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# Nutritional Value and Applications of Spirulina in Functional Foods: A Comprehensive Review

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## ABSTRACT

Humans use microalgae and cyanobacteria (blue-green algae) as their food sources. Owing to their potential applications in biotechnology, they have garnered significant attention in recent years. Microalgae and cyanobacteria are remarkable sources of a variety of valuable compounds, which includes biologically active compounds with antifungal, antiviral, anticancer and antibacterial properties. There are two species of spirulina *viz*. *S. platensis* and *S. maxima*, are consumed as food by humans because of their high content of protein. Spirulina, a microalga that explodes in saline water, has become a widely recognized "superfood" owing to its diverse nutrient content, which includes proteins, minerals, carbohydrates and a variety of phytopigments. It is an abundant source of various bioactive components, including phenolic acids, phytocyanins and β-carotene. Additionally, it contains flavonoids with potent antioxidant, anti-inflammatory, immunomodulatory and anticancer properties. Spirulina is already present in a variety of dairy and food products such as beverages, dried foods, snacks, pasta and yogurt. However, Spirulina presents numerous challenges, including the need for technological advancements in food safety, processing difficulties and concerns about contamination and safety. Recent research has suggested that addressing these issues could potentially resolve malnutrition, hidden hunger and specific chronic diseases. The current review concentrate on the nutritive value of Spirulina, its numerous health benefits and its incorporation into numerous food products, which underscores its status as a sustainable solution for human health and nutrition.

**Key words:** Applications, Functional foods, Health benefits, Nutritional value, Spirulina.

Spirulina, classified under Cyanophyta with two species such as *Spirulina platensis* and *Spirulina maxima* are the most important which has gained recognition as a potential food source for the future owing to its comprehensive nutrient profile, including all essential dietary components. Commercial spirulina production is well-developed worldwide, with most cultivation in tropical or semi-tropical regions due to the conditions favouring the microalga's growth. Spirulina grows optimally in water that is alkaline, saline (with salinity >30 g/L), at high pH levels varying from 8.5 - 11.0 and temperatures ranging from 30 to 35°C, where there is a lot of solar radiation at altitude. Since spirulina is an obligate photoautotroph, it cannot thrive on organic carbon substrates in the absence of light (Balkrishna *et al.,* 2023). Spirulina is cultivated worldwide due to its rich nutritional profile, rapid growth rate and minimal resource requirements. Major producers around the world include the United States, China, Thailand, Taiwan, Japan and India. They produce over 10,000 tons each year (Habib *et al.,* 2008; FAO, 2020).

Spirulina is one of the most thoroughly investigated and marketed algae and is known for its high protein content. Additionally, due to its easily digestible properties and numerous health benefits, notable global organizations such as WHO and FAO have recognized Spirulina as a superfood or food in the future (Singh *et al.,* 2023). Additionally, microalgae have more valuable cellular components than biomass from agricultural sources such as food crops (*e.g.*, corn, barley, potatoes, sugar cane and potatoes) and lignocellulosic biomass such as straw, grass and wood (Costa *et al.,* 2019). They include proteins,

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lipids, polysaccharides, antioxidants and pigments. *Spirulina platensis* has the potential to produce significant amounts of biomass and carbohydrates when cultivated in mixotrophic environments (Pulz and Gross, 2004).

The diverse applications of Spirulina in the food, medicine, biofuel, cosmetics and agricultural sectors demonstrate its biological and economic importance. Spirulina is regarded as a natural remedy by individuals worldwide and it is employed in the production of nutritional supplements and functional meals as a result of its documented properties. Due to the increasing demand for food, nutraceuticals and pharmaceuticals, Spirulina serves as a sustainable alternative for health enhancement and malnutrition mitigation (Ramirez-Rodrigues, *et al.,* 2021). Spirulina is a blue-green, multicellular, filamentous cyanobacterium. Its name is derived from the Latin words for "helix" and "spiral," which are indicative of the organism's physical structure, which involves the formation of tiny strands that rotate. Spirulina is a large organism, with a length of 0.5 millimeters, despite being unicellular. In lesser species, the cell diameter ranged from 1 to 3 µm, while in larger species, it ranged from 3 to 12 µm. Because cells can divide easily and tend to stick together in colonies, Spirulina sp. is a large and easy-to-harvest biomass (Richmond 1984; Ljubic *et al.* 2018; De Marco Castro *et al.* 2019).

