2</sup> land/year/kg oil produced whereas microalgae use only 0.1-0.2 m<sup>2</sup> land/year/kg oil. Microalgae is not only considered as an alternative protein source, is considered also as the leading alternative to plants for sustainable phytosterol production due to have a lot of advantage (Randhir et al., 2020: 3).

A significant impact of agriculture on the environment is the use of water. About 70% of all surface and groundwater is used for agricultural activities (Meyer and Hayes, 2017: 3). The water required to produce a variety of food and fodder plants is 500-2000 L of water per kilogram of plant produced. Producing 1 kg of animal protein takes approximately 100 times more water than producing 1 kg of grain protein (Pimentel and Pimentel, 2003: 662). As water resources have become as limited as land, it should be noted that beef production has a significantly larger water footprint compared to alternative meat and plant sources, although there are some exceptions (Meyer and Hayes, 2017: 3).

It is stated that although microalgae cultivation needs a large amount of water regardless of the growing system used, this water can be recovered or recycled comparatively easily, but fresh water will be required due to evaporation losses from growing systems based on open ponds. There are researchers who suggest that this could affect the sustainability of large scaled microalgal production, only replacing evaporation losses with fresh water will use three times the amount of fresh water used for watering in the entire agricultural land mass of the USA. Nevertheless, the possibility of using salt water or degraded water for microalgal production is expressed (Randhir et al., 2020: 4).

The composition of the atmosphere is changing with the excessive use of fossil fuels, destruction of forests, wrong land use, unconscious consumption of natural resources, gases

released into the atmosphere and additional problems created by rapid population growth. As a result of this, unusual weather conditions called global climate change are experienced today. The biggest reason for this change is that the greenhouse gases, whose accumulations in the atmosphere increase rapidly as a result of various human activities, disrupt the radiation balance of the earth and as a result, they tend to increase the surface temperatures of the world with the contribution of urbanization, by strengthening the natural greenhouse effect (Kayıkçıoğlu and Okur, 2012: 25).

Agricultural food production is responsible for 30% of greenhouse gases emitted globally, occupies 40% of usable land and affects 70% of water resources such as rivers, lakes and groundwater. Although animal foods provide 18% of calories from food and 37% of food-borne protein, they are disproportionately responsible for 83% of agricultural land occupation and 58% of food-related greenhouse gas emissions (Polat and Yılmaz Tuncel, 2021: 137). And yet, microalgae are suggested as a sustainable food source for humans and animals. Because it has the potential to reduce environmental problems caused by the expansion of land based food production and provide solutions for global food security (Kusmayadi et al., 2021: 1).

Microalgae have valuable nutrients including omega 3 and omega 6 long chain polyunsaturated fatty acids. Moreover, it has lower chemical contamination and higher purity compared to marine fish, which is a source for these nutrients (Kusmayadi et al., 2021: 1). As a source of protein, DHA and EPA microalgae biomass has been found to have similar or lower environmental effects than fish fillet obtained through aquaculture and hunting (Schade et al., 2020: 3008).

On the other hand, it is reported that the use of microalgae in the form of protein powder is not more environmentally friendly than plant sources and its environmental impact is in the same range as animal protein sources (Smetana et al., 2017: 166). However, microalgae contain a wide variety of nutrients. One of them is beta-carotene. Therefore, it was determined that the environmental effects of producing the same nutritional combination of protein and beta-carotene from carrot + tofu were higher than producing Spirulina tablets (Ye et al., 2018: 154).

When processed for meat substitutes, a highmoisture extruded *Chlorella* resulted in a more environmentally sustainable product than beef and pork, with present technology readiness level and economy of scale for microalgae production (Caporgno and Mathys, 2018: 3). Moreover, it is reported that the environmental effects of microalgae production can be decreased. It has been indicated that these effects will decrease 4.5 times when hydrolyzed food waste is used as a carbon source. Therefore, it is stated that microalgae can stand out as one of the most sustainable protein sources (Kusmayadi et al., 2021: 6).

## 5. CHALLENGES ENCOUNTERED IN ALGAL-BASED FOOD APPLICATIONS

Although microalgae-based products have slowly started to take their place in food markets as healthy food, they need progress in the identification, cultivation, product development and promotion of algal species in order to replace traditional foods.

