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SPIRULINA (ARTHROSPIRA PLATENSIS): AN ALTERNATIVE SOURCE OF NUTRIENTS - A REVIEW

SPIRULINA (ARTHROSPIRA PLATENSIS): UMA FONTE ALTERNATIVA DE NUTRIENTES - UMA REVISÃO

ESPIRULINA (ARTHROSPIRA PLATENSIS): UNA FUENTE ALTERNATIVA DE NUTRIENTES - UNA REVISIÓN

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ABSTRACT
Spirulina (Arthrospira platensis) is a blue-green cyanobacterium that grows in fresh and salt water. It is known to be a rich source of nutrients, including proteins, vitamins, minerals, and antioxidants. One of its main applications is its use as nutritional supplement, where Spirulina is often consumed to its high protein content and other essential nutrients. It is especially popular among vegetarians and vegans due to its complete protein quality. Some studies suggest that Spirulina may have several health benefits, such as reducing cholesterol, controlling blood pressure, strengthening the immune system and protecting against cardiovascular diseases. It has also been reported to act as a detox agent, since Spirulina is known for its ability to detoxify the body, helping to remove heavy metals and toxins from the body. In the cosmetics field, due to its antioxidant and nourishing properties, Spirulina is used in several products, such as facial creams, hair masks, and body lotions to promote skin and hair health. It is also used in agriculture as an organic fertilizer and in animal feeding, especially in aquaculture, as a source of protein for fish and shrimp. In summary, Spirulina is a valuable source of nutrients and has a variety of applications, from nutritional supplements to cosmetics and agriculture. Its health benefits and potential for sustainable use make it a popular choice in many areas. Therefore, in this article we review the applications of Spirulina (Arthrospira platensis).

Keywords: *Arthrospira platensis*. Nutritional supplement. Health. Proteins. Cosmetics.

RESUMO
A espirulina (Arthrospira platensis) é uma cianobactéria verde-azulada que cresce em água doce e salgada. É conhecida por ser uma rica fonte de nutrientes, incluindo proteínas, vitaminas, minerais e antioxidantes. Uma de suas principais aplicações é o uso como suplemento nutricional, onde a espirulina é frequentemente consumida por seu alto teor de proteína e outros nutrientes essenciais. É especialmente popular entre

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vegetarianos e veganos devido à sua qualidade de proteína completa. Alguns estudos sugerem que a espirulina pode ter vários benefícios à saúde, como redução do colesterol, controle da pressão arterial, fortalecimento do sistema imunológico e proteção contra doenças cardiovasculares. Também foi relatado que atua como um agente detox, já que a espirulina é conhecida por sua capacidade de desintoxicar o corpo, ajudando a remover metais pesados e toxinas do corpo. No campo da cosmética, devido às suas propriedades antioxidantes e nutritivas, a espirulina é usada em vários produtos, como cremes faciais, máscaras capilares e loções corporais para promover a saúde da pele e do cabelo. Também é utilizada na agricultura como fertilizante orgânico e na alimentação animal, especialmente na aquicultura, como fonte de proteína para peixes e camarões. Em resumo, a espirulina é uma fonte valiosa de nutrientes e possui uma variedade de aplicações, desde suplementos nutricionais a cosméticos e agricultura. Seus benefícios à saúde e seu potencial para uso sustentável a tornam uma escolha popular em diversas áreas. Portanto, neste artigo, revisamos as aplicações da espirulina (Arthrospira platensis).

Palavras-chave: *Arthrospira platensis*. Suplemento Nutricional. Saúde. Proteínas. Cosméticos.

RESUMEN

La espirulina (Arthrospira platensis) es una cianobacteria de color verde azulado que crece en agua dulce y salada. Es conocida por ser una rica fuente de nutrientes, incluyendo proteínas, vitaminas, minerales y antioxidantes. Una de sus principales aplicaciones es su uso como suplemento nutricional, donde se consume frecuentemente por su alto contenido en proteínas y otros nutrientes esenciales. Es especialmente popular entre vegetarianos y veganos debido a la calidad completa de sus proteínas. Algunos estudios sugieren que la espirulina puede tener varios beneficios para la salud, como reducir el colesterol, controlar la presión arterial, fortalecer el sistema inmunitario y proteger contra enfermedades cardiovasculares. También se ha reportado que actúa como agente desintoxicante, ya que la espirulina es conocida por su capacidad para desintoxicar el cuerpo, ayudando a eliminar metales pesados y toxinas. En el sector cosmético, debido a sus propiedades antioxidantes y nutritivas, la espirulina se utiliza en diversos productos, como cremas faciales, mascarillas capilares y lociones corporales para promover la salud de la piel y el cabello. También se utiliza en la agricultura como fertilizante orgánico y en la alimentación animal, especialmente en la acuicultura, como fuente de proteínas para peces y camarones. En resumen, la espirulina es una valiosa fuente de nutrientes y tiene diversas aplicaciones, desde suplementos nutricionales hasta cosméticos y agricultura. Sus beneficios para la salud y su potencial de uso sostenible la convierten en una opción popular en muchos ámbitos. Por ello, en este artículo analizamos las aplicaciones de la espirulina (Arthrospira platensis).

Palabras clave: *Arthrospira platensis*. Suplemento Nutricional. Salud. Proteínas. Cosméticos.

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1 INTRODUCTION

Hunger is a major problem that affects millions of people around the world and encompasses several fields including politics, economics, human rights, agriculture. Solving this problem requires innovative strategies, which including the use of methods biotechnology an effective tools in combating food shortages [1]. Issues such as hunger, food insecurity, and poverty are consequences of the serious economic and social situation of the population through deficient and/or unequal income distribution [2]. Second [3][4], the highest occurrences of food insecurity and malnutrition have been recorded in undeveloped countries due to the expected population increase by 2050, and this will put severe pressure on the available food system, and the shortage of these foods could be a barrier to a healthy diet and this will occur due to insufficient financial resources to obtain these foods. New evidence continues to point to a rise in world hunger after a prolonged decline, leaving considerable work to be done towards a food secure world a serious problem to be resolved [5].

Food insecurity is one of the most pressing issues in the world, the government and food security experts have been meeting for years to discuss issues related to hunger and food insecurity [6]. The tangle of technical and political factors illustrates the need for critical research into quantifying food insecurity and more multifaceted approaches to measuring food insecurity are needed [7].

Insufficient financial resources to obtain food can be a barrier to a healthy diet. Dietary cost is inversely associated with dietary energy density and adversely with nutrient density, as the costs of grain, bean, sugar and oil products tend to be lower than those of fresh foods such as vegetables, fruits, meat, and fish. The unavailability of these foods and the high content of essential nutrients they contain, ends up leading to malnutrition, which is highly prevalent in developing countries and leads to a multitude of problems, as it weakens the immune system, which leads to an increased risk of infections. and diseases related to diet, which causes a great public health concern, because although there is no shortage of necessary food on the family table, what is of concern are foods with low nutritional value that bring with them comorbidities such as obesity, diabetes, hypertension and heart disease [8]. According to [9], there is a direct relationship between good nutrition, health and physical and mental well-being of the individual. This relationship between physical and mental health is complex, and the presence of one could accelerate the development of the other [10].

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The American Nutrition Society defines malnutrition as an imbalance between nutrient needs and intake, resulting in cumulative energy, protein, or micronutrient deficits that can negatively affect growth, development, and other relevant outcomes. This definition assumes a state of malnutrition, which constitutes loss of protein energy and micronutrient deficiency, and obtaining food is a crucial issue for the development of human beings, as it ensures the existential minimum [11]. Second [12] Hunger, malnutrition and food insecurity result in various adverse social, mental and physical health effects.

In order to combat the growing chronic deficiency of micronutrients prevalent throughout the world, research aimed at meeting nutritional requirements has been carried out using food fortification and enrichment, so that nutritional needs can be met, such as fortification of vitamin D, iron and other foods and beverages fortified with these minerals [13].

[14] report that a global trend towards healthier eating habits has been growing, and this ends up considerably boosting the search for natural alternatives capable of positively modulating human health. The use of microalgae biomass as an alternative food source has been studied and explored due to its great biotechnological potential and high nutrient content, in order to discover new forms of use through the development of new products according to pre-determined affinity [15]. In this sense, the insertion of alternative sources of nutrients becomes a key factor and microalgae, as they present a considered nutritional value, mainly proteins, fatty acids and amino acids, deserve to be highlighted in this scenario.

Microalgae are microscopic organisms that can grow in a wide variety of environments, including ponds, lakes, sea, rivers and wastewater, can be cultivated year-round and can produce high biomass titers due to the high efficiency of converting photons into biomass. The optimum pH of most microalgae ranges from pH 7 to 9, while salinity (20-30%) and temperature have been reported to be optimum in the range of 20%-30% and 20°C to 30°C, respectively [16]. These comprise a vast diversity of microorganisms, from prokaryotic cyanobacteria to eukaryotic microalgae that can synthesize bioactive substances using carbon dioxide, nutrients (nitrogen, phospore, potassium) and solar energy proficiently and which are perceived as ideal candidates for modern nutraceuticals or foods. functional [17].

It is currently estimated that there are 50,000 known species studied with applications in various areas such as pharmaceuticals, food, agriculture and cosmetics [18]. Among these, food supplements based on Spirulina (Arthrospira platensis), a cyanobacterium, which is sold as a food supplement for humans and animals, due to its rapid growth and high concentration of nutrients [19]. The development of new products from Spirulina is a very interesting biotechnological approach, as it is one of the richest sources of protein, containing 55-70% and with good digestibility [20].

Therefore, this article aims to demonstrate the importance of using Spirulina as an alternative source of nutrients, with emphasis on protein. However, it also brings to light some possibilities of high added value for using Spirulina, which could be an extremely viable alternative in combating the mitigation of malnutrition in the population in the coming years, in addition to being promising sources of natural pigments, fatty acids unsaturated, amino acids, among others.

2 METHODOLOGY

The literature review was carried out through an electronic search for free materials available such as pubmed/medline, scielo, researchgate, google academic and also on the capes journal portal, in different languages, Portuguese, English and Spanish from the last five years preferably. To select relevant research material, search terms were used in general publication keywords, such as "microalgae", "Spirulina platensis", "bioactive compounds", "alternative proteins", "nutritional values and bioavailability", "hunger in the world".

A complete reading of scientific articles and reviews was carried out, always prioritizing relevant aspects in relation to the different ways of applying Spirulina platensis and its versatility, which can be applied in different areas. Highlighting the main results present in the texts of the articles selected for reading.

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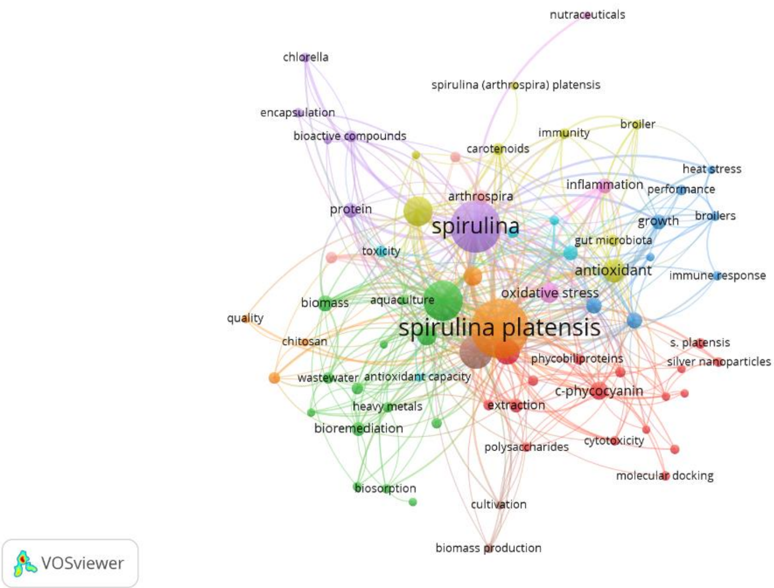
Figure 1

Descriptive bibliometric analysis of Spirulina platensis and its applications

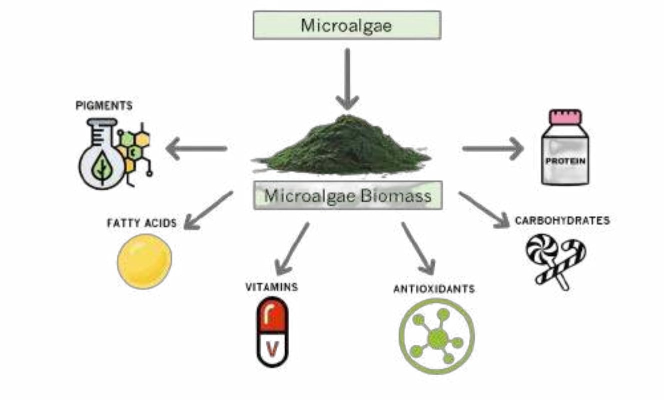


3 MICROALGAE

Microalgae are known as unicellular microorganisms that easily develop in adverse environments such as saline or brackish aquatic environments. They are autotrophic beings, that is, they produce their own food, have relevant photosynthetic efficiency, in addition to being excellent carbon fixers [29]. There are also some heterotrophic microalgae, which depend on substrates and are capable of growing in dark environments, and can also grow in mixotrophic cultures, that is, they can grow as either autotrophic or heterotrophic, depending on the availability of light and CO2 [32]. Microalgae can be prokaryotic or eukaryotic organisms, and can vary in size, morphology and other characteristics. Their composition basically consists of proteins, carbohydrates, vitamins and lipids. For their growth, microalgae need a suitable location, inorganic nutrients and a carbon source. Depending on the type of microalgae used, numerous bioactive molecules (mainly secondary metabolites such as unsaturated fatty acids, pigments, amino acids) can be obtained from its biomass for commercial purposes in various industrial segments (fig. 2) [33], which include pharmaceuticals, cosmetics, nutraceuticals, functional foods, and biofuels [34].

Figure 2

Applications of microalgae biomass in industrial segments [The author]



Microalgae only entered the market at the end of the last century, when technologies were developed specifically for four species, Spirulina (Arthrospira platensis), Chlorella vulgaris, Dunaiella salina, and Nannochloropsis oceanica, where they reached the level of large-scale cultivation production in closed and open environments [35]. One of the most important groups of microalgae are cyanobacteria, which are photosynthetic microorganisms spread across many phyla and capable of growing in fresh, brackish, or salt water [36]. Within this group is Spirulina (Arthrospira platensis), which specifically requires specially designed methods as well as an adequate nutrient medium and photoperiod for its growth [37].

4 SPIRULINA (ARTHROSPIRA PLATENSIS)

Spirulina (Arthrospira platensis) is a cyanobacterium with a filamentous structure, blue-green in color, which stands out due to its high protein content (between 55 and 70% of its dry weight) [38] and its rich composition in vitamins, pigments, polyunsaturated fatty acids, linoleic acid, antioxidants (such as beta-carotene, phycocyanin, tocopherols, phenolic compounds), and minerals such as potassium, sodium, calcium, magnesium, iron, zinc [39]

It is one of the most widely cultivated commercial microalgae that can provide raw materials for food, pharmaceuticals, animal feeding, and bioenergy [40]. This microalgae contains a high amount of protein with a low lipid content, low calories and cholesterol free, which can be compared with meat and meat products in terms of protein quantity, being sold in several countries as a natural pigment and as a food supplement, mainly in powder form [41].

Spirulina (fig. 3) is the first cyanobacterium cultivated and processed on an industrial scale using modern biotechnology methods. More than 128,000 tons of Spirulina were consumed in 2016, and it is estimated that by 2026 its consumption will increase to 321,000 tons [42]. Spirulina is generally found in tropical and subtropical lakes in Africa and Central and South America. Due to the optimal pH range in which it develops (9.5 – 9.8) and because it tolerates moderate concentrations of salts, the Spirulina cultivation medium becomes less viable for the development of other microorganisms and therefore its cultivation presents low susceptibility to contamination [43].

Figure 3

Microscopic view of Spirulina (Arthrospira platensis) *[The author]*

5 PRODUCTION PROCESS OF SPIRULINA

Microalgae can be cultivated by different methods of supplying nutrients for their growth: autotrophic, heterotrophic, mixotrophic and photoautotrophic [44]. Spirulina platensis is a photoautotrophic organism. It depends on light as the main source of energy, particularly to carry out the photosynthesis process [45]. Nutrients present in culture medium not only affect the metabolism of the microalgae, but also their rate of development and the composition of the finished product [46].

In the culture environment, temperature, pH, carbon dioxide and light intensity are the main controllable factors to promote the growth rate of Spirulina species [47], it is worth highlighting that the availability of medium and also the amount of nutrients to be used may vary according to the cultivation system. The cultivation of microalgae is commonly carried out in two ways: open systems, such as tanks or lagoons, or in closed systems, such as photobioreactors. In both cultivation models, Spirulina receives energy directly from natural light sources for photosynthesis [48].

Open cultivations have low construction costs and large production capacity, with simplicity of maintenance being one of their advantages compared to closed systems [43]. Open systems comprise natural lagoons and artificial tanks, using sunlight and CO2 from the atmosphere, and which are also characterized by a low ratio between the illuminated surface and the volume of the cultivation tank, currently accounting for the majority of the biomass market produced, the commonly used type being the raceway (race track type) [49].

The cultivation of microalgae for biomass production can be done in photobioreactors (FBRS). These systems have high operating costs due to the control of system parameters, such as temperature, pH, input and output of nutrients and gases, among others [50]. In general, the use of photobioreactors for the cultivation of microalgae has some advantages, among which it is possible to highlight the greater control of conditions, since the system is closed and there is no contact with the external environment, reducing the probability of contamination by organisms other than those cultivated and the reduction of excessive loss through evaporation, which is aggravated on hot and dry days in open crops [51]. Furthermore, photobioreactors also have high efficiency in biomass production when using CO2 injection into the medium, enhancing cell multiplication [35].

6 NUTRITIONAL VALUES AND BIOAVAILABILITY

Microalgae are a relatively new, sustainable food source of nutritional compounds. These organisms can produce large quantities of proteins of high biological value, long-chain polyunsaturated fatty acids, carotenoids, vitamins, minerals and phenolic compounds, among others [39]. Due to its high protein content, Spirulina biomass can be added to food products, as some studies have shown that it does not present toxicity, being considered GRAS (GENERALLY RECOGNIZED AS SAFE). The cultivation of Spirulina can have different purposes, from application in food to animal feed, as they stand out for their high protein content [42].

The nutritional value of a protein depends on its ability to supply essential amino acids, which ultimately reflects on its bioavailability for the body. Certain factors can influence this issue, such as: structural conformation, presence of other antinutritional compounds and effects of processing conditions with other nutrients [52].

Bioavailability must be demonstrated as the analyzed compound is efficiently digested and absorbed and then exerts an effect on health. However, for ethical and practical reasons, there are challenges in measuring the bioactivity of a compound, the fraction of a given compound or its metabolite that reaches systemic circulation usually defined as bioavailable, without considering bioactivity [53].

There is currently great interest in the production of microalgae as they are considered a rich source of highly nutritious and functional ingredients. Microalgae synthesize bioactive molecules, including vitamins, carotenoids, peridinin, phycocyanin, polyunsaturated fatty acids and phytosterols, among others [54]. The interest in Spirulina is mainly due to its chemical composition, which varies between significant amounts of proteins, carbohydrates and lipids, see table 1. In addition to vitamins, organic acids, pigments and minerals present. This is why this microalgae stands out as a raw material for the development of new food products [18].

Table 1

Spirulina platensis nutritional table source [55]

Macronutrients	Value per 100 g	Micronutrients	Value per 100g	Vitamins	Value per 100g
Potassium (K)	0.147	Iron (Fe)	67.0	B1	3.01
Phosphorus (P)	0.087	Manganese (Mn)	2.8	B2	7.36
Sodium (Na)	0.056	Zinc (Zn)	1.6	B3	3.55
Magnesium (Mg)	0.048	Copper (Cu)	1.5	B6	2.45
Calcium (Ca)	0.036	-	-	B9	0.07
				B12	0.12

The health benefits of these constituents have increased the demand for microalgae production. In this context, the isolation of bioactive compounds from microalgae has gained considerable relevance due to the high productivity of microalgae. Furthermore, bioactive compounds composed of microalgae have important commercial applications, as they are used as food additives, nutraceuticals, and in the pharmaceutical industry [54]. Spirulina has a higher iron content than foods considered rich in iron. Currently, the Brazilian national health surveillance agency (ANVISA) recommends a maximum consumption of 1.6 grams of Spirulina per day so that there is a guarantee of safety in relation to the ingestion of the product (fig. 4) by humans, since some studies have reported the occurrence of both side effects and illnesses resulting from the administration of doses higher than the one recommended [56].

Figure 4

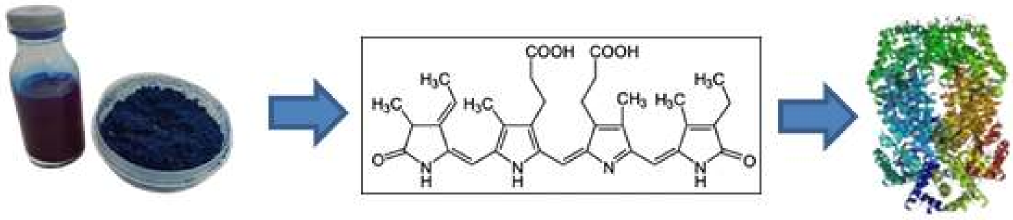
Some of the reported benefits that Spirulina microalga provides when consumed [The author]

Bioactive compounds isolated from Spirulina have shown therapeutic properties, including anti-inflammatory, antioxidant and antimicrobial activities [57]. These compounds are also used as natural coloring for food and cosmetics, which are carotenoids, chlorophyll and phycobiliprotein [58]. Phycobiliprotein falls into four main classes: allophycocyanin, a blue-green pigment that has absorption in the 650-655 nm range;phycocyanin, a blue pigment that has absorption in the range of 615-640 nm;phycoerythrin, a purple pigment that has absorption in the range of 565-575 nm; and phycoerythrocyanin, an orange pigment that has absorption in the 575 nm range [59].

Phycocyanins (fig. 5a) are commonly known as proteins (fig. 5c) (phycobiliproteins) and are large and highly soluble in water and in Spirulina phycocyanin is present at a high level, around 40 to 60% of its composition (fig. 5b). Phycocinain has high antioxidant capacity, anti-inflammatory and hepatoprotective effects. It is mainly used as a natural colorant in the food and cosmetics industry, due to its intense blue color, and its main application is in chewing gum, ice cream, soft drinks, and sweets [60]. On the other hand, phycocyanin degrades easily when exposed to high temperatures, humidity and light, losing, during storage or during technological processing processes, a good part of its functional properties.[61].

Figure 5

Phycocyanin (a), chemical structure (b) and spatial conformation of the protein (c). [The author]



7 BIOTECHNOLOGICAL APPLICATIONS

The search for bioactive compounds in recent decades has increased and led to a growing interest in the study of microorganisms such as cyanobacteria due to the possibility of commercial application in different areas, such as nutrition, human and animal health, wastewater treatment, energy production and chemical and pharmaceutical industries, among others [62]. Spirulina contains one of the richest sources of protein, see table 2, with proteins from meat and fish and soybeans being superior. The dry mass of Spirulina is mostly made up of proteins, between 60% and 75%, varying according to the species and growth conditions [63].

Table 2

Comparison of Spirulina macronutrient composition with other microorganisms and foods (on a dry basis) [42].

protein source	Protein (%)	Lipids (%)	Carbohydrates (%)	Ash (%)
Beef	57.1	37.1	2.0	3.1
Corn	11.2	3.9	85.2	1.3
Wheat	13.6	1.5	84.1	1.4
Soy	46.7	7.1	40.9	5.3
Bacillus subtilis	63.1	4.4	2.1	9.9
Saccharomyces cerevisiae	37.1	2.1	39.4	8.2
Spirulina	65.0	2.0	20.0	5.1

Due to its nutritional content rich in proteins, essential fatty acids, vitamins and minerals, Spirulina has been widely studied in large countries such as the USA, Japan, India, and France for food production. In Brazil, it is still in the development phase, In some places, microalgae are already cultivated on a large scale to serve as food enrichment [64]. Some properties such as low extraction cost, biomass drying, high protein digestibility, high protein content, presence of vitamins and pigments (chlorophyll-a and phycocyanin), significant amount of essential amino acids and tolerance to alkaline pH, are factors that increase interest in the biotechnology sector and production [63].

Metabolites produced by these cyanobacteria and other types of microalgae have been studied in recent decades as biotechnological products with high commercial value (table 3), having been observed in their first use as food by the Chinese as a food product, and nowadays, also as a source of fatty acids, pigments, carotenoids, and proteins that are widely researched for cosmetic products, as well as supplements for humans and animals, some metabolites can be precursors of drugs against bacteria, fungi or used in the treatment of plants [65].

Table 3

Applications of the biotechnological potential of commercially produced microalgae and cyanobacteria [63]

COMPONENTS	APPLICATIONS
Proteins and vitamins	Human and animal food
Pigments: beta-carotene, xanthophylls and phycobilins	As dyes, in diagnostics, cosmetics (skin treatments) and analytical reagents
Enzymes and substances with antibiotic properties	Therapeutic purposes
Gamma-linolenic acid	Prostaglandin stimulant, regulation of cholesterol synthesis
Long-chain hydrocarbons and esterified lipids	Fuel oil
Hydrogen	Biogas

Due to its high nutritional value, several studies are aimed at evaluating the health benefits provided by the ingestion of Spirulina biomass and the production of biomass for application in food [66]. However, adding biomass to food requires some marketing challenges that need to be overcome, mainly the intensity of the green color and the flavor and aroma of the fish, due to this [18] nanoencapsulated compound from Spirulina microalga in order to eliminate or reduce odors, control the release of bioactive compounds at the target site and increase the bioavailability of these compounds.

In recent decades, microalgae biotechnology has been gaining importance and its applications range from the simple production of biomass for food, as already commercial, and valuable products for pharmaceutical applications and it is expected that these products will become very competitive in the market due to their greater biological value, improvement in the cultivation process and lower production cost than synthetic products [35].

8 FOOD APPLICATIONS

Human nutrition and understanding dietary needs, as well as optimal provision thereof, are critical. Changing lifestyles, dynamic reorganization of micro and macro niches, and scarcity of nutritional sources contribute to an increasing prevalence of malnutrition and other health risks [67], and the use of alternative food sources with functional properties has been growing in recent years, and one of these solutions is the incorporation of Spirulina into foods, which are relatively easy to cultivate and process, which contains proteins, vitamins, minerals, carbohydrates, pigments and compounds with high antioxidant potential [61].

The incorporation of Spirulina biomass into foods adds nutritional value to already known products (fig. 6), in a sustainable and practical way. There are several studies with the aim of enriching foods with the addition of Spirulina, such as yogurts, functional drinks, enriched tomato sauce, pasta, cookies, plant-based “mayonnaise”, gelatins, cookies, kefir, among others. [68] studied the production of a freeze-dried yogurt enriched with Spirulina microalga and its evaluation regarding physicochemical characteristics, antioxidants and sensory acceptance and as a result they obtained greater antioxidant activity and an increase in protein content with the addition of Spirulina. [69] added Spirulina and exotic tropical fruits to fermented milk to produce a yogurt rich in flavors and adding nutritional and economic value to the product.

Figure 6

Spirulina (Arthrospira platensis) muffins developed at the Amazon Biotechnology Center – CBA [The author]

Spirulina, when used as an ingredient, is capable of promoting health benefits due to its high content of proteins, fiber, minerals, monounsaturated and polyunsaturated fatty acids, and antioxidant potential, in addition to improving color and texture characteristics. It also reduces the sedimentation rate, increases solubility and reduces hygroscopicity in chocolate milk formulations. [70] developed and characterized a functional sauce formulated with Spirulina (Arthrospira platensis) biomass, adding nutritional value to the product. Two sauces were prepared: control (without Spirulina) and sauce containing 4% Spirulina. The sauce with the addition of Spirulina showed a significant increase in protein content, around 60% higher than the control, indicating an improvement in the nutritional quality of the developed product.

Due to its great nutritional value as a source of proteins and minerals, the biscuit and snack industry has been increasingly interested in incorporating microalgae biomass, particularly Spirulina, into its products. In addition to biscuits, Spirulina biomass has been incorporated into the pasta manufacturing industry, in order to produce pasta enriched with improved nutritional, sensory and therapeutic benefits, in the production of a wide variety of dairy products to improve the nutritional content of fermented dairy products [71]. [72], highlighted that a study carried out in a food technical school, Spirulina has aroused interest in research due to its properties related to reducing the risk of diseases. This cyanobacterium was shown to have a positive effect on increasing the viability of microorganisms, such as bifidobacterium and lactobacillus, present in the intestinal flora.

The main obstacles to incorporating Spirulina biomass into foods are its odor, taste and color characteristics, which are perceived by people as unpleasant. One of the strategies used to overcome this problem was its encapsulation for use as an ingredient, making the appearance of the food more homogeneous. In a study the encapsulation of Spirulina protein hydrolysates has carried out for application in food and, as a result, the encapsulation process was able to increase antioxidant activity and also presented color and texture without changes when applied [66].

In some cases, odors can cause an unpleasant taste when added to a food product, resulting in a significantly negative impact on consumer acceptance. Therefore, pretreatment is necessary to reduce or remove odors [73]. For the food market, the creation of new products becomes essential, taking advantage of the demand of consumers who desire these innovations. Therefore, the food field that shows the greatest increase is the one that adds some health benefit to the products. However, in addition to good nutritional value, the food also has to be tasty and meet consumer expectations. This acceptance is an important part in the development or improvement of the product [74].

9 SPIRULINA MARKET TRENDS

The global microalgae market was estimated at US$3.4 billion in 2020 and is expected to reach US$4.6 billion in revised orders by 2027 [75]. Geographically, the main producers of microalgae biomass are in Taiwan, the United States, Japan, China, Spain, Brazil, Israel, Myanmar and Germany, comprising an annual dry biomass production of 19,000 tons [76].

Four species of microalgae Spirulina platensis, Chlorella vulgaris, Dunaliella salina and Nannochloropsis oceanica) reached the production level in large-scale cultivation in an open system, while a few more unicellular species were successfully expanded in cultivation systems carried out in closed systems [35].

Currently, Spirulina is commercially produced in several parts of the world, including China, Thailand, India, Australia, and the USA, and this microalgae has been mainly marketed in the form of dry powder, flakes, tablets, and capsules [77]. Furthermore, part of the production of Spirulina biomass is also destined for isolated components, which are used in the food, cosmetic and pharmaceutical industries [61].

The importance and use of synthetic carotenoid pigments began to decline due to their potential toxic effects. Nowadays, a transition has been stimulated towards green solutions and natural products and the global natural products market is estimated to reach US$1.5 billion by 2020 [78]. Phycocyanin, a natural pigment extracted from

Spirulina, is a bioactive peptide, with a global market estimated at US$245.5 million by 2027 [79]. However, a major limitation in large-scale production of cyanobacterial pigments is installation and operation costs. Thus, basic and applied research is still needed to overcome such limitations and allow cyanobacteria to enter the global market [80].

The current microalgae food market is mainly divided into two categories. One category involves the large-scale cultivation of microalgae to obtain biomass and high-value metabolites and the other category involves the use of microalgae to develop new food resources, including protein analogues, mainly used in food development [81]. Global ecopower intends to produce 40 tons of Spirulina per year in each of its units (Spiruline de l'hers and spiruline d'anjou). Management will decide on the amount of phycocyanin that will be produced according to demand and based on an extraction rate of around 15%.

The production of living microalgae biomass in the quantity necessary to saturate the global and national markets continues to be a complex issue, in technological and technical terms [82]. However, as part of the development direction of the future food field, there are still many problems to be solved for microalgae-based foods. Challenges such as high production costs, low product acceptance and unknown safety are the current bottlenecks that restrict practical application. The joint efforts of people in various fields are needed to promote the development of microalgae-based foods [83].

A study investigated motivational consumption and barriers to the adoption of Spirulina through two qualitative studies and a quantitative survey with 1325 Belgian participants, with the participation of sporty individuals, vegetarians and foodies, and compared with a group of life enthusiasts [84]. The positive and negative points regarding the addition of ecologically made foods with Spirulina were evaluated. The results showed that health consciousness and willingness to compromise on taste are the main motivational drivers of adoption intention for sporty individuals, vegetarians, and foodies. Neophobia had a negative effect on adoption for foodies, while for sporty individuals and vegetarians there was no effect at all. They concluded that neither dietary intake nor environmental concerns are factors that prevent people from adopting the consumption of foods made from Spirulina and that the dissemination of these types of foods implies their use and distribution on the market.

This type of products as dietary supplements, food and beverages, cosmetics and personal care products, animal feed, natural colorants, and health and wellness products. Seek to generate nutritional alternatives that also provide nutraceuticals, taking advantage of the amount of bioactive compounds they present. However, toxicological evaluation is essential to guarantee a product suitable for consumption [85].

10 FINAL CONSIDERATIONS

The microalga Spirulina (Arthrospira platensis) has a high nutritional value and is of paramount importance when it is a natural product, as its composition presents superior nutritional values compared to other crops, such as meat, fish and certain vegetables. Due to its high content of bioactive compounds, this microalga has pharmacological effects such as antioxidant, antimicrobial and anti-inflammatory action, which contributes to the formulation of new products with functional claims. Therefore, biotechnological technologies and processes are being applied in the development of nutraceutical supplements, chemical products, cosmetics, and food products that contain this microalga. Furthermore, the elucidation of these bioactive compounds and synergistic mechanisms of Spirulina should be further explored to understand its bioavailability, effects on health and human nutrition. In this context, this review research discussed trends and perspectives of the microalga Spirulina (Arthrospira platensis), aiming to stimulate the industrial development of new bioproducts for consumption, through an overview of the composition and its potential for different applications in functional foods.

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