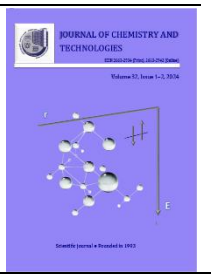
Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

Journal of Chemistry and Technologies

pISSN 2663-2934 (Print), ISSN 2663-2942 (Online).

journal homepage: http://chemistry.dnu.dp.ua
editorial e-mail: chem.dnu@gmail.com



UDC 582.263

GREEN ALGAE: FOCUS ON INNOVATION, FUNCTIONALITY AND NATURALNESS

Lyudmyla V. Peshuk[1], Daria Y. Prykhodko[1*], Olha V. Kozhemiaka[2], Svetlana A. Petrenko[3]

[1]Oles Honchar Dnipro National University, 72, Gaharina av., 49000, Dnipro, Ukraine
[2]MEAT FACTORY "FAVORITE PLUS" LTD, 76, Vasyl Sukhomlynskyi st., 52005, SMT Slobozhanske, Dnipropetrovsk region, Ukraine
[3]Odesa State Agrarian University, 99, Kanatna str., 65039, Odessa, Ukraine

Received 9 October 2024; accepted 17 January 2023; available online 25 April 2024

Abstract

Today, the need to research natural resources and their introduction into the food industry is intensifying. This is influenced by the rapid increase in the number of the population, the deterioration of the quality of food raw materials and the lack of micronutrients in it. The awareness of consumers about the quality of the diet and supporters of a healthy lifestyle indicates the need to develop food products of a new generation. Due to their high nutritional value, reduced environmental impact and economic sustainability, microalgae as functional ingredients are used to improve the characteristics of a wide range of food products. The combination of various forms of algae biomass with traditional food products will allow not only to expand the production of completely new products, but also to involve in the technological process a segment of raw materials that is new for Ukraine and is familiar to the countries of the East and Europe. Commercial and industrial interest in these organisms is gaining momentum in many countries of the world. Food and beverage manufacturers are expanding the use of microalgae in the food industry to meet consumer demand for organic products adapted to the new diets and eating habits of the world's population. Green microalgae are most popular as ingredients and biologically active additives. Their balanced amino acid composition, rich content of vitamins, macro-microelements, fatty acids, pigments gives these microorganisms advantages in filling the body's deficiency in essential substances. This highlights the importance of conducting research, implementing developments and innovations regarding the use of microalgae by society.

Keywords: microalgae; chlorella; ecology; organic food; feed; cultivation; safety.

ЗЕЛЕНІ ВОДОРОСТІ: ФОКУС НА НОВАЦІЇ, ФУНКЦІОНАЛЬНІСТЬ ТА НАТУРАЛЬНІСТЬ

Людмила В. Пешук[1], Дар'я Ю. Приходько[1], Ольга В. Кожемяка[2], Світлана О. Петренко[3]

[1]Дніпровський національний університет імені О. Гончара, пр. Гагаріна, 72, 49000, м. Дніпро, Україна
[2]ТОВ М'ЯСНА ФАБРИКА "ФАВОРИТ ПЛЮС", вул. Василя Сухомлинського, 76, 52005, СМТ Слобожанське, Дніпропетровська область, Україна
[3]Одеський державний аграрний університет, вул. Канатна, 99, 65039, м. Одеса, Україна

Анотація

На сьогоднішній день загострюється необхідність у дослідженні природніх ресурсів та впровадженні їх у харчову індустрію. На це впливає стрімке збільшення чисельності населення, погіршення якості харчової сировини та нестача в ній мікронутрієнтів. Обізнаність споживачів щодо якості раціону та прихильників здорового способу життя вказує на потребу розробки продуктів харчування нового покоління. Завдяки високій харчовій цінності, зниженому впливу на навколишнє середовище та економічній стійкості, мікроводорості як функціональні інгредієнти використовуються для покращення характеристик широкого спектру харчових продуктів. Поєднання різних форм біомаси водоростей з традиційними продуктами харчування дозволить не тільки розширити виробництво зовсім нових продуктів, а й залучити до технологічного процесу новий для України сегмент сировини, який є звичним для країн Сходу та Європи. Комерційний та промисловий інтерес до цих організмів набирає обертів в багатьох країнах світу. Виробники продуктів та напоїв розширюють використання мікроводоростей в харчовій індустрії для задоволення попиту споживачів у органічних продуктах, пристосованих до нових дієт та харчових звичок населення світу. Зелені мікроводорості користуються найбільшою популярністю в якості інгредієнтів та біологічно активних добавок. Їх збалансований амінокислотний склад, багатий вміст вітамінів, макро- мікроелементів, жирних кислот, пігментів надає цим мікроорганізмам переваг щодо заповнення дефіциту організму в есенціальних речовинах. Це підкреслює важливість проведення досліджень, впровадження розробок та інновацій щодо вживання мікроводоростей суспільством.

Ключові слова: мікроводорості, хлорела, екологія, органічні продукти харчування, корми, культивування, безпека.

**Corresponding author: e-mail: dasha0972310144@gmail.com*

doi: 10.15421/jchemtech.v32i1.288749

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

Introduction

In the modern world, the main threat to the health of the population is hunger, lack of food and massive deterioration of its quality. High-calorie diets with a large amount of refined products in the daily diet, combined with a sedentary lifestyle, inevitably lead to such health problems as obesity, diabetes, diseases of the gastrointestinal tract and cardiovascular pathologies. People concerned about poor health are looking for ways to change their diet and become more aware of its quality. Mass popularization of diets, vegetarianism, the growing of supporters of healthy natural products indicates the need to introduce safe raw materials, which will become a natural source of new compounds with biological activity that can be used as functional ingredients [1]. Such a raw material is algae, as it is a source of many indispensable nutrients, capable of establishing a high-quality supply of vitamins, macro- and microelements with the diet, thereby satisfying the needs of the body. In addition, algae are rich in protein, with a balanced content of amino acids, fatty acids, pigments, and have anticarcinogenic and antioxidant properties [2; 3].

Among the huge number of different algae, only some representatives of red, brown and green algae are considered edible [4]. These organisms have been used as food by the inhabitants of Asia for centuries, due to their nutritional value and mass cultivation. Currently, red algae are used mainly as hydrocolloids, such as agar and carrageenan [5]. In addition to consumption, brown algae have become the main raw material for the production of alginates [6]. Only a few tens of thousands of algae out of the total number of species are described in the literature. The genetic analysis and ranking of their types is still ongoing and there is still no complete classification, however, in recent years, the most frequent research on algae is the representatives of green microalgae, which are distributed on the world market as components of dishes, superfoods and food supplements, the commercialization and cultivation of which is gaining circulation in China, Japan, Korea, among European countries and the USA [7]. Although this raw material is new on the market of food products and supplements, there is already noticeable competition between global manufacturers and a fairly wide selection of products using them.

Discussion of the results of the analysis

Today, solving the problem of healthy nutrition is the most important and urgent task related to the social stability of society and the health of the population. The problem of lack of biologically active substances in the diet of Ukrainians can be solved by using seaweed and functional additives from them. In recent years, there has been a growing interest in algae as promising dietary supplements. This is due to their specific composition and ability to synthesize unique polysaccharides, uncharacteristic for terrestrial vegetation and various biologically active substances that correlate immunological, adaptogenic and biostimulating functions of the human body.

The analysis of domestic and foreign sources showed the relevance, perspective and expediency of developing technology for the production of culinary products using seaweed, which will allow not only to expand the range of functional food products with an increased content of micronutrients, but also to preserve the environment.

Currently, there are 28,000 species of algae that have been used for centuries as food and medicinal and preventive means. Residents of China and Japan used algae as early as the 8th century, and over time their use gained popularity in the seaside areas of France, Ireland, Scotland, Norway and other European countries.