Consequently, the UNWFC (United Nations World Food Conference) acknowledged *Spirulina platensis* as a nutritious food source. Spirulina has been used for centuries as a nutritional supplement due to its high concentration of nutritive ingredients. Furthermore, researchers have identified impacts on fecundity, egg and plumage color and milk yield when S. platensis was used as forage (Grosshagauer *et al.,* 2020). In one study, the adaptability of the alga to its nutrient levels and its recognized anti-inflammatory, antiviral, antibacterial, antioxidant, antidiabetic and anticancer properties were investigated. As a result, people refer to such algae as a "superfood." Furthermore, a variety of products, including yogurt, ice cream and confectionery, have been used as natural colorant (Jung *et al.,* 2019; Ramirez-Rodrigues *et al.,* 2021).

The nutritional characteristics of *S. platensis* are currently being investigated by researchers. This single-cell protein is distinguished by its abundance of components, which include antioxidant pigments, β-carotene, carotenoids, essential amino acids, fatty acids, proteins and phycocyanin. At present, researchers are investigating the nutritional quality and influence of *S. platensis* on growth, immunity, antioxidants, antitoxicology, anticancerogenic properties, cholesterol and glucose metabolism and fertility. Consequently, S. platensis may serve as a viable alternative and/or nutrient in the future (Ramirez-Rodrigues *et al.,* 2021; Lafarga *et al.,* 2020; Thevarajah *et al.,* 2022). Considering aforementioned points, this review offers information on the nutritional value, health benefits and applications of Spirulina, underscoring its status as a sustainable superfood that is instrumental in the advancement of global nutrition and health.

## Nutritional composition

Spirulina is predominantly composed of 55-70% protein and 5-6% lipid (w/w). The total lipid content is composed of 1.5-2% polyunsaturated fatty acids (Wu *et al.* 2016). Spirulina spp. contains α-linolenic acid (36% total PUFAs), vitamins (B1, B2, B3, B6, B9, B12, vitamin C, D and E), minerals (K, Ca, Cr, Cu, Fe, Mg, Mn, P, Se, Na, Zn) and pigments (Desai and Sivakami 2007; Demir and Tukel 2010). The general proximate composition of Spirulina can be summarized as follows (in percentage of desiccated weight): Proteins make up 50-70% of the diet, carbohydrates 15-25%, lipids 6-13%, nucleic acids 4.2-6% and minerals 2.2-4.8%. Table 1 illustrates the nutritional profile of Spirulina.

### Protein

Spirulina provides more protein (50-70% of dried weight) than meat, eggs, dry milk, grains and soybeans and includes all essential amino acids except methionine, cysteine and lysine. It beat all plant proteins, including legumes (Sharoba, 2014). Due to the lack of cellulose barriers, Spirulina protein digests 83-90% better than pure casein (95.1%). De Marco Castro *et al.* (2019) reported that Spirulina has Net protein utilization (NPU) of 53.00 - 92.00% and a Protein efficiency ratio (PER) of 1.8-2.6.

### Carbohydrates

*S. platensis* main polymer is a glycogen-like branching polysaccharide. Microalgae synthesise carbohydrates through photosynthesis and carbon fixation. They play various roles, including structural components of cell walls or metabolic energy stores. They consist mainly of sugars such as glucose - 97%, rhamnose - 2.7% and mannose - 0.4% (Chwil *et al.,* 2024). The percentage of carbohydrates represents about 15-25% of the dry weight of *S. platensis*. Specific polysaccharides, such as sodium *S. platensis* (Na-SP) and calcium *S. platensis* (Ca-SP), have interesting antiviral, immunostimulatory and anticoagulant properties (Begum *et al.,* 2024). In addition, the rich composition of S. spirulina oligosaccharides indicates that its consumption supports intestinal microflora growth. The acidic polysaccharides present in *Spirulina platensis*, thanks to their content of sulphate esters, sulphate groups and

**Table 1:** Nutritional profile of spirulina (% of Dried weight).

| Component | Range (%) |
|---|---|
| Total proteins | 50-70 |
| Carbohydrates | 15-25 |
| Fats | 06-13 |
| Nucleic acids | 4.2-6.0 |
| Minerals | 2.2-4.8 |

