Review Article

Spirulina, food of past, present and future

Fatemeh Matufi [1], Ali Choopani [2, *]

[1]Department of biology, Payame Noor University (PNU), Tehran, Iran
[2]Department of Biochemistry, Faculty of Biologic Science, Payame Noor University, Tehran, Iran

***Corresponding author:**. Ali Choopani,. Department of Biochemistry, Faculty of Biologic Science, Payame Noor University, Tehran, Iran. E-mail: choopani.ali3266@gmail.com*

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ABSTRACT

Spirulina is a multicellular and filamentous blue-green microalgae. Its contains large amounts of protein (70 % dry weight), carotenoid (4000 mg/kg),omega-3 and omega-6 polyunsaturated fatty acids, Gamma Linoleic Acid (GLA), sulfolipids, glycolipids, polysaccharides, provitamins; vitamin A, vitamin E, vitamins B, mineral such as magnesium, iron, calcium, manganese, potassium, selenium and zinc. Due to its cost-effective and high nutritional value, it has used as protein-rich food and animal feed for improving meat production. This product commercially produced in large outdoor pools under controlled conditions. This microalga has soft cell walls that easily digested. New experimental supports the immunomodulation and antiviral effects of Spirulina. After that, it is used for astronauts on space missions. Although Spirulina might symbolize a functional food with potential helpful effects on human health. Therefore, the effect of food containing should evaluate in the future.

***Keywords*:** Spirulina, cyanobacterium, provitamin, supplementation, new foods

INTRODUCTION

Spirulina that microscopic photosynthetic and filamentous cyanobacteria (blue-green algae) that have along the past of use as food. Cyanobacteria are the first group of evolved bacteria 3.5 billion years ago that can convert atmospheric carbon dioxide using water, carbon and oxygen compounds.

Spirulina name derives from the helical or spiral form of its filaments as is shown in figure 1.

Arthrospira is the technical name of a cyanobacteria genus comprising a total group of edible cyanobacteria sold underneath the name Spirulina. The cell organization of Spirulina is classic of a prokaryote gram-negative bacterium with a lack of membrane-bound organelles. The cell wall constitutes a weak cover that is composed of several layers, mostly of a peptidoglycan and lipopolysaccharide nature. The Spirulina cells have various considerations, for example, thylakoid layers with carboxysomes, phycobilisomes, ribosomes, gas vacuoles, and DNA, just as polyglycan, cyanophycin, polyphosphate [2-6]. Spirulina is a Superfood. It is the most nutritious, concentrated whole food to humankind. It a rich exciting history, a fascinating biological and ecological niche in the plant kingdom. Spirulina is actually an astonishing food, full of nutritional wonders [7]. Spirulina has an extraordinary capacity to survive under conditions that are much too harsh for other algae [8]. Habitats with wide Spirulina growth comprise the Pacific Ocean near Japan and Hawaii, large freshwater lakes in Africa, North America, Mexico, and South America. Two species of Spirulina that most normally used in nutritional supplements are *Spirulina platensis* and *Spirulina maxima* [8]. Spirulina, contains (70 % dry weight) protein, Gamma Linoleic Acid (GLA), omega-3 and 6 polyunsaturated fatty acids, carotenoid (4000mg/kg), polysaccharides, sulfolipids, glycolipids, vitamin A, vitamin E, vitamins B, provitamins, and minerals, including calcium, manganese, potassium, selenium, iron, magnesium, and zinc [7]. It is a potential drug therapy for treatment oxidative stress-induced diseases [9].

Moreover, Spirulina pills and capsules, there are also pastries, blocks, and *Spirulina* containing chocolate bars, marketed as health food. Other Spirulina products formulated for weight loss and as a support for quitting drug-addictions [10]. The environmentally Compatible Spirulina does not need fertile ground, has a rapid growth, and takes less energy input and less water per kilogram than soya and corn proteins [11]. Due to its cost-effective and high nutritional value, Spirulina has used as a protein-rich animal feed for improving meat production and quality [12]. Also, has projected as a sustainable move toward to prevent Protein Energy Malnutrition (PEM) and Protein Energy Wasting (PEW) in humans [11].

Figure 1. Microscopic form of Spirulina [1].

History

In the sixteenth century, when the spanish invaders dominated Mexico, they discovered that the Aztecs living in the Valley of Mexico in the capital Tenochtitlan were collecting a new food from the lake [13]. Spanish chroniclers described fishermen with fine nets collecting this blue colored from the lagoons and making a blue-green cake from it. Other myths say Aztec messenger runners took Spirulina on their marathons. Still, a living population of alga Spirulina, the only remains of the Lake Tuxococcus today. Inside the place that is known for the Lake Chad, which is house to the Kanembu populace, they get sodden alga in mud pots, channel out the water through packs of material and spread out the green growth in the sand like the shore of the lake for daylight drying. Semi-arid algae harvested in small squares and taken to the villages were to completely dry in the sunlight [14]. In 1940, a French phycologist, Dangeard, published a report on the utilization of dihé by the Kanembupeople near Lake Chad [15]. Dengard also reminded that these algae were abundant around the lakes in the Rift Valley of East Africa that the main food was for flamingos there. Then in 1964 to 1965 a botanist, Jean Léonard, on a Belgian ship in the Red Sea reported green and edible cakes sold at local markets of Fort-Lamy (now N'Djamena) in Chad [16]. When locals said the sold cakes came close to Chad Lake, Leonard identified the connection between these cakes and algae blooms. In 1967, Spirulina introduced as a fantastic food source for the future at the International Society for Microbiology [12]. Research on the nutritional properties

of Spirulina showed a high protein content, of the order of 60–70 percent of its dry weight; it also showed the excellent quality of its proteins (balanced essential amino acid content). This primary information was sufficient to begin many research projects for industrial purposes in the 1970. Because microorganisms (yeast, chlorella, Spirulina, some bacteria and molds) seemed at that time to be the most direct route to inexpensive proteins, single-cell proteins. In the same period when Léonard rediscovered Spirulina in Africa, a demand expected from a company named Sosa-Texcoco Ltd by the "college français du petrol" to search for a blooming of alga occurrence in the evaporation ponds of their sodium hydrogencarbonate output potency in a lake near Mexico City. As a result, the first accurate and systematic study done for Spirulina growth and physiology. This study was part of the Ph.D. thesis [17], based on the creation of the first large-scale production plant for Spirulina [12]. While finally, no microorganism fulfilled its promise of cheap protein, Spirulina continued to give rise to investigate and rising production, reflecting its perceived nutritional assets [18].

Chemical Structure and food potency

Analysis of Spirulina showed that it is an important source of proteins, vitamins, dietary minerals, and pigments.

The biochemical composition depends upon the specific source, culture conditions, and area of production [19-22]. The protein content of Spirulina (50–70 % of the dry weight) superior to meat, dried milk, eggs, soybeans or grains. Spirulina proteins are total, since all the essential amino acids. The maximum values for the necessary amino acids are those for leucine, valine, and isoleucine. When compared to standard nutritious proteins (from meat, eggs or milk), it is somewhat lacking in methionine, cysteine, and lysine, but is higher to all plants including proteins [23]. Spirulina has endorsed as “the food of the future” with “excellent constituents” that contribute to high energy. Some of these constituents, such as polysaccharides (Rhamnose and Glycogen) and essential fat (GLA), are effectively absorbed by cells and help to produce energy. Spirulina is requested for the richest source of provitamin A (β-carotene), with 20 g of Spirulina also fulfilling of vitamins B1 (thiamine), B2 (riboflavin) and B3 (niacin) [5,19,20,15,24]. Its mineral content dependent on the culture medium. Interesting minerals in Spirulina are iron, calcium, phosphorus, and potassium [5,19]. Spirulina increases healthy

lactobacillus in the intestine, enabling the production of Vitamin B6 that also helps in energy production [25]. Spirulina is a resource of chlorophyll, Phycocyanin, and Carotenoids. Both the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), as one of the main foods recommended Spirulina during long-term space missions [26]. Since many of the obtainable blue-green algae species are known to produce a toxin (microcystins, in particular, MCYST-LR), it is very essential to elucidate the specific species used for human use as in all probability there is a danger of species substitution or contamination of Spirulina with other cyanobacteria. It is particularly important in countries where no such regulation exists on this type of product. When the algal cells or filaments of Spirulina transformed into powder, it can grant the basis for a variety of food products, such as soups, sauces, pasta, snack foods, instant drinks and other recipes [27].

Spirulina also used to prepare food with other ingredients. For example, instant noodles, stylish noodles, nutritious blocks, beverages, and cookies [27]. Also, microalgal biomass has studied in several food products oil-in-water emulsions, vegetable puddings, biscuits and kinds of pasta as is shown in figure 2.

The effect of microalga concentration on the product color parameters investigated, as well as its stability through the processing conditions and along storage time [28]. Many foods aimed at the juvenile market advertised as containing the delicious Spirulina with its blue-green color. Add it to milkshakes, jellies, biscuits or cakes [28,29]. The enrichment of Spirulina platensis has studied in wheat flour to prepare fresh pasta to estimate the green color and dietary enrichment in addition to practical properties due to the existence of the bioactive compounds in the cyanobacterium [30]. Besides, Sharma and Dunkwal have been enriched biscuits by Spirulina [31].