Seaweed cultivation is practically waste-free compared to terrestrial plants, as they do not have stems, leaves and roots, which indicates the ecological and economic sustainability of their cultivation. Algae have valuable properties and a wide nutritional composition due to the high content of protein, fiber, carbohydrates, fatty acids, vitamins and minerals, uncharacteristic of most food products. Every year, development and research on the use of algae as a dietary balanced raw material is increasing. This is due to the variety of their functional properties, specific composition and ability to treat pathological conditions of the body. Seaweeds have anti-carcinogenic properties, removing salts of heavy metals, pesticides, radionuclides and other harmful substances from the human body. Global medical studies have shown that in countries where seaweed is regularly consumed by the population, there is a significantly lower percentage of people prone to obesity and cardiovascular diseases [8].

In modern conditions, a diet consisting of natural products, taking into account age characteristics, is often unable to provide the body with the necessary amount of iodine, therefore it is advisable to develop food products using it.

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

Numerous studies have proven that the main approach to solving the problem of iodine deficiency is to increase its consumption by iodizing food products. For the prevention of iodine deficiency and its enrichment of food products, seaweed is appropriate, as it contains up to 3000 μg of iodine per 100 g of raw material, depending on the species. However, it should be taken into account that the content of iodine in algae can vary depending on the species, season, depth, pollution and temperature of water bodies, lighting and other factors [9].

Global sales of seaweed products are gaining momentum due to their wide variety and increased development and innovation in the seaweed product category. There are about 110 commercial microalgae producers in the Asia-Pacific region, with capacities ranging from 3 to 500 tons/year. Microalgae production is mainly concentrated in East and Southeast Asia - about 9/10 algae cultivation enterprises. Among them, a large number of commercial algae producers are located in China, Taiwan, and India [10]. According to the results of research conducted by various authors, the most cultivated types of microalgae in Europe are Spirulina, Chlorella spp., Nannochloropsis spp. and Haematococcus pluvialis (Fig. 1) [11].

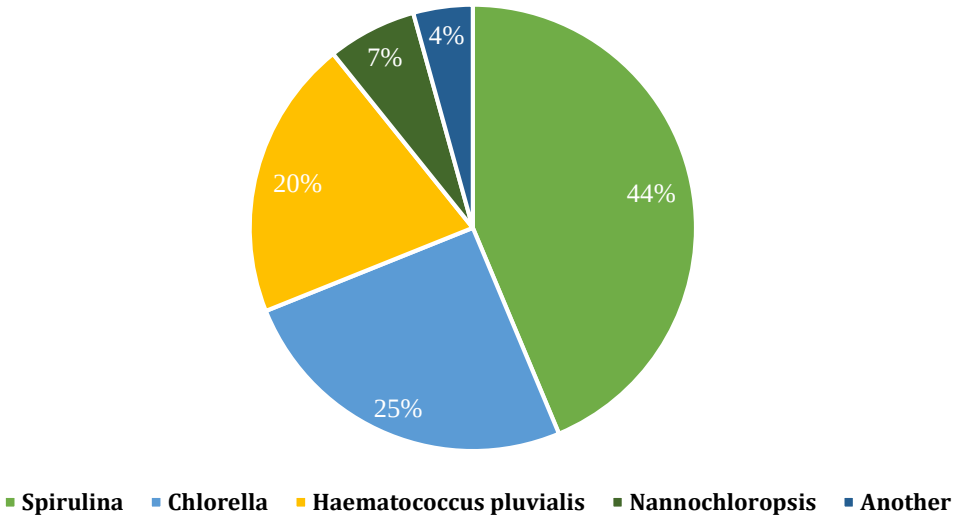


Fig. 1. Share of microalgae production in Europe

From an ecological point of view, algae production is an important natural mechanism for reducing excess CO_2, thus ensuring a smaller greenhouse effect, which indicates the relevance of large-scale algae cultivation, equally valuable for the economy and the environment [12]. Sunlight, water, CO_2, inorganic nutrients are the main requirements for zero-waste cultivation of algae. Recently, great attention has been paid to another aspect of the use of microalgae in the economic life of a person - the ecological one. Taking into account economic efficiency, it is believed that chlorella is a promising organism for the treatment of wastewater from food processing enterprises, poultry farms and livestock farms. In view of the enormous biological diversity of microalgae and recent developments in the field of genetic and metabolic engineering, it is believed that microalgae, in particular chlorella , is the most promising source of a wide range of products (Fig. 2): proteins, fatty acids, neutral and polar lipids, polysaccharides, antioxidants, vitamins, dyes, hydrogen, oxygen, etc.

Based on this, there are different ways of using microalgae biomass or components obtained from them (Fig. 2). In agriculture, it is used to feed plants, feed poultry, animals, beekeeping and fish farming. The feed additive is used in the form of suspension and paste, in some cases - in the form of powder and granules. The inclusion of chlorella in feed rations leads to an increase in meat productivity up to 35 %, milk productivity - up to 20 %, egg production of chickens – up to 30 %, and also reduces feed costs by 10–15 %. The value of green organic fodder also lies in the fact that it contributes to increasing the resistance of animals to various diseases. Since the middle of the 20th century, chlorella has been used to purify water and restore air composition on space stations and submarines. Microalgae can act as a link in ecosystems closed with gas and water, i.e. provide biological regeneration of air and reproduction of food due to its metabolic activity.

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

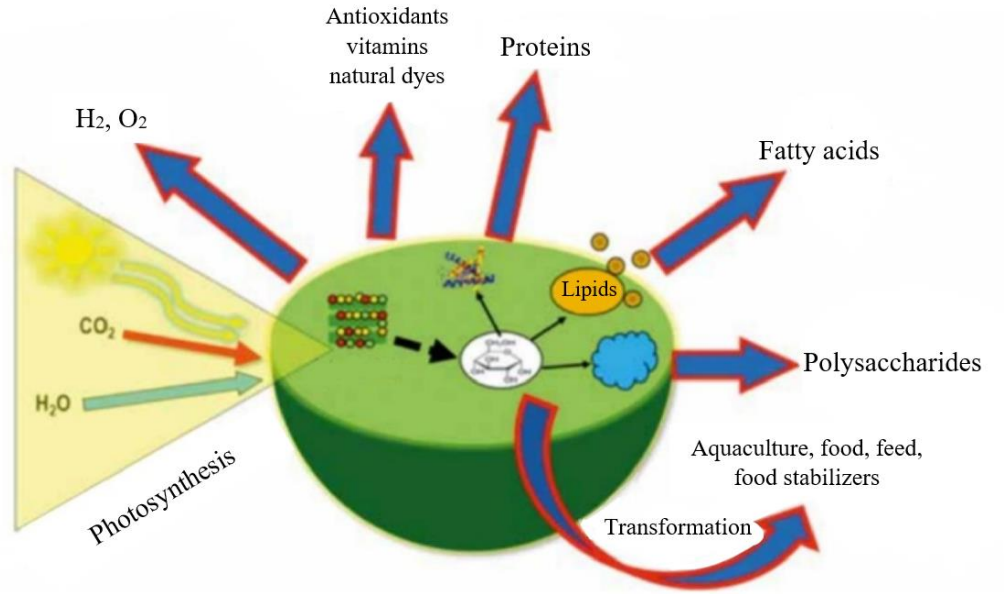


Fig. 2. An overview of the possible products that can be obtained from chlorella

Because of this, chlorella has complex possibilities of its implementation in the development of the space industry. It has been established that chlorella by absorbing carbon dioxide is able to provide a person with oxygen and dispose of the products of his life activity, for an almost unlimited time, while being synthesized in such a time that a person is not able to completely absorb all the green biomass formed. Specialists in space nutrition are engaged in the development of new technologies of special products using microalgae, which will be as balanced as possible to suppress the exhaustion of astronauts on long flights [13].

Production plants combine different production systems, such as photobioreactors with fermenters or open ponds. Overall, this method is the most common system used for microalgae production (71 %), while open ponds and fermenters account for 19 % and 10 % of the total number of production plants, respectively. Due to the rapid growth compared to other raw materials, the production of microalgae requires 20 times less land than for growing soybeans, and 40 times less than for corn, and 200 times less than for growing livestock for meat raw materials [11].

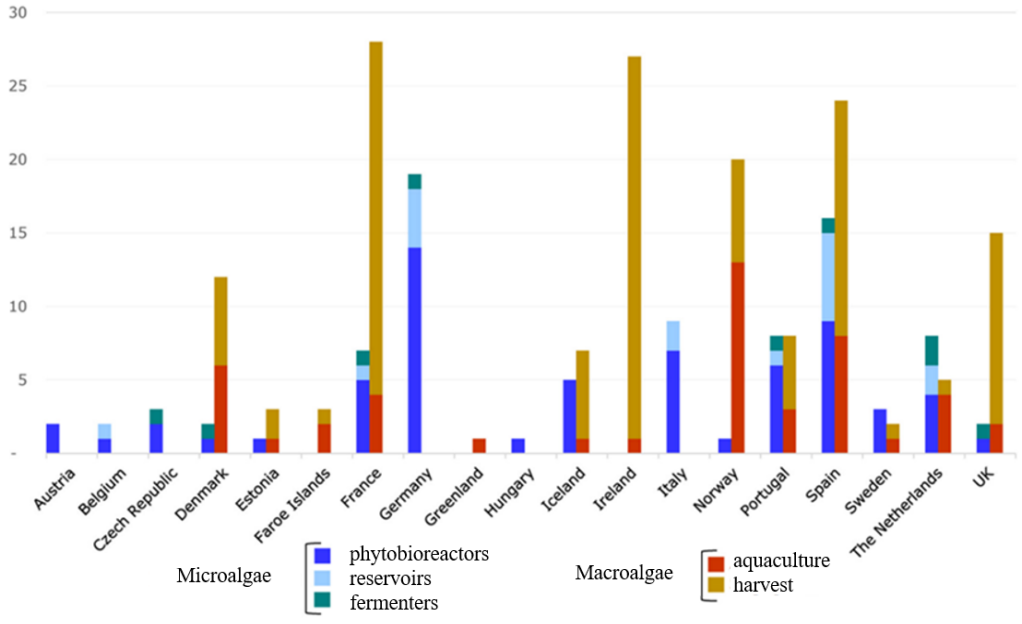


Fig. 3. The number of enterprises producing macro- and microalgae in European countries

The new green raw material is considered promising not only as a food component. Algae are used in animal feed, as a fertilizer, chlorella suspension is an organic, environmentally safe fertilizer, which includes elements in a balanced state for restoring soil fertility, medicine, pharmacology, cosmetology and many other integral areas of life. Chlorella processing products are used in cosmetology as dyes, creams, emulsifiers, gelling agents and detergents [14].

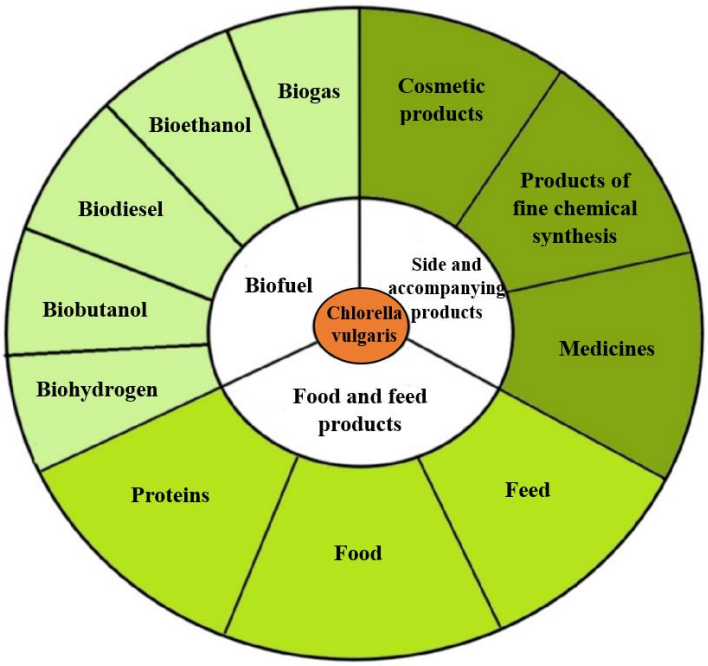


Fig. 4. Use of chlorella biomass or components derived from it

The increase in demand for ecologically clean raw materials also affected the prevalence of the use of algae. Today, they are sold in fresh, fermented, frozen, dried, powdered, liquid, granular, and tablet form [16].

Fig. 5. Assortment of chlorella microalgae in various forms

Algae currently make up more than 8 % of the total diet of Japanese people, which is a 20 % increase over the past decade. The influence of Asian cuisine on European consumers caused the

need to conduct research on their safety and production potential [17]. Thus, during the last decades, the biochemical composition and functional properties of algae of different strains have been thoroughly investigated and scientifically confirmed as safe raw materials by the US Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) [18]. It is expected that by the end of 2023, the value of the world market for algae products will reach 4,810 million euros, the most successful representatives of which are Asia, North America, and Europe (Fig. 3) [19].

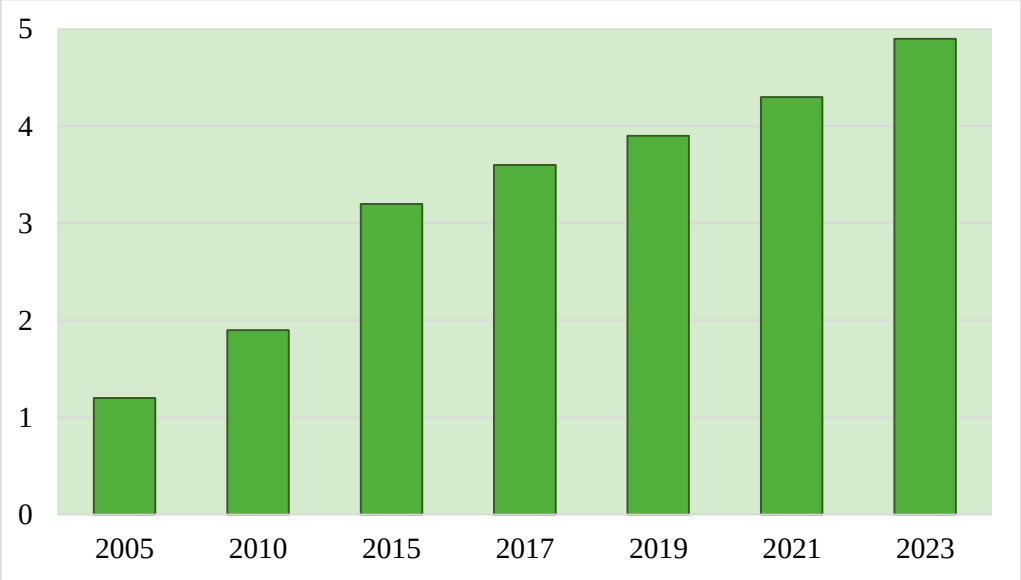


Fig. 6. The value of the world market of algae products, million euros/year

The need for high-quality protein raw materials is growing massively in accordance with the rapid increase in the global population. As you know, according to the United Nations, by 2050, the world's population will exceed 9 billion people, which will steadily affect food shortages, protein shortages, and the need to expand its sources. According to the FAO, food production should be increased by 60 % in the near term, with an emphasis on high-quality natural raw materials that can replace livestock products. Meat is a major part of people's diets around the world, but meat, especially red meat, contains significant amounts of saturated fat, which raises cholesterol levels. Meat products, such as hamburgers, sausages, salami, ham products – the range of which is very wide (diverse) on the food market, contain a large amount of salt as a necessary ingredient to preserve, improve taste and texture. In addition, manufacturers add artificial flavor enhancers, dyes and preservatives to the recipes, the regular use of which leads to the development of diseases of the gastrointestinal tract and the appearance of allergic reactions. As you know, protein is the main energy component of the human body. It helps to form cells and tissues, supports the work of the immune system and metabolic processes in the body. Protein imbalance leads to the disruption of all interdependent structural and functional processes in the body, affects the deterioration of the physical state of health, as well as the quality of skin, hair, and nails. For normal life, a person needs to consume from 0.8 to 2 g of protein per 1 kg of weight per day, which becomes extremely difficult, given the progressive lack of protein resources [20].

The protein content of algae, depending on the strain, varies from 6 to 70 %, which indicates the possibility of their use in the meat industry as a replacement for a part of animal raw materials, without reducing the protein content, but also increasing the biological value of the obtained product [21]. Microorganisms with a high protein content are green microalgae chlorella (Chlorella vulgaris) and spirulina (Spirulina platensis) (Table 1). The protein of which is balanced and easily digestible, which is rarely found in raw materials accepted as the main source of vegetable protein (mushrooms, legumes). For example, the content of leucine, the most important essential amino acid that stimulates brain functions and increases the level of muscle energy, in green microalgae is almost twice as high the content of this amino acid in red meat, which is a product of regular consumption in many countries [22; 23].

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

Table 1

Biological value of microalgae Chlorella vulgaris and Spirulina platensis [24; 25]

Amino acids	Chlorella vulgaris	Spirulina platensis
Essential amino acids, mg/100 g of raw material		
Valin	2935	2789
Isoleucine	1925	2534
Leucine	4330	3969
Lysine	3900	2262
Methionine + cysteine	1779	1267
Threonine	2350	3961
Phenylalanine + tyrosine	4235	3936
Tryptophan	1060	1760
Non-essential amino acids, mg/100 g of raw material		
Aspartic acid	4590	3069
Glutamic acid	6120	4963
Serine	2025	2035
Proline	2440	2292
Histidine	1091	2739
Glycine	2925	2126
Alanine	4090	1210
Arginine	3185	2613

Today, green microalgae are at the forefront of superfoods, thanks to their balanced content of essential components. An integral component of health maintenance is a full supply of vitamins and minerals to the body. Unfortunately, a large number of the population suffers from hypovitaminosis and mineral deficiency, which adversely affects the quality of life, suppressing well-being. Manufacturers of synthetic vitamin supplements and nutritional supplements have flooded the market with products of various price categories and massively advertise means of complex action on the body. Unfortunately, a large number of such products is only a marketing move, since synthetic additives are not able to be fully absorbed by humans [26]. The only really effective way to avoid problems with the lack of these elements is a balanced diet and the introduction into the daily diet of ingredients with multifunctional properties of natural origin, capable of saturating the body with natural active components. Green microalgae Chlorella has a uniquely balanced content of macro-microelements, such as potassium, calcium, magnesium, sodium, iron, phosphorus, zinc, copper and others [27], as well as vitamins: β-carotene (provitamin A), thiamin (B_1), riboflavin (B_2), nicotinic acid (B_3), pantothenic acid (B_5), pyridoxine (B_6), biotin (B_7), cobalamin (B_{12}), ascorbic acid (C), which indicates its superiority over artificial nutrients (Table 2) [28].

Table 2

Indicators of the vitamins and minerals composition of Chlorella vulgaris, mg/100 g of raw material [27, 28]

Vitamins		Mineral substances	
B_1	1.7	Ca	1425.0
B_2	4.3	Mg	851.0
B_3	23.8	Na	101.0
B_5	1.1	K	1197.0
B_6	1.4	P	58.0
B_9	0.9	Zn	293.0
B_{12}	0.1	Fe	82.2
A	30.8	Cu	48.4
C	10.4	Mn	15.5

Microalgae acts as a biostimulant, has a beneficial effect on most functions of the living organism, has bactericidal properties, can fight against pathogens of dysentery, Escherichia coli, typhoid, and many other diseases. With the help of chlorella, carotene is better absorbed, metabolic

processes in the body are normalized, blood composition is improved. Chlorella has an anti-inflammatory effect and promotes faster bone marrow regeneration. No food product, except for chlorella, contains such an amount of proteins, fats, carbohydrates, vitamins and minerals [29].

Chlorella cell walls have three layers, the middle layer contains cellulose microfibrils, and the outer layer is polymerized carotenoid material. It is this outer layer that gives chlorella its detoxifying properties. The material binds heavy metals, agrochemicals, pesticides and toxins and then transports them outside the body. The digestive tract does not have the ability to independently destroy this strong cell wall. That is why, for the maximum assimilation of microalgae by the body, the process of crushing the chlorella cell wall without destroying the cell contents was invented and patented. This technology made it possible to increase the digestibility of chlorella from 47% to more than 80%, which naturally influenced the increase in its use as a food additive [30].

When studying the lipid composition of different types of microalgae, Chlorella was found to be the largest producer of polyunsaturated fatty acids, such as omega-3 and omega-6 [31]. As you know, linoleic fatty acid (ω-6) enters the body with refined products, the use of which, unfortunately, is daily. Thus, in the diet of most people, the ratio of omega-3 to omega-6 reaches an average of 1:20, while the optimum for the high-quality functioning of all life processes is 1:4, i.e., omega-6 today exceeds the permissible norm by 5 times. This indicates the need to increase raw materials, the content of linolenic fatty acid (ω-3) in which will exceed the value of ω-6. Table 3 shows the fatty acid composition of microalgae, showing the preference of chlorella [32].

Table 3

Fatty acid composition of microalgae, g/100 g of fat

Fatty acid	Chlorella vulgaris	Spirulina platensis	Dunaliella salina	Thalassiosira
Saturated, including	16.7	37.1	20.3	24.6
Myristic ($C_{14:0}$)	0.7	0.2	0.6	4.6
Palmitine ($C_{16:0}$)	14.4	35.4	15.4	19.6
Stearic ($C_{18:0}$)	1.6	1.5	2.9	0,4
Monounsaturated, including	21.7	5.7	49.3	32.2
Palmitoleic ($C_{16:1}$)	4.1	1.2	2.1	31.5
Oleic ($C_{18:1}$)	17.6	4.5	47.2	0.7
Polyunsaturated, including	27.7	16.7	28.9	3.1
Linoleic ($C_{18:2}$) ω6	11.9	12.2	17.7	2.0
Linolenic ($C_{18:3}$) ω3	15.8	4.5	11.2	1.1

In addition to being a food additive, chlorella microalgae are used as a dye, flavor enhancer, and antioxidant [33]. Natural pigments such as chlorophyll, phycobiliproteins and carotenoids are among the most sought-after high-value metabolites produced by these algae. Chlorella is the richest source of chlorophyll on the planet, approved as a food additive E140, and used as a green colorant in many foods and beverages, such as pasta, sauces, candies, lemonades, absinthe, and wasabi [34]. Once in the stomach, chlorophyll exhibits detoxifying properties, cleanses the body of impurities, heavy metals (mercury, cadmium, arsenic, lead), which often come with animal raw materials, thereby counteracting the occurrence of poisoning and allergic reactions. Chlorophyll initiates the production of interferon, promotes regeneration, has antimicrobial, anti-inflammatory, anti-oncological effects, is structurally similar to hemoglobin, helps to improve the condition of anemia, helps with diseases of the upper respiratory tract, diseases of the dental profile, as well as cardiovascular and digestive systems [35]. The anticancer effect of chlorophyll has also been confirmed. Its derivative element is chlorophyllin, capable of preventing the emergence of cancer cells, actively combating existing ones, inhibiting the growth of pathogenic microorganisms, without disrupting the vital activity of beneficial bacteria [36; 37].

In the Far East, Chlorella vulgaris has been known since ancient times not only as a food source, but as a major alternative medicine. Chlorella belongs to the oldest plants of our planet. According to estimates of some scientists, its age reaches 2 billion years. It is a unique biological

natural product. No other plant, aquatic or terrestrial, has as many useful properties as chlorella. During its many years of history, chlorella has participated in wars, space programs and has been a real hit in Japan, the country of longevity, for more than 50 years. Chlorella stimulates the human immune system. Therefore, chlorella is used for the production of various drugs and vitamins [38].

Today, chlorella is one of the most scientifically researched algae in human history, with a huge number of medical and scientific publications. As for human health, no negative side of this microorganism has been recorded so far. Microalgae has a wide range of health-promoting applications as a functional ingredient, provides stimulation of the immune system, prevention and treatment of diseases. These algae are an excellent nutraceutical because they contain polyphenols, beta-carotene, ascorbic acid, lycopene, alpha-tocopherol, xanthophylls, and PUFAs. Studies show that chlorella is effective in the treatment of diabetes, hypoglycemia, arthritis, peptic ulcers, liver damage, asthma, high blood pressure, and anemia [39; 40].

The way of life of a modern person is associated with an increase in the load on the psycho-emotional system and, in the vast majority, with a decrease in physical activity compared to previous generations, accordingly, the composition of the diet should show a complex therapeutic and preventive effect, in order to predict the development of pathological conditions. Chlorella is a memory-enhancing superfood and is often referred to as "brain food". It contains vital nutrients needed by the brain to maintain memory. The human brain has the highest concentration of RNA (ribonucleic acid) in the body, which is vital for memory and learning. However, brain cells have a limited ability to produce nucleosides and nucleotides, which are necessary for RNA synthesis. The level of RNA gradually decreases with age, which may be a factor in age-related memory loss. Thus, adding natural sources of nucleosides and nucleotides to the diet can provide the building blocks needed to support brain health [33].

Conducted studies have established that regular use of chlorella improves the growth dynamics of children, maintaining health in old age, including Alzheimer's disease, paralysis, convulsions, multiple sclerosis, nervousness and other known disorders of the nervous system. People suffering from degenerative diseases have reported positive results within a month of taking chlorella daily. Of course, constant development of research on this issue is needed, but if microalgae are really able to influence the recovery of nerve cells, it could become one of the greatest discoveries of modern times [33].

Chlorella has powerful antiviral properties. This is due to the content of lipids, about 40% of which are represented by glycolipids and sulfoglycolipids, which contribute to the increase of immune system cells that perform protective functions against the herpes virus, HIV-1, cytomegalovirus, influenza, measles and other diseases [33].

A decrease in physical activity, working in offices, the spread of fast food and an increase in refined food have led to a global obesity pandemic. As of 2022, it is known that about 40 % of the world's population regularly overeats, of which 750 million are obese. Of course, the use of a small amount of microalgae is not able to ensure weight loss, but there are several obvious facts that prove the positive effect of algae in the matter of weight loss. Taking chlorella can reduce cravings for sweet and carbohydrate foods. This is evidenced by the high content of the element magnesium in this microalgae. Deficiency of this trace element leads to intense dependence of the body on chocolate, which contains magnesium. When using microalgae, the body maintains the necessary level of magnesium, which is why the desire to have another snack does not arise [41].

Enrichment of the body with protein from these algae takes place in the same way. It is a sufficient amount of protein in the body that ensures a constant level of sugar in the blood, which counteracts any hypoglycemic tendencies that cause a constant need to consume sweets. In other words, the protein of these superfoods simply blocks the hypoglycemic appetite of the human body [41].

Regarding the amount of chlorella consumption to reveal the above-mentioned medicinal properties, a dose of 1-2 teaspoons of chlorella (~ 5–10 g) is sufficient, and for health purposes only 0.5 teaspoons of algae (~ 3 g) is enough. It is important to regularly use it in courses of 21–40 days, according to the individual needs of the body [42].

One of the promising scientific directions in the complex secondary prevention of diseases of various organ systems is diet therapy and the use of functional food products, i.e. food products that have sufficient organoleptic properties and have a pronounced health-improving effect for humans. Such products should be available, convenient to

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

use and intended for systematic use, or can be a supplement to the main diet. According to the data analyzed above, chlorella has undoubted possibilities of use as one of such products [42].

In the 1940s, two researchers, Jorgensen and Konwit, fed a concentrated soup with the microalgae chlorella to 80 patients in a leper colony in Venezuela. Improvements in the physical condition of patients became the first documented evidence of the potential of microalgae as a health supplement. Research on the dietary value of Chlorella for human health began in the early 1950s, when the use of Chlorella as a food source was initiated in the midst of the global food crisis [43].

Commercial use of Chlorella was first started in 1961 by Nihon Chlorella Inc., which was established using the mass cultivation facilities of the Japan Microalgae Research Institute (commonly known as the Chlorella Institute). This institute was built in 1957 in the suburbs of Tokyo as a pilot facility for the research and development of mass cultivation of microalgae, with special attention to the cultivation of Chlorella. The institute supplied large quantities of dried Chlorella cell mass for food and medical research to the National Institute of Nutrition in Tokyo and to the laboratories of a number of Japanese universities and hospitals [44].

The technologies of mass cultivation and production of dried biomass with good digestibility, as well as offering it to the public in a convenient tablet form, helped establish the Chlorella industry as a new health food product in Japan in 1964 [45]. Today, in Japan, chlorella is bred even in swimming pools on the roofs of houses. A plant is being designed in the Mississippi River Delta, where it is planned to receive 30 tons of chlorella daily, containing 50 % proteins, which is equal to the production of 35,000 tons of beef (this amount can provide protein nutrition for about 3 million people).

Commercialization of Chlorella as a superfood in tablet form was initiated in 1964 by a businessman who believed in its value and was only supported much later by nutritional and clinical reports on the algae. The growing demand for chlorella is evidenced by the rapid increase in the volume of its cultivation. By 1975, the total production of chlorella was about 200 tons per year; in the 1980s, it exceeded 1,000 tons; in the 1990s, it approached 2,000 tons per year [46]. World companies engaged in the production of chlorella for food purposes are listed in Table 4 [47; 48].

Table 4

World producers of Chlorella for food needs [47; 48]

Food supplement	**America:** Valensa International (USA); NP Nutra (USA)
	Asia: Yunnan Green A Biological Project (China); Tianjin Norland Biotech (China); Taiwan Chlorella Manufacturing (Taiwan); Wilson Group (Taiwan); FEBICO (Taiwan); Parry Nutraceuticals (India); Seagrass Tech (India)
	Europe: Allmicroalgae (Portugal); Buggypower (Portugal); Duplaco (Netherlands); Ecoduna (Arrangement); BlueBioTech (Germany); NeoAlgae (Spain); ФГ «У Самвела» (Ukraine); ТОВ «Хлорелла Украина» (Ukraine)
Food ingredient	**Asia:** Taiwan Chlorella Manufacturing (Taiwan)
	Europe: Allmicroalgae (Portugal); Algama (France); Phycom (Netherlands); Duplaco (Netherlands); Corbion (Netherlands); Ecoduna (Arrangement); Algomed/RoquetteKloetze (Germany)

In Ukraine today, consumer awareness of the use of microalgae is only gaining momentum, but the part of the population that is interested in buying green raw materials for food needs is growing rapidly. Of course, this is inextricably linked to the trends of healthy, balanced nutrition, which Western countries have been imposing on us recently. Regarding producers, Ukraine currently has two enterprises that cultivate chlorella – ТОВ «Хлорела Україна» and ТМ «Жива Хлорела» together with FG «У Самвела» [49; 50].

Over the past decade, some companies engaged in the production and commercialization of food have begun to participate in the development of products containing microalgae [51]. For example, in Europe, Follow Your Heart introduced consumers to a vegan egg substitute made from local microalgae. In France, organic mayonnaise with the addition of chlorella is popular among supporters of plant-based nutrition. In Asia, supermarket shelves are filled with a huge assortment of snacks, snacks, sauces, lemonades, isotonic drinks, pasta and bakery products using algae, which are really recognized by the

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

population [52; 53]. In North and South America, microalgae-containing products such as organic cucumber and avocado soup containing spirulina and a high-protein protein bar have also recently appeared in Canada [54].

Microalgae have potential as natural sources of food ingredients, but currently, chlorella and spirulina are preferred by producers and consumers as superfoods [55]. Products containing microalgae biomass can be divided into those in which they are used only as a dye, and those in which microalgae are a full-fledged ingredient to provide the resulting product with nutritional and functional properties (Fig. 7) [56].

Fig. 7. Assortment of products with Chlorella and Spirulina algae [56]

Chlorella is an amazing algae that has no analogues. Extracts are mainly used to enrich liquid products such as health drinks, soft drinks, tea, beer or spirits. Algae biomass used in the production of bread, cookies, candies, ice cream, chocolate, bean curd as a food additive to increase their nutritional and health value. Chlorella powder is added to yogurts, kefir, ryazhanka, fruit juices, ice cream, etc.

In Japan, it is practiced to obtain a powder from chlorella. This powder is a high-calorie product and is often added to flour and used to prepare bakery products (chlorella helps improve the work of yeast), the products turn out lush, smell delicious and do not go stale for a long time. In addition, chlorella powder is added to sauces, main dishes and ice cream.

We have developed a number of products with the addition of chlorella, namely semi-finished meat cuts (1.5 % and 3 %) [57; 58], meat loaves (3;%) [59], semi-finished products in a dough shell (3.0 % and 4.0 %) [60], pastes (0.5 %, 1.0 %, 2.0 %, 3.0 %), sauces (3 %), mayonnaise (30 % and 60 % suspension) [61].

In the countries of Asia and Europe, people are aware of the use of microalgae and have learned to use it on a par with the food products we are used to. In fact, using these superfoods is not difficult. The most convenient way is to improve daily meals with algae in powder form or in the form of a suspension. For example, it is recommended to use chlorella and spirulina in dried form in the amount of ~ 10 g per day. It has been proven that with the addition of microalgae up to 3 % per 100 g of raw material, the organoleptic

Journal of Chemistry and Technologies, 2024, *32*(1), 138-152

characteristics, apart from the appearance of a green color, remain unchanged, but the content of essential components for the body improves significantly.

Table 3

Brands and products with microalgae [56]

Trademark	Company	Product description	Producing country	Additional Information
Happy Plane	Happy Planet Foods, Canada	Green fruit cocktail with Spirulina and Chlorella	Canada	Contains Spirulina and Chlorella
Natali PotaBio	Nature et Aliments, France	Soup with spinach and Spirulina	Spain	AB and EU Green Leaf logo
Frecious Slow Juice	Frecious, Netherlands	Vegetable juice containing Chlorella	Netherlands	AB and EU Green Leaf logo
OHi	OHi Foods, USA	Plant-based bar without gluten, grains and soy	USA	Contains organic Spirulina and Chlorella
Tohato Harvest	Tohato, Japan	Crispy cookies	Japan	Contains Chlorella
Ginbis	Ginbis, Japan	Baked bean and seaweed crackers	Japan	Contains Chlorella
Urban Remedy	Urban Remedy, USA	Cashew milk with Spirulina	USA	USDA Certified Organic
Honest Fields	SC Honest Fields Europe, Romania	Organic cakes with Chlorella	Romania	AB and EU Green Leaf logo
Simply Raw Protein RAWBA	Merlo's Best, Germany	Fruit bar with Spirulina	Germany	AB and EU Green Leaf logo

The taste and smell of algae are usually perceived differently, but most often consumers note the similarity with green tea, the aroma of cut grass with a taste characteristic of seafood, but the pronounced taste is completely lost when microalgae is combined with other components of the recipe [59]. Mostly, microalgae are used to prepare first courses, pasta, meat products and semi-finished products, desserts, fruit and vegetable smoothies and other drinks. From the point of view of giving the product a green color, in some product segments, for example, lemonades or confectionery products is a big plus, as it will reduce the use of artificial dyes. Today, manufacturers much more often use synthetic dyes instead of natural dyes, because they are cheaper and more convenient to use, but they have a negative effect on the human body. Such natural dyes as beetroot or spinach are not always appropriate to use, since the juice of these vegetables loses its color during some types of heat treatment, and green microalgae have a more intense and stable pigment, which allows it to retain its bright green color [60].

Chefs and restaurateurs also did not miss microalgae. Gastronomy around the world is developing with an inclination to use a variety of organic ingredients to create new dishes and interest whimsical consumers, not only with taste qualities, but also with the originality of components and presentations. In the menus of many world-renowned Michelin restaurants, inventive chefs-innovators such as René Redzepi, João Rodríguez, José Aviles, Leonel Pereira, Ricardo Costa, Ángel Leon and others use algae not only in vegetarian menus, but in general, as an equivalent component in dishes and sauces [62].

Conclusions

Today, the use of algae in many industrial fields is rapidly gaining momentum. The food industry is no exception. Consumer priorities are changing in favor of natural, healthy food when using organic raw materials to diversify the diet and provide it with balance. Green microalgae are one of the most popular superfoods on the market of nutritional supplements both for enriching products with protein and micronutrients and providing them with functional properties. Microalgae Chlorella is widely distributed on the market of the USA, European and Asian countries not only as a biologically active supplement, but also as an ingredient in the formulation of various products and ready meals, due to its high amino acid, vitamin and mineral composition. After all, thanks to their curative and preventive properties, microalgae are able to cleanse the body at the cellular level, remove toxins, poisonous substances and strengthen immunity. Today, most of the world's companies consider green algae to be the raw material of the future, actively conduct research and cultivate their various strains. Brands, in turn, distribute an assortment of products with algae, which are actively interested in supporters of healthy food, athletes and vegetarians. Microalgae have a unique, compared to most products on the market, nutritional profile, are able to cover the nutritional needs of the rapidly growing global population, have absolutely no toxic metabolites and

decomposition products, thereby not harming the environment. Algae can restore lands killed and destroyed by pesticides, clean rivers, be economically profitable due to rapid growth, and ecological feed for livestock.

References

[1] Alongi, M., Anese, M. (2021). 'Re-thinking functional food development through a holistic approach'. *Journal of Functional Foods, 81,* 104466. https://doi.org/10.1016/j.jff.2021.104466

[2] Araujo, R., Peteiro, C. (2021). *Algae as food and food supplements in Europe, EUR 30779 EN*, Publications Office of the European Union, Luxembourg, 1–39. https://doi.org/10.2760/049515

[3] Hosseinkhani, N., Janice, I., Cauley, M., Ralph, J. (2022). Key challenges for the commercial expansion of ingredients from algae into human food products Author links open overlay. *Algal Research, 64*, 102696. https://doi.org/10.1016/j.algal.2022.102696

[4] Smith, G., Tredici, R., Boussiba, S. (2021). What are algae? *Position Paper, EABA, 2*, 7–9. https://doi.org/10.13140/RG.2.2.31633.35688

[5] Aziz, E., Batool, R., Usman Khan, M., Rauf, A., et al. (2020). An overview on red algae bioactive compoundsand their pharmaceutical applications. *Journal of Complementary and Integrative Medicine,* 20190203. https://doi.org/doi:10.1515/jcim-2019-0203