Biomass efficiency in microalgae production is still not sufficient to meet food industry needs. Microalgal food prices are quite expensive compared to traditional food prices, they should be able to compete with traditional food prices. For example, in 2017 Smetana et al.

evaluated the sustainability of microalgae as a food/feed protein source using the life cycle assessment method. It has been reported that protein production requires a more complex system than conventional sources, and according to the results obtained, Chlorella and Spirulina have worse environmental effects than conventional protein sources (Smetana et al., 2017).

Reducing the cost of microalgae production is closely related to biotechnological developments. Increasing biomass efficiency will reduce production costs. For this reason, new bioreactor design, development of new species using genetic engineering methods, rapid sampling and development of efficient screening methods are important (Beal et al., 2015). Reducing the cost of microalgae production is closely related to biotechnological developments. Increasing biomass efficiency will reduce production costs. For this reason, new bioreactor design, development of new species using genetic engineering methods, rapid sampling and development of efficient screening methods are important (Beal et al., 2015). Also the addition of microalgal biomass to foods can cause various difficulties, mainly due to their intense color or fishy taste and odor (Lafarga, 2019). However, sensory quality can be increased with product development studies.

## 6. CONCLUSION

Today, many people are already facing hunger. On the other hand, the world population is increasing day by day and more and more people are in need of nutrition. However, existing food production systems produce by using limited resources in the world. In addition to the limited resources used for food production, one of the deadlocks in this process is that the production systems create some negative effects on the environment and make the resources more limited. This situation, especially in recent years, has led researchers to search for alternative food sources that are environment friendly and can obtain more efficiency using less resources. At this point, microalgae have emerged as a promising food source. One of the reasons for this is that microalgae are rich in nutritional components that can be used in both human and animal nutrition. Another important reason is the indications that resources can be used more efficiently during the production of microalgae and microalgal food components and their negative effects on the environment can be reduced compared to other food production systems. Therefore, microalgae stand out as a sustainable alternative to meet the increasing nutritional needs and as a functional food component today, where there is an increasing interest in healthy nutrition.

However, there are some problems concerning microalgae. It is possible to list these as the environmental effects being close to traditional food production systems in some cases, the high cost, some hesitation about sensory acceptability and general acceptance by the consumer. However, although it is suggested that there may be some difficulties and limitations related to its production and use, it is thought that research and development studies in production technologies as well as product development and promotion studies will contribute significantly to overcoming these difficulties.

### **Autobiography of Cansu AKGÜL**

The author was born in Edirne. She graduated from Ege University, Food Engineering Department in 2013. In the same year, she started her master's degree at Yıldız Technical University, Institute of Science and Technology, Department of Food Engineering. She completed her thesis on developing a new bread formulation for the nutrition of celiac patients in 2016. During this period, she worked as a Quality Control Engineer and Project Manager in the food

industry. She started to work as a lecturer at Istanbul Aydın University in 2017, and started her doctorate at Yıldız Technical University Food Engineering Department in the same year. She is at the dissertation stage and continues her academic life.

#### Autobiography of Nuray CAN

The author is a graduate of Sakarya University, Department of Food Engineering. She completed his master's degree in Tekirdağ Namık Kemal University, Department of Food Engineering and still continues her doctorate education. She works as a lecturer at Istanbul Aydın University Food Quality Control and Analysis Program.