Figure 2. Use of Spirulina in foods [1].

Genetically information

Whole-genome sequences of several Spirulina strains have already appeared in the literature. *Arthrospira*. *platensis* NIES-39 genome structure estimated to be a single circular chromosome of 6.8 Mb, yielding 6,630 protein-coding genes, two sets of rRNA genes and 40 tRNA genes [32]. Whole-genome sequencing of the *Spirulina Arthrospira PCC 8005* strain, which selected by the European Space Agency (ESA) as a nutritional product and an oxygen producer of the Micro-Ecological Life Support System Alternative (MELISSA) for long term, operated space missions. Showed the presence of 6,279,260 bases with an average GC content of 44.7 %, 5.856 protein-coding sequences and 176 genes encoding RNA were also predicted [33]. The draft genome was approximately 6.0 Mb in total, with 5,690 protein-coding sequences [34].

Spirulina Main Applications

Approximately one-third of the world complex feed manufacturing is for chickens and this new industrial market has challenged producers to formalize feeds to use higher quality elements [35]. Spirulina is one of the high-quality natural feed additives that can be used in animal and poultry nutrition. In this respect, Ross and Dominy and Nikodémusz *et al.*

reported that hens that had *Spirulina* in their diet had higher levels of production and fertility than the control group. Moreover, Sakaida Takashi, found that egg yolk color was considerably superior by the addition of Spirulina to laying hen diets [36]. Spirulina is cheaper than other animal foods. China is using Spirulina as a partial substitute of imported feed to encourage the growth, immunity, and viability of prawns (example *Penaeus monodon*). Spirulina containing feed found to reduce the cultivation time and mortality, and increase shell thickness of scallop. The survival rate of abalone (*Haliotismidae*) improved by 37.4 percent. Feeding with Spirulina helped to improve disease resistance of high-value fish resulting in an improvement in their survival rate from 15 to 30 percent [4]. Ghaeni in 2010 has been used Spirulina as a supplement in the green tiger prawn larvae diet [37]. Also, the effect of the *Spirulina platensis* meal has evaluated as a feed additive on the growth and survival of *Litopenaeusschmitti* shrimp larva [38].

Safety and Acceptability

The Food and Drug Administration (FDA) has categorized *Arthrospira* harvest as Generally Recognized As Safe (GRAS) for human using up and the Dietary Supplements. Information Expert Committee (DSI-EC) fulfilled that there is not a serious risk to health with using up of Spirulina [39]. Reported side effects associated with Spirulina eating are sleeplessness and gastric problems with uncertain or unlikely causality [39] and only a few cases of severe side effects have reported, including a case of rhabdomyolysis after the consumption of 3 g in a day for 1 month [40]. Two cases of anaphylaxis from tablets with spirulina have been reported [41,42]. One in a 17-year-old man accused of dermatitis, allergies, rhinitis, and a possible syndrome of pollen-food (oral tomato and cucumber allergies) [42]. Three cases of autoimmune-mediated skin damage have been reported, one in an 82-year-old woman [43]. Whereas the other two cases were seen in subjects eating Spirulina as a multi-component nutrient component (organic cayenne pepper, ethylsulfonylmethane, and algae Aphanizomenon flos-aquae and Spirulina or Ginseng, Ginkgo biloba, and Spirulina) [44]. In this regard, it is well known that plant-food and herbal supplements could have adverse effects, such as hepatotoxicity and autoimmune hepatitis [45]. Besides, the two cases described by Lee and Werth [43] involved a 57-year-old

man with known pemphigus vulgar is and a 45-year-old woman with a history of hypertension, chronic migraines, and fibromyalgia. Furthermore, a case report of hepatotoxicity occupied a 52-year-old Japanese man who had a history of hypertension, hyperlipidemia and Type 2 Diabetes (T2D) and taking medications (amlodipinebesilate, simvastatin, and acarbose) [46]. In this context, potential food-drug interactions have hypothesized for Spirulina [47] and phenolic phytochemicals [48-50]. Spirulina should, therefore, be carefully ingested in patients with diseases, particularly in patients with cytochrome P450 enzyme substrates, such as immunosuppressants, antihypertensive, and lipid reduction drugs [46-50]. Although Spirulina can be considered safe in healthy subjects, sensory characteristics of practical food are important in the consumer getting of the product. Baby food formulations with Spirulina have a high acceptance rating in the range of 82.7 to 96.3 and the trained panelists assigned the high scores to products with Spirulina 5 % [51]. No huge contrasts were seen by semi-prepared specialists between the pomegranate squeezes and figure pomegranate refreshment with Spirulina (4 %) and Echinacea (6 %) extricates (improved by sativoside 5 %) in appearance, shading, scents, and consistency [52]. Trained panelists gave a higher score to a snack with 2.5 % of Spirulina, but the addition of 7.5 % or more decreased the acceptability [53]. The level of Spirulina in pasta considered adequate is diverse in prepared and undeveloped specialists. Specifically, pasta with a level of Spirulina maxima up to 2 % lean toward by undeveloped specialists contrasted with control pasta [53], while the best one-via prepared specialists [54], whereas the most preferable one-by trained panelists [55] was the pasta enriched with 10 % *Spirulina platensis*. The latter was not satisfactory for consumers [56] who considered less acceptable also, pasta produced with integral wheat flour. The percentage of Spirulina that did not reduce the acceptability is lower for ice cream compared with supplemented pasta. A board of judges considered ice cream with 0.15 % of Spirulina a qualified production when compared to 0 % and 0.075 % ice creams, due to the light green (pistachio) color, but the sharp green color reduced overall acceptableness of the ice cream with 0.23 % and 0.3 % of Spirulina [57]. On the contrary, yogurt with Spirulina 0.3 % had a higher degree compared to 0.1 %, 0.2 %, and 0.5 % of Spirulina [58].

Malik et al. suggested that the lower score eat 0.1% level when compared to control might attribute to dull color, appearance and less acidic flavor that is necessary for satisfactoriness of yogurt, whereas the low satisfactoriness of the 0.5 % can be due to increased acidity and intense green color [57]. It is well known that Spirulina causes a decline in pH yogurts, due to its effect on Lactobacilli growth and viability [41,59,60]. Guldas and Irkin with trained panelists who did not assign excessive sour taste to acidophilic yogurt, reported that 0.5 % of Spirulina powder addition was more acceptable than 1 % [61]. It is actually because of that slightly greenish color and algal flavor of the latter compared to the former. Therefore, dissimilar sensory expectations, experiences, knowledge, learning, and approach to eat affect the overall satisfactoriness [62, 63].

Aspects of Health

Although historically Spirulina used as a food component, it has carefully investigated using *in vitro* and *in vivo* experiments, including cell and tissue culture, animal testing as well as human clinical trials, for its role in human health management. Recent analysis indicates that Spirulina, a unicellular blue-green alga may have a variety of health benefits and therapeutic properties and it has antioxidant and anti-inflammatory role [64]. Spirulina also used for health food, feed, and biochemical products since the 1980s. It is almost nutritious wholly food known to science, furthermore, Spirulina has no side effects and is non-toxic [65-67]. A huge number of publications in peer-reviewed scientific journals and book chapters covering the health aspects of Spirulina have appeared during the last three decades. These articles described experimental approaches involving whole-cell Spirulina provision, various cell extracts, and purified biomolecules, aiming at elucidating the potential health benefits of the consumption of this microalga, so far with thrilling results. Potentiality health personal effects included immunomodulation, antioxidant, antineoplastic, antiviral agent and bactericide activities, as well as certain effects for malnutrition, hyperlipaemia, diabetes, obesity, inflammatory allergic reactions, heavy metal/chemical-induced toxicity, radiation harm and anemia [6,20,21,68-73]. In this respect, the most promising active Spirulina constituents appeared to be the protein phycocyanin,30 sulfated polysaccharide fractions [74] GLA [75] and certain sulfolipids [76].

While these medicinal claims may base on experimental observations, more research needed. Randomized studies in humans seen to rate the effectiveness of Spirulina as potential pharmaceuticals, understand the mechanisms of action specific Spirulina biomolecules, their short-term and long-term effects and the safety of their use in practical foods.

DISCUSSION

Effects against Hyperlipidemia

The antioxidant activity of Spirulina *maxima* has evaluated against lead acetate-induced hyperlipidemia and oxidative damage in the liver and kidney of male rats. The outcomes indicated that Spirulina maxima forestalled the lead acetic acid derivation actuated significant changes in plasma and liver lipid levels and on the cancer prevention agent status of the liver and kidney. On the other hand, *Spirulina maxima* successfully improved the biochemical parameters of the liver and kidneys relative to the normal values of the control group [77]. Decreases in blood pressure and plasma lipid concentrations, particularly triacylglycerol, lipoprotein-cholesterol demonstrated because of oral using up of Spirulina. It has also shown to Indirectly, Cholesterol changes and high-density lipoprotein cholesterol values. A water extract from Spirulina may inhibit the intestinal absorption of dietetic fat by inhibiting pancreatic lipase activity [78].

Radiation Protective Effects

Radiation protection offered by Spirulina might be because of the phytopigments (carotenoids, chlorophyll, and phycocyanin) just as polysaccharides. Spirulina can elevate the activity of all the antioxidant related enzymes viz., superoxide dismutase, catalase, glutathione peroxidase, and glutathione reductase considerably. The effect may be due to the high phytopigments (carotenoids, chlorophyll, and phycocyanin) in Spirulina [64,75,79].

Effects against Nephrotoxicity

The hepatoprotective action of Spirulina fusiform is against Gal-N induced hepatotoxicity in mice. The defensive viability of Spirulina fusiformis is exceptionally encouraging as prove by the inversion of the adjusted qualities consequent organization potentially by advancing the recovery of hepatocytes that reestablish honesty and it affirmed by the histopathological considers. The hepatoprotective property of the extract may be attributed to the presence of various constituents that are present in

Spirulina fusiformis [79]. Still a broad study needed to understand the mechanism of use of Spirulina fusiformis for protecting against galactosamine-induced hepatotoxicity [80].

Effects against Diabetes, Obesity, and Hypertension

According to Takai *et al.*, a water-soluble fraction of Spirulina was found effective in reducing the serum glucose levels in starvation while the water-insoluble portion suppressed glucose level at glucose loading [81]. Similar results found in other studies. In a human clinical study involving 15 diabetics, a significant decline in the fasting blood sugar level of patients observed after 21 days of 2 g in a day Spirulina supplementation. Becker et al. in1989 have discovered that a valuable eating routine of 2.8g of Spirulina more than about a month brought about a factually huge decrease of body weight in large outpatients [82]. Spirulina has also found to suppress high blood pressure in rats. A vasodilation property of rat aortic rings by Spirulina possibly dependent upon a cyclooxygenase-dependent product of arachidonic acid and nitric oxide has been reported by Paredes-Carbajal *et al.* Cheng-Wu Z *et al*. did a preliminary study on the effect of polysaccharides and phycocyanin on peripheral blood and hematopoietic system of bone marrow in mice [83,84]. Their studies showed that C-phycocyanin and polysaccharides from Spirulina had a high Erythropoietin (EPO) activity [85].

Probiotic Effects

Probiotic microorganisms are live microbial food consumed as human food supplement for century supplement which usefully affects the host animal because of its best-known nutritional value. Spirulina contains improving its microbial balance. The probiotic efficiency of *Spirulina platensis* is for lactic acid bacteria and a potent antibacterial activity against human pathogenic bacteria [86].

Other Effects

Spirulina contains phenolic acids, tocopherols, and ß-carotene that known to display antioxidant properties. Miranda *et al.*, evaluated the antioxidant capacity of a Spirulina extract [87]. The antioxidant activity of a methanolic extract of Spirulina checked out *in vitro* and *in vivo*. Results obtained show that Spirulina provides most antioxidant protection facing both *in vitro* and *in vivo* systems. It was shown to avert cataract [88] , acute allergic rhinitis [89], cerebral ischemia [90] and vascular reactivity [91] and has been exposed to be effective against

cadmium [92] and arsenic induced-toxicities [64,93]. In recent years, some of its properties have confirmed during studies while additional pharmacological properties require proving. *Spirulina platensis* is effectively suppressed peripheral sensitization via modulation of glial activation, improved motor mending in collagen-induced arthritic rats [94].

The Side Effects

Upset stomach, feeling a bit sick, hiccups, and mild diarrhea. Nausea and constipation could come from gastric over-acidity and poor digestion. Feeling hungry, dizzy and low on energy could be side effects in people who suffer from hypoglycemia and anemia Slight fever could be a response to the body metabolism. Spirulina a concentrated protein and could raise the internal heat level. Enthusiasm and sleeping problems could come from the fact that the body burns excessive fats. It is advisable in these cases to take Spirulina only in the morning. Headaches could come from poor digestion and normally only a very brief and rare healing crisis. Sweat Detoxification the lung, the skin, and the stools. During the period of detoxification, depending on the toxicity, the period of change can change [95].

CONCLUSION

According to researches, Spirulina is one of nature's most potent superfoods. Now, what is clear is that Spirulina is a healthy and safe food supplement significant side effects for healthy people. Because of the unique features and richness of vitamins and minerals, it recommended as the best supplement.

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