[6] Remya, R., Samrot, V., Suresh, S. (2022). Bioactive Potential of Brown Algae. *Adsorption Science & Technology, 12*, 7–9. https://doi.org/10.1155/2022/9104835

[7] Andrade, L. M., Andrade, C. J., Dias, M., Nascimento, C. A. O., Mendes, M. A. (2018). Chlorella and Spirulina Microalgae as Sources of Functional Foods, Nutraceuticals, and Food Supplements. *MOJ Food Process Technol, 6*(1), 45–58. https://doi.org/10.15406/mojfpt.2018.06.00144

[8] Khavari, F., Saidijam, M., Taheri, M., & Nouri, F. (2021). Microalgae: therapeutic potentials and applications. *Mol Biol Rep, 48*(5), 4757–4765. https://doi.org/10.1007/s11033-021-06422-w

[9] Smyth, P. P. A. (2021). Iodine, Seaweed, and the Thyroid. *European Thyroid Journal, 10*(2), 101–108. https://doi.org/10.1159/000512971

[10] Sathasivam, R., Radhakrishnan, R., Hashem, A., & Abd_Allah, E. F. (2017). Microalgae metabolites: A rich source for food and medicine. *Saudi Journal of Biological Sciences, 26*(4), 209–222. https://doi.org/10.1016/j.sjbs.2017.11.003

[11] Araújo, R., Vázquez-Calderón, F., Sánchez-López, J., Stefansson, T., Ullmann, J., (2021). Current status of the algae production industry in Europe: an emerging sector of the blue bioeconomy. *Front. Mar. Sci, 7*, 1–24. https://doi.org/10.3389/fmars.2020.626389

[12] Hea, S., Barati, B. (2022). Carbon migration of microalgae from cultivation towards biofuel production by hydrothermal technology: A review. *Fuel Processing Technology, 240*, 2–8. https://doi.org/10.1016/j.fuproc.2022.107563

[13] Mitali, A., B., Singh, K., M., Sanjeev, R., Prajapati, K. (2022). Techno-economic analysis of microalgae cultivation for commercial sustainability: A state-of-the-art review. *Journal of Cleaner Production, 370,* 133456. https://doi.org/10.1016/j.jclepro.2022.133456

[14] Chandra, R., Iqbal, H., Vishal, G., Lee, H., Nagra, S. (2019). Algal biorefinery: A sustainable approach to valorize algal-based biomass towards multiple product recovery. *Bioresour. Technol., 278*, 346–359. https://doi.org/10.1016/j.biortech.2019.01.104

[15] Panahi, Y., Darvishi, B., Jowzi, N., Beiraghdar, F. (2015). Chlorella vulgaris: A Multifunctional Dietary Supplement with Diverse Medicinal Properties. *Current Pharmaceutical Design, 22*(2), 164–173. https://doi.org/10.2174/1381612822666151112145226

[16] Holdt, L., Kraan, S. (2011). Bioactive compounds in seaweed: functionalfood applications and legislation. *J Appl Phycol, 23*, 54397. https://doi.org/10.1007/s10811-010-9632-5

[17] Camacho, F., Macedo, A., Malcata, F. (2019). Potential Industrial Applications and Commercialization of Microalgae in the Functional Food and Feed Industries: A Short Review. *Marine Drugs, 17*(6), 2–32. https://doi.org/10.3390/md17060312

[18] Vaz, B., Moreira, J., Morais, M., Costa, J. (2016). Microalgae as a new source of bioactive compounds in food supplements. *Curr Opin Food Sci, 7*, 73–77. https://doi.org/10.1016/j.cofs.2015.12.006

[19] Brasil, B., Siqueira, F. G., Salum, T., Zanette, C. M., Spier, M. R. (2017). Microalgae and cyanobacteria as enzyme biofactories. *Algal Res. 25,* 76–89. https://doi.org/10.1016/j.algal.2017.04.035

[20] Housni, F. E., Saenz, E., López Larios, M., Llanes Cañedo, C. (2022). Association between nutritional status, deficiency of protein, iron and vitamins, caloric intake and food security in Mexican school children. *Progr Nutr, 24*(1), 2022013. https://doi.org/10.23751/pn.v24i1.10900

[21] De Carvalho, J. C., Magalhães, A. I., de Melo Pereira, G. V., Medeiros, A., Sydney, E. B., Rodrigues, C. (2020). Microalgal biomass pretreatment for integrated processing into biofuels, food, and feed. *Bioresource Technology, 300*, 122719. https://doi.org/10.1016/j.biortech.2019.122719

[22] 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. https://doi.org/10.1016/j.algal.2019.101617

[23] Lai, Y. C., Chang, C. H., Chen, C. Y., Chang, J. S., Ng, I. S. (2019). Towards protein production and application by using Chlorella species as circular economy. *Bioresour. Technol., 289*, 121625. https://doi.org/10.1016/j.biortech.2019.121625

[24] Raczyk, M., Polanowska, K., Kruszewski, B., Grygier, A., Michałowska, D. (2022). Effect of Spirulina (Arthrospira platensis) Supplementation on Physical and Chemical Properties of Semolina (Triticum durum) Based Fresh Pasta. *Molecules, 27*(2), 355. https://doi.org/10.3390/molecules27020355

[25] Bito, T., Okumura, E., Fujishima, M., Watanabe, F. (2020). Potential of Chlorella as a Dietary Supplement to Promote Human Health. *Nutrients, 12*(9), 2524. https://doi.org/10.3390/nu12092524

[26] Pincemail, J., Kaci, M., Kevers, C., Tabart, J., Ebabe, E. R. (2019). PAOT-Liquid Technology: An easy electrochemical method for evaluating antioxidant

capacity of wines. *Diseases 7*, 10. https://doi.org/10.3390/diseases7010010

[27] Kai Ru, I. T., Sung, Y. Y., Jusoh, M., Wahid, M. E. A., Nagappan, T. (2020). Chlorella vulgaris: a perspective on its potential for combining high biomass with high value bioproducts, Applied Phycology. *Applied Phycology, 1*(1), 1–10. https://doi.org/10.1080/26388081.2020.1715256

[28] Andrade, L. M., Andrade, C. J., Dias, M., Nascimento, C. A., Mendes, M. A. (2018). Chlorella and spirulina microalgae as sources of functional foods, nutraceuticals, and food supplements; an overview. *MOJ Food Processing & Technology, 6,* 1–14. https://doi.org/10.15406/mojfpt.2018.06.00144

[29] Bito, T., Okumura, E., Fujishima, M., Watanabe, F. (2020). Potential of Chlorella as a Dietary Supplement to Promote Human Health. *Nutrients, 12*(9), 2524. https://doi.org/10.3390/nu12092524

[30] Damude, H. G., Kinney, A. J. (2008). Enhancing plant seed oils for human nutrition. *Plant Physiol. 147*, 962–968. https://doi.org/10.1104/pp.108.121681

[31] Mallick, N., Mandal, S., Singh, A. K., Bishai, M., Dash, A. (2012). Green microalga Chlorella vulgaris as a potential feedstock for biodiesel. *J. Chem. Technol. Biotechnol. 87,* 137–145. https://doi.org/10.1002/jctb.2694

[32] Liu, B., Benning, C. (2013). Lipid metabolism in microalgae distinguishes itself. Curr. Opin. *Biotechnol. 24*, 300–309. https://doi.org/10.1016/j.copbio.2012.08.008

[33] Borowitzka, M. A. (2018). *Microalgae in medicine and human health: A historical perspective. In Microalgae in Health and Disease Prevention*. Academic Press, London. https://doi.org/10.1016/b978-0-12-811405-6.00009-8

[34] Hughey, J. R., Maggs, C. A., Mineur, F., Jarvis, C., Miller, K. A., Shabaka, S. H. and Gabrielson, P. W. (2019). Genetic analysis of the Linnaean Ulva lactuca (Ulvales, Chlorophyta) holotype and related type specimens reveals name misapplications, unexpected origins, and new synonymies. *Journal of Phycology, 55*(3), 503–508, https://doi.org/10.1111/jpy.12860

[35] Wang, E., Braun, M. S., Wink, M. (2019). Chlorophyll and chlorophyll derivatives interfere with multi-drug resistant cancer cells and bacteria. *Molecules, 24*, 2968. https://doi.org/10.3390/molecules24162968

[36] Zhang, T., Zhang, R., Zhao, G., Liu, W., Pan, L., Tong, Y., Jiang, M., Zhang, H., Xiao, Z., Pandol, S. J., Fu, X., Han, Y. P., Zheng, X. (2022). Plant green pigment of chlorophyllin attenuates inflammatory bowel diseases by suppressing autophagy activation in mice. *American Journal of Physiology Gastrointestinal and Liver Physiology, 323*, 102–113. https://doi.org/10.1152/ajpgi.00291.2021

[37] Suvorov, N., Pogorilyy, V., Diachkova, E., Vasilev, Y., Mironov, A., Grin, M., (2021). Derivatives of Natural Chlorophylls as Agents for Antimicrobial Photodynamic Therapy. *International Journal of Molecular Sciences, 22*, 6392. https://doi.org/10.3390/ijms22126392

[38] An, H. J., Rim, H. K., Lee, J. H., Seo, M. J., Hong, J. W., Kim, N. H., Kim, H. M. (2008). Effect of Chlorella Vulgaris on Im-Mune-Enhancement and Cytokine Production In Vivo and In Vitro. Food Sci. Biotechnol., 17, 953–958.

[39] Gómez-Zorita, S., González-Arceo, M., Trepiana, J., Eseberri, I., Fernández-Quintela, A., Milton-Laskibar, I., Aguirre, L., González, M., Portillo, M. P. (2020). Anti-Obesity Effects of Macroalgae. *Nutrients, 12*, 2378. https://doi.org/10.3390/nu12082378

[40] Torres-Tiji, Y., Fields, F. J., Mayfield, S. P. (2020). Microalgae as a future food source. *Biotechnol. Adv., 41*, 107536. https://doi.org/10.1016/j.biotechadv.2020.107536

[41] De Souza Queiroz, J., Barbosa, C. M., da Rocha, M. C, Bincoletto, C., Paredes-Gamero, E. J., de Souza Queiroz, M. L. (2012). Chlorella vulgaris treatment ameliorates the suppressive effects of single and repeated stressors on hematopoiesis. *Brain Behav Immun, 29*, 39–50.

[42] Saide, A., Martínez, K. A., Ianora, A., Lauritano, C. (2021). Unlocking the Health Potential of Microalgae as Sustainable Sources of Bioactive Compounds. *Int J Mol Sci, 22*(9), 4383. https://doi.org/10.3390/ijms22094383

[43] Iwamoto, H. (2004). Industrial production of microalgal cell-mass and secondary products major industrial species Chlorella. Richmond A, editor. Handbook of microalgal culture. Oxford: Blackwell, 255–263.

[44] Liu, J., Chen, F. (2016). Biology and Industrial Applications of Chlorella: Advances and Prospects. *Adv Biochem Eng Biotechnol, 153,* 1–35. https://doi.org/10.1007/10_2014_286

[45] Nagayama, J., Maruyama, I., Uchikawa, T., Takasuga, T., Shimomura, H. (2015). Effects of Chlorella Supplementation on Decreasing Concentrations of Dioxins in the Blood of Pregnant Japanese Women. *Clinics Mother Child Health, 12*, 1000175. https://doi.org/10.4172/2090-7214.1000175

[46] Alves Silva, D., Guimarães, L. (2022). Strategy for the cultivation of Chlorella vulgaris with high biomass production and biofuel potential in wastewater from the oil industry. *Environmental Technology & Innovation, 25*, 102204. https://doi.org/10.1016/j.eti.2021.102204

[47] Camacho, M., M. (2019). Potential Industrial Applications and Commercialization of Microalgae in the Functional Food and Feed Industries: A Short Review. *Marine Drugs, 17*(6), 312. https://doi.org/10.3390/md17060312

[48] Olaizola, M., Grewe, C. (2019). Commercial microalgae cultivation systems. In A. Hallmann, & P. H. Rampelotto (Eds.), *Grand Challenges in Algae Biotechnology*, 3–34. https://doi.org/10.1007/978-3-030-25233-5_1

[49] FG «U Samvel». (in Ukrainian). https://chlorela.com.ua/

[50] «Chlorella Ukraine» LLC. (in Ukrainian). https://hlorella.jimdofree.com/

[51] Prüser, T. F., Braun, P. G., Wiacek, C. (2021). Microalgae as a novel food. *Potential and legal framework. Ernahrungs Umschaum, 68*(4), 78–85. https://doi.org/10.4455/eu.2021.016

[52] Khemiri, S. (2020). Microalgae biomass as an additional ingredient of gluten-free bread: dough rheology, texture quality and nutritional properties. *Algal Res, 50*, 101998. https://doi.org/10.1016/j.algal.2020.101998

[53] Fradique, M., Batista, A. P., Nunes, M. C., Gouveia, L., Bandarra, N. M., Raymundo, A. (2010). Chlorella vulgaris and Spirulina maxima biomass incorporation in pasta products e part I: Preparation and evaluation. *J. Sci. Food Agric., 90*, 1656–1664. https://doi.org/10.1002/jsfa.3999

[54] Lafarga, T. (2019). Effect of microalgal biomass incorporation into foods: nutritional and sensorial attributes of the end products. *Algal Resear, 41*, 101566. https://doi.org/10.1016/j.algal.2019.101566

[55] Andrade, L. M., Andrade, C. (2018). Chlorella and spirulina microalgae as sources of functional foods,

nutraceuticals, and food supplements; an overview. *MOJ Food Processing & Technology, 6*(1), 45–58. https://doi.org/10.15406/MOJFPT.2018.06.00144

[56] Barkia, I., Saari, N., Manning, S. R. (2019). Microalgae for high-value products towards human health and nutrition. *Mar. Drugs, 17*, 304. https://doi.org/10.3390/md17050304

[57] Peshuk, L. V., Prykhodko, D. Y. (2023). Development of the newest healthy food products using green algae. *Science bulletin of poltava university of economics and trade. Series «technical sciences»*, (3), 28–32. https://doi.org/10.37734/2518-7171-2022-3-5

[58] Peshuk, L. V., Novikova, N. V., Prykhodko, D. Y. (2023). Algae as a «superfood» in the technology of healthy food meat products. *Taurida Scientific Herald. Series: Technical Sciences*, (1), 96–103. https://doi.org/10.32851/tnv-tech.2023.1.10

[59] Peshuk, L. V., Simonova, I. (2022). A modern trend is health products with microalgae. *Scientific Bulletin of LNUVMB named after S. Z. Gzhitskyi*, 24(97), 33–38. https://doi.org/10.32718/nvlvet-f9709

[60] Peshuk, L. V., Prykhodko, D. Y. (2022). Modern technologies for the use of green microalgae in semi-finished products. *Scientific Collection «InterConf»*, 297–302.

[61] Bakhmach, V. O., Peshuk, L. V., Chernushenko, O. O., Savchenko. A. M., Petrenko, S. O. (2022). Use of innovative technologies and components in emulsion products. *Bulletin of the National Technical University «KhPI». Series: Innovative research in students' scientific works*, 1(1363), 18–22. https://doi.org/10.20998/2220-4784.2022.01.03

[62] Pérez-Lloréns, J. L. (2020). Microalgae: From staple foodstuff to avant-garde cuisine. *International Journal of Gastronomy and Food Science, 21*, 100221. https://doi.org/10.1016/j.ijgfs.2020.100221