### REFERENCES

1. ABD EL BAKY, H.H., EL BAROTY, G.S.I., IBRAHEM, E.A. (2015). Functional Characters Evaluation of Biscuits Sublimated with Pure Phycocyanin Isolated from *Spirulina* and *Spirulina* Biomass. *Nutrición Hospitalaria*. 32(1), 231-241.
2. ABURTO, N. J., ZIOLKOVSKA, A., HOOPER, L., ELLIOTT, P., CAPPUCCIO, F. P., & MEERPOHL, J. J. (2013). Effect of lower sodium intake on health: systematic review and meta-analyses. *BMJ* 346: f1326.
3. ADARME-VEGA, T. C., LIM, D. K., TIMMINS, M., VERNEN, F., LI, Y., & SCHENK, P. M. (2012). Microalgal biofactories: a promising approach towards sustainable omega-3 fatty acid production. *Microbial cell factories*, 11(1), 1-10.
4. AHMAD, I., ABDULLAH, N., YUZIR, A., KOJI, I., MOHAMAD, S.E. (2020). Efficacy of Microalgae as a Nutraceutical and Sustainable Food Supplement. *3<sup>rd</sup> Icaresearch Symposium (ICARS) Proceedings*. 22 September 2020 Malaysia. Innovation Centre in Agritechnology for Advanced Bioprocessing, 6-10.
5. AK, B., AVŞAROĞLU, E., IŞIK, O., ÖZYURT, G., KAFKAS, E., ETYEMEZ, M., USLU, L. (2016). Nutritional and Physicochemical Characteristics of Bread Enriched with Microalgae *Spirulina platensis*. *Int. Journal of Engineering Research and Application*. 6(12)(Part-4), 30-38.
6. ARAÚJO, R., VÁZQUEZ CALDERÓN, F., SÁNCHEZ LÓPEZ, J., AZEVEDO, I. C., BRUHN, A., FLUCH, S., & ULLMANN, J. (2021). Current status of the algae production industry in Europe: an emerging sector of the blue bioeconomy. *Frontiers in Marine Science*, 7, 626389.
7. AYDEMİR, S., ÖNER, Z. (2020). Farklı Konsantrasyonlarda *Spirulina platensis* Eklenmiş Yoğurtların Kimyasal ve Mikrobiyolojik Özellikleri. *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi*. 24(3), 553-565.
8. BALBOA, E. M., CONDE, E., MOURE, A., FALQUÉ, E., & DOMINGUEZ, H. (2013). In vitro antioxidant properties of crude extracts and compounds from brown algae. *Food chemistry*, 138(2-3), 1764-1785.
9. BARKA, A., & BLECKER, C. (2016). Microalgae as a potential source of single-cell proteins. A review. *Base*. 10.25518/1780-4507.13132
10. BAŞ, A., PEKSEVER, D., EL, S. N. (2021). Sürdürülebilir Protein Kaynakları: Bitki, Böcek, Yapay Et ve Tek Hücre Proteinleri, *3. Uluslararası Türk Dünyası Fen Bilimleri ve Mühendislik Kongresi Book of Proceedings*. 14-15 Haziran 2021 Niğde, Türkiye. TURK-COSE, 1-8.
11. BEAL, C. M., GERBER, L. N., SILLS, D. L., HUNTLEY, M. E., MACHESKY, S. C., WALSH, M. J., ... & GREENE, C. H. (2015). Algal biofuel production for fuels and feed in a 100-ha facility: A comprehensive techno-economic analysis and life cycle assessment. *Algal Research*, 10, 266-279. <https://doi.org/10.1016/j.algal.2015.04.017>
12. BLEAKLEY, S., HAYES, M. (2017). Algal Proteins: Extraction, Application, and Challenges Concerning Production. *Foods*. 6(33), 1-34.
13. BOUKID, F., & CASTELLARI, M. (2021). Food and beverages containing algae and derived ingredients launched in the market from 2015 to 2019: a front-of-pack labeling perspective with a special focus on Spain. *Foods*, 10(1), 173.
14. CAN, B., BAYRAM, H.M., ÖZTÜRKCAN, S.A. (2021). Çevresel Sorunlara Karşı Çözüm Önerileri: Güncel Sürdürülebilir Beslenme Uygulamalarına Genel Bakış. *Gıda*. 46(5), 1138-1157.

15. CAPORGNO, M.P., MATHYS, A. (2018). Trends in Microalgae Incorporation into Innovative Food Products with Potential Health Benefits. *Front. Nutr.* 5(58), 1-10.
16. CERÓN-GARCÍA, M. C., GONZÁLEZ-LÓPEZ, C. V., CAMACHO-RODRIGUEZ, J., LÓPEZ-ROSALES, L., GARCIA-CAMACHO, F., & MOLINA-GRIMA, E. (2018). Maximizing carotenoid extraction from microalgae used as food additives and determined by liquid chromatography (HPLC). *Food Chemistry*, 257, 316-324.
17. CHACÓN-LEE, T.L., GONZÁLEZ-MARIÑO, G.E. (2010). Microalgae for "Healthy" Foods-Possibilities and Challenges. *Comprehensive Reviews in Food Science and Food Safety*. 9, 655-675.
18. CHEN, C., TANG, T., SHI, Q., ZHOU, Z., & FAN, J. (2022). The potential and challenge of microalgae as promising future food sources. *Trends in Food Science & Technology*, 126:99-112. <https://doi.org/10.1016/j.tifs.2022.06.016>.
19. CHEW, K. W., YAP, J. Y., SHOW, P. L., SUAN, N. H., JUAN, J. C., LING, T. C., ... & CHANG, J. S. (2017). Microalgae biorefinery: high value products perspectives. *Bioresource technology*, 229, 53-62.
20. CHICHAIBELU, B. B., BEKCHANOV, M., VON BRAUN, J., & TORERO, M. (2021). The global cost of reaching a world without hunger: Investment costs and policy action opportunities. *Food Policy*, 104, 102151.
21. ÇELEKLİ, A., ALSLIBI, Z.A., BOZKURT, H. (2019). Influence of Incorporated *Spirulina platensis* on the Growth of Microflora and Physicochemical Properties of Ayran as a Functional Food. *Algal Research*. 44(101710), 1-6.
22. DEL MONDO, A., SMERILLI, A., SANÉ, E., SANSONE, C., & BRUNET, C. (2020). Challenging microalgal vitamins for human health. *Microbial Cell Factories*, 19(1), 1-23. 10.1186/s12934-020-01459-1
23. DRAAISMA, R.B., WIJFFELS, R.H., SLEGGERS, P.M.E., BRENTNER, L.B., ROY, A., BARBOSA, M.J. (2013). Food Commodities from Microalgae. *Current Opinion in Biotechnology*. 24, 169-177.
24. EDELMANN, M., AALTO, S., CHAMLAGAIN, B., KARILUOTO, S., & PIIRONEN, V. (2019). Riboflavin, niacin, folate and vitamin B12 in commercial microalgae powders. *Journal of Food Composition and Analysis*, 82, 103226.
25. EL-BAZ, F.K., ABDO, S.M., HUSSEIN, A.M.S. (2017). Microalgae *Dunaliella salina* for Use as Food Supplement to Improve Pasta Quality. *Int. J. Pharm. Sci. Rev. Res.* 46(2), 45-51.
26. FAO (2017). The future of food and agriculture-Trends and challenges. Rome: Food and Agriculture Organization of the United Nations, 978-92-5-109551-5.
27. FAO, IFAD, UNICEF, WFP & WHO, (2021). The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets. for all, FAO, Roma.
28. FAO, IFAD, UNICEF, WFP, WHO (2022). The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome: FAO, 978-92-5-136499-4.
29. GARCIA-VAQUERO, M., BRUNTON, N., & LAFARGA, T. (2021). Microalgae as a source of pigments for food applications. In *Cultured Microalgae for the Food Industry* (pp. 177-198). Academic Press.
30. GEADA, P., MOREIRA, C., SILVA, M., NUNES, R., MADUREIRA, L., ROCHA, C. M., ... & TEIXEIRA, J. A. (2021). Algal proteins: Production strategies and nutritional and functional properties. *Bioresource Technology*, 332, 125125.
31. GÓMEZ-LOREDO, A., BENAVIDES, J., & RITO-PALOMARES, M. (2016). Growth kinetics and fucoxanthin production of *Phaeodactylum tricornutum* and *Isochrysis galbana* cultures at different light and agitation conditions. *Journal of Applied Phycology*, 28(2), 849-860.
32. GÜROY, B. (2020). Determination of the Phycocyanin, Protein Content and Sensory Properties of Muffins Containing Spirulina Powder or Fresh Spirulina. *Journal of Food and Feed Science-Technology*. 23: 10-18.
33. HERNÁNDEZ-CARMONA, G., CARRILLO-DOMÍNGUEZ, S., ARVIZU-HIGUERA, D. L., RODRIGUEZ-MONTESINOS, Y. E., MURILLO-ÁLVAREZ, J. I., MUÑOZ-OCHOA, M., & CASTILLO-DOMÍNGUEZ, R. M. (2009). Monthly variation in the chemical composition of *Eisenia arborea* JE Areschoug. *Journal of applied phycology*, 21(5), 607-616.

34. HOSSEINKHANI, N., MCCAULEY, J. I., & RALPH, P. J. (2022). Key challenges for the commercial expansion of ingredients from algae into human food products. *Algal Research*, 64, 102696.
35. IFEANYICHUKWU, C.D., NWAIZUGBO, I.C. (2020). Exploring Critical Factors Influencing Sustainable Food Consumption: A Conceptual Review. *European Journal of Business and Innovation Research*. 8(1), 32-42.
36. ISMAIL, B.P., SENARATNE-LENAGALA, L., STUBE, A., BRACKENRIDGE, A. (2020). Protein Demand: Review of Plant and Animal Proteins Used in Alternative Protein Product Development and Production. *Animal Frontiers*. 10(4), 53-63.
37. JIN, H., CHUAI, W., LI, K., HOU, G., WU, M., CHEN, J., ... & HU, Q. (2021). Ultrahigh-cell-density heterotrophic cultivation of the unicellular green alga *Chlorella sorokiniana* for biomass production. *Biotechnology and Bioengineering*, 118(10), 4138-4151.
38. KAYIKÇIOĞLU, H.H., OKUR, N. (2012). Sera Gazi Salınımlarında Tarımın Rolü. *Journal of Adnan Menderes University Agricultural Faculty*. 9(2), 25-38.
39. KUMAR, R., HEGDE A.S., SHARMA, K., PARMAR, P., SRIVATSAN, V. (2022). Microalgae as a Sustainable Source of Edible Proteins and Bioactive Peptides-Current Trends and Future Prospects. *Food Research International*. 157(111338), 1-22.
40. KUSMAYADI, A., LEONG, Y. K., YEN, H. W., HUANG, C. Y., & CHANG, J. S. (2021). Microalgae as sustainable food and feed sources for animals and humans-biotechnological and environmental aspects. *Chemosphere*, 271, 129800.
41. KUSMAYADI, A., LEONG, Y.K., YEN, H.W., HUANG, C.Y., CHANG, J.S. (2021). Microalgae as Sustainable Food and Feed Sources for Animals and Humans-Biotechnological and Environmental Aspects. *Chemosphere*. 271(129800),1-9.
42. KUSMAYADI, A., SUYONO, E. A., NAGARAJAN, D., CHANG, J. S., & YEN, H. W. (2020). Application of computational fluid dynamics (CFD) on the raceway design for the cultivation of microalgae: a review. *Journal of Industrial Microbiology and Biotechnology*, 47(4-5), 373-382.
43. LAFARGA, T. (2019). Effect of microalgal biomass incorporation into foods: Nutritional and sensorial attributes of the end products. *Algal Research*, 41, 101566. <https://doi.org/10.1016/j.algal.2019.101566>.
44. LEVASSEUR, W., PERRÉ, P., & POZZOBON, V. (2020). A review of high value-added molecules production by microalgae in light of the classification. *Biotechnology advances*, 41, 107545.
45. LI, Y., QIN, J. G., BALL, A. S., & MOORE, R. B. (2009). Perspectives on marine phytoplankton as sources of nutrition an bioenergy.
46. LIANG, S., LIU, X., CHEN, F., CHEN, Z. (2004). Current microalgal health food R&D activities in China. *Hydrobiologia*. 512, 45-48.
47. LV, H., CUI, X., WAHID, F., XIA, F., ZHONG, C., & JIA, S. (2016). Analysis of the physiological and molecular responses of *Dunaliella salina* to macronutrient deprivation. *PLoS One*, 11(3), e0152226.
48. MARKOU, G., ANGELIDAKI, I., & GEORGAKAKIS, D. (2012). Microalgal carbohydrates: an overview of the factors influencing carbohydrates production, and of main bioconversion technologies for production of biofuels. *Applied microbiology and biotechnology*, 96(3), 631-645.
49. MATOS, J., CARDOSO, C., BANDARRA, N. M., & AFONSO, C. (2017). Microalgae as healthy ingredients for functional food: a review. *Food & function*, 8(8), 2672-2685.
50. MEYER, N., REGUANT-CLOSA, A. (2017). "Eat as If You Could Save the Planet and Win!" Sustainability Integration into Nutrition for Exercise and Sport. *Nutrients*. 9(412), 1-34.
51. NICCOLAI, A., ZITTELLI, G.C., RODOLFI, L., BIONDI, N., TREDICI, M.R. (2019). Microalgae of Interest as Food Source: Biochemical Composition and Digestibility. *Algal Research*. 42(101617), 1-9.
52. ONACIK-GÜR, S., ŻBIKOWSKA, A., MAJEWSKA, B. (2018). Effect of *Spirulina (Spirulina platensis)* Addition on Textural and Quality Properties Of Cookies. *Ital. J. Food Sci.* 30, 1-12.
53. ÖZDEMİR, G., GÜÇER, E. (2018). Food Waste Management within Sustainability Perspective: A Study on Five Star Chain Hotels. *Journal of Tourism and Gastronomy Studies*. 6(1), 280-299.
54. PENG, J., YUAN, J. P., WU, C. F., & WANG, J. H. (2011). Fucoxanthin, a marine carotenoid present in brown seaweeds and diatoms: metabolism and bioactivities relevant to human health. *Marine drugs*, 9(10), 1806-1828.

55. PIMENTEL, D., PIMENTEL, M. (2003). Sustainability of Meat-Based and Plant-Based Diets and the Environment. *Am J Clin Nutr.* 78, 660-663.
56. POLAT, H., YILMAZ TUNCEL, N. (2021). Sürdürülebilir Et Üretimi. *Gıda.* 46(1), 134-151.
57. RANDHIR, A., LAIRD, D.W., MAKER, G., TRENGOVE, R., MOHEIMANI, N.R. (2020). Microalgae: A Potential Sustainable Commercial Source of Sterols. *Algal Research.* 46(101772), 1-13.
58. RUOCCO, N., COSTANTINI, S., GUARINIELLO, S., & COSTANTINI, M. (2016). Polysaccharides from the marine environment with pharmacological, cosmeceutical and nutraceutical potential. *Molecules,* 21(5), 551.
59. SASA, A., SENTURK, F., USTUNDAG, Y., & EREM F. (2020). Alglerin Gıda veya Gıda Bileşeni Olarak Kullanımı ve Sağlık Üzerine Etkileri. *Uluslararası Mühendislik Tasarım ve Teknoloji Dergisi,* 2(2), 97-110.
60. SCHADE, S., STANGL, G.I., MEIER, T. (2020). Distinct Microalgae Species for Food-Part 2: Comparative Life Cycle Assessment of Microalgae and Fish for Eicosapentaenoic Acid (EPA), Docosahexaenoic Acid (DHA), and Protein. *Journal of Applied Phycology.* 32,2997-3013.
61. SIDARI, R., & TOFALO, R. (2019). A comprehensive overview on microalgal-fortified/based food and beverages. *Food Reviews International,* 35(8), 778-805.
62. SINGH, H., SINGH, J., SINGH, S. K., SINGH, N., PAUL, S., SOHAL, H. S., ... & JAIN, S. K. (2019). Vitamin E TPGS based palatable, oxidatively and physically stable emulsion of microalgae DHA oil for infants, children and food fortification. *Journal of Dispersion Science and Technology.*
63. SINGH, P., SINGH, R., JHA, A., RASANE, P., GAUTAM, A.K. (2015). Optimization of a Process for High Fibre and High Protein Biscuit. *J Food Sci Technol.* 52(3), 1394-1403.
64. SINGH, U. B., & AHLUWALIA, A. S. (2013). Microalgae: a promising tool for carbon sequestration. *Mitigation and Adaptation Strategies for Global Change,* 18(1), 73-95.
65. SMETANA, S., SANDMANN, M., ROHN, S., PLEISSNER, D., & HEINZ, V. (2017). Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology,* 245, 162-170.
66. SOLETTI, D., BINAGHI, L., LODI, A., CARVALHO, J. C. M., & CONVERTI, A. (2005). Batch and fed-batch cultivations of *Spirulina platensis* using ammonium sulphate and urea as nitrogen sources. *Aquaculture,* 243(1-4), 217-224.
67. SPOLAORE, P., JOANNIS-CASSAN, C., DURAN, E., ISAMBERT, A. (2006). Commercial Applications of Microalgae. *Journal of Bioscience and Bioengineering.* 101(2), 87-96.
68. SZMEJDA, K., DULIŃSKI, R., BYCZYŃSKI, L., KARBOWSKI, A., FLORCZAK, T., ŻYŁA, K. (2018). Analysis of the Selected Antioxidant Compounds in Ice Cream Supplemented with *Spirulina (Arthrospira platensis)* Extract. *Biotechnol Food Sci.* 82(1), 41-48.
69. TOHAMY, M.M., ALI, M.A., SHAABAN, H.A.G., MOHAMAD, A.G., HASANAIN, A.M. (2018). Production of Functional Spreadable Processed Cheese Using *Chlorella vulgaris*. *Acta Sci. Pol. Technol. Aliment.* 17(4), 347-358.
70. TORRES-TIJL, Y., FIELDS, F.J., MAYFIELD, S.P. (2020). Microalgae as a Future Food Source. *Biotechnology Advances.* 41(107536), 1-13.
71. TUIK (2013). Nüfus Projeksiyonları, 2013-2075. <https://data.tuik.gov.tr/Bulten/Index?p=Nufus-Projeksiyonlari-2013-2075>  
15844#:~:text=2050%20y%C4%B1%C4%B1nda%20D%C3%BCnya%20n%C3%BCfusu%209,yeri%20ise%2024%20olarak%20de%C4%9Fi%C5%9Fecektir. [Date of Access: 03.09.2022].
72. TUIK (2022). Dünya Nüfus Günü, (2022). <https://data.tuik.gov.tr/Bulten/Index?p=Dunya-Nufus-Gunu-2022-45552> [Date of Access: 03.09.2022].
73. URSIN, V. M. (2003). Modification of plant lipids for human health: development of functional land-based omega-3 fatty acids. *The Journal of nutrition,* 133(12), 4271-4274. <https://doi.org/10.1093/jn/133.12.4271>
74. UZUNER, S., & HAZNEDAR, A. Fonksiyonel Gıda İçin Sağlıklı Takviye: Mikroalgler. *Sinop Üniversitesi Fen Bilimleri Dergisi,* 5(2), 212-226.
75. VAN KRIMPEN, M. M., BIKKER, P., VAN DER MEER, I. M., VAN DER PEET-SCHWERING, C. M. C., & VEREIJKEN, J. M. (2013). Cultivation, processing and nutritional aspects for pigs and poultry of

European protein sources as alternatives for imported soybean products (No. 662). Wageningen UR Livestock Research.

76. VIGANI, M., PARISI, C., RODRÍGUEZ-CEREZO, E., BARBOSA, M.J., SIJTSMA, L., PLOEG, M., ENZING, C. (2015). Food and Feed Products from Microalgae: Market Opportunities and Challenges for the EU. *Trends in Food Science & Technology*. 42, 81-92.
77. WELLS, M.L., POTIN, P., CRAIGIE, J.S., RAVEN, J.A., MERCHANT, S.S., HELLIWELL, K.E., SMITH AG, CAMIRE, M.E., BRAWLEY, S.H. (2017). Algae as Nutritional and Functional Food Sources: Revisiting Our Understanding. *J Appl Phycol*. 29, 949-982.
78. YE, C., MU, D., HOROWITZ, N., XUE, Z., CHEN, J., XUE, M., ZHOU, Y., KLUTTS, M., ZHOU, W. (2018). Life Cycle Assessment of Industrial Scale Production of *Spirulina* Tablets. *Algal Research*. 34, 154-163.
79. ZHOU, L., LI, K., DUAN, X., HILL, D., BARROW, C., DUNSHEA, F., ... & SULERIA, H. (2022). Bioactive compounds in microalgae and their potential health benefits. *Food Bioscience*, 101932. <https://doi.org/10.1016/j.fbio.2022.101932>

%5

BENZERLİK ENDEKSİ

%1

İNTERNET KAYNAKLARI

%5

YAYINLAR

%1

ÖĞRENCİ ÖDEVLERİ

BİRİNCİL KAYNAKLAR

1

"Encyclopedia of Marine Biotechnology",  
Wiley, 2020

Yayın

%1

2

coek.info

İnternet Kaynağı

%1

3

Adi Kusmayadi, Yoong Kit Leong, Hong-Wei  
Yen, Chi-Yu Huang, Jo-Shu Chang. "Microalgae  
as sustainable food and feed sources for  
animals and humans – biotechnological and  
environmental aspects", Chemosphere, 2021

Yayın

%1

4

Cheng Chen, Tao Tang, Qianwen Shi, Zuodong  
Zhou, Jianhua Fan. "The potential and  
challenge of microalgae as promising future  
food sources", Trends in Food Science &  
Technology, 2022

Yayın

%1

5

Martín P. Caporgno, Alexander Mathys.  
"Trends in Microalgae Incorporation Into  
Innovative Food Products With Potential  
Health Benefits", Frontiers in Nutrition, 2018

%1

6

Submitted to Cornell University

Öğrenci Ödevi

%1

Alıntıları çıkart

üzerinde

Eşleşmeleri çıkar

< %1

Bibliyografyayı Çıkart

üzerinde