Source: Li and Qi 1997; Bashir *et al.* 2016.

amino residues, are capable of inducing the synthesis of tumour necrosis factor and polysaccharide extracts from the alga show chemoprotective activity (Bortolini *et al.,* 2022). It has been proven that the heteropolysaccharide (SP90-1) present in spirulina, consisting of glucose, rhamnose, galactose, glucuronic acid, xylose and fructose, exhibits immunostimulatory and anticancer effects by inhibiting the growth of A549 lung cancer cells (Chwil *et al.,* 2024). Researchers have also found immunomodulatory and antiviral high-molecular-weight anionic polysaccharides in Spirulina (Parages *et al.,* 2012).

### Fat

The fat content in spirulina is between 6% and 9% (Wang *et al.,* 2023). A study by Grosshagauer *et al.* (2020) found that *Spirulina platensis* had an average fat content of 10.0%. The fats in *S. platensis* are mostly polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA) and saturated fatty acids (SFA). The main fat is γ-linoleic acid (30-35%), which is an important PUFA for cell membranes. Other fats include glycolipids and essential fatty acids like ω3 and ω6 (Bohorquez-Medina *et al.,* 2021). The fats in Spirulina are comprised of a saponifiable fraction (83%) and a non-saponifiable fraction (17%). The former contains essential pigments, paraffins, sterols and other compounds. In *S. maxima* and *S. platensis*, linolenic acid accounts for 10-20% and 49% of their fatty acid content, respectively. Therefore, we can consider Spirulina to be a reliable source of linoleic acid comparable to human milk and certain vegetable oils such as evening primrose, borage, blackcurrant seed and hemp oil. *S. maxima* also contain saturated palmitic acid, as well as unsaturated oleic and linoleic acids, which together account for over 60% of its lipid content.

Spirulina's primary lipids are monogalactosyl- and sulfoquinovosyl-diacylglycerol as well as phosphatidylglyce rol (Petkov and Furnadzieva, 1988). An examination of the fatty acid composition revealed that the ω6 fatty acid content ranged from 23.1% to 24.5%, whereas the ω3 fatty acid, specifically alpha-linolenic acid, was present in minimal amounts. The fatty acids derived from *S. platensis* may be incorporated into dietary regimens to address lipid metabolism disorders, with a particular emphasis on polyunsaturated fatty acids (Li *et al.,* 2019).

## Health benefits

### Bioactive compounds

Phenolic compounds, which are molecules that contain a benzene ring with at least one hydroxyl substituent, are the primary component of products that originate from plants. Teas (Bortolini *et al.,* 2021), fruits and their derivatives (Rossetto *et al.,* 2020), edible florals (Bortolini *et al.,* 2022) and algae (Machu *et al.,* 2015) are among the products in consideration. The most prevalent phenolic chemical categories in Spirulina were phenolic acids and flavonoids. Chlorophyll, carotenoids and phycocyanin are additional bioactive components that contribute to the color of this algae.

The main carotenoids in spirulina include β-carotene, canthaxanthin, astaxanthin, lutein and zeaxanthin. β-carotene is the predominant carotenoid in spirulina, accounting for up to 80% of the total carotenoids. It functions as a potent antioxidant and serves as a photoprotector and precursor for the synthesis of vitamin A in the body, thereby supporting health and immune function (Maoka, 2020). Lutein and zeaxanthin have been shown to beneficially delay the progression of ocular diseases such as age-related macular degeneration and cataracts (Mrowicka *et al.,* 2022). Canthaxanthin (β, β-carotene-4,42 -dione) is a keto-carotenoid naturally produced in a wide array of organisms, exhibiting strong antioxidant activity. It has been reported to be a more effective antioxidant than â-carotene (Naguib, 2001). From a commercial perspective, canthaxanthin is one of the most significant xanthophylls due to its extensive applications (Perera and Yen, 2007). Astaxanthin, a naturally occurring xanthophyll carotenoid with strong antioxidant properties, has demonstrated anti-inflammatory activity and has been reported to offer protective benefits against acute lung injury, attributed to its substantial antioxidant capabilities. These carotenoids work synergistically to provide antioxidant protection, support ocular and dermal health and contribute to spirulina's overall nutritional and functional benefits. The diverse carotenoid profile renders spirulina a valuable dietary source of these essential phytonutrients.

The probiotic, antioxidant, antibacterial, antiviral, anticancer, anti-inflammatory and antidiabetic activities of these organisms benefit human health. The food industry has become increasingly dependent on algae due to these characteristics, notably in the development of products in the fields of medicine, chemistry, cosmetics and pharmaceuticals (Bortolini *et al.,* 2022).

### Prebiotic effects

Jamil *et al.* (2015) conducted a study to evaluate the prebiotic effects of spirulina as a growth and immune promoter in broiler poultry. According to these findings, Spirulina is a natural feed additive that has the potential to substantially increase broiler production, thereby potentially reducing production costs. Another study examined the prebiotic efficacy of blue-green algae in relation to probiotic microorganisms. It was found that the extracellular products made by *Spirulina platensis* help lactic acid bacteria like *Lactococcus lactis, Streptococcus thermophiles, Lactobacillus casei, Lactobacillus acidophilus* and *Lactobacillus bulgaricus* grow (Gupta *et al.,* 2017).

As a prebiotic diet additive or pollen substitute, spirulina has the potential to considerably enhance the health of honeybees (Ricigliano and Simone-Finstrom, 2020). The authors suggest that the health of pollinators could be enhanced by the addition of Spirulina as a prebiotic additive, as it could increase the abundance and metabolism of beneficial intestinal flora. The prebiotic effect of *Spirulina platensis* is a consequence of its composition, which is abundant in oligosaccharides. According to Cai *et al.* (2022a), the consumption of this nutrient has the potential to stimulate the development of intestinal microfloras. Elwakil *et al.* (2024) also investigated the potential of *Spirulina platensis* as a super prebiotic to improve the antibacterial efficacy of *Lactobacillus casei*. These results indicated that the antibacterial activity and probiotic live count of *S. platensis* were substantially improved at a concentration of 5 mg/mL.

**Antitumor activity and immune system**

*Spirulina platensis*, a cyanobacterium, may boost the immune system and prevent cancer and viral infection (Hirahashi *et al.,* 2002). Recent research has shown that Spirulina (*Arthrospira sp.*) can be used to treat and prevent cancer. It is unclear whether Spirulina can reduce the adverse effects of chemotherapy in patients with malignant tumors. Microalgae derivatives may boost immunity and fight cancer in addition to probiotics. *S. platensis* polysaccharides contain several sulfate groups, esters and amine residues. Sulfate groups play a pivotal role in inhibiting tumor cell proliferation, inducing apoptosis and preventing angiogenesis by disrupting growth factor binding and signaling pathways (Mendhulkar *et al.,* 2020). These factors immune system function, tumor necrosis synthesis, phagocytosis and interleukin production (Cai *et al.,* 2022a). Spirulina suppresses tumor cell migration and invasiveness and has antiangiogenic properties (Bortolini *et al.,* 2022). Ge *et al.* (2019) found that spirulina lowers myelosuppression and increases immune function following chemotherapy in malignant tumour patients.

A study by Subramaiam *et al.* (2021) discovered that adding γT3 (gamma-tocotrienol) to Spirulina did not make it more effective in fighting cancer or changing the immune system in a genetically modified mouse model of breast cancer. Similarly, Hirahashi *et al.* (2002) examined the blood cells of volunteers before and after oral administration of a hot water extract of Spirulina and discovered that it directly affects myeloid lineages and either directly or indirectly affects natural killer cells. Natural killer-mediated IFN gamma production requires cooperative IL-12 and IL-18.

Polysaccharides have potential as adjuvant therapies in cancer treatment, as they not only enhance the body's immune response against cancer cells but also counteract the immunosuppressive effects of conventional chemotherapy drugs. These polysaccharides can activate T cells, B cells, natural killer cells and macrophage-dependent immune responses (Chaiklahan *et al.,* 2013). Additionally, they stimulate the production of cytokines, such as IL-2, IFN-γ and TNF-α, thereby enhancing immune surveillance and the body's capacity to target and eliminate malignant cells. Their structural complexity and charge density also enable them to scavenge free radicals, thereby reducing DNA damage and oxidative stress, which are key contributors to carcinogenesis.

**Neuroprotective effects**

Many recent studies have revealed that Spirulina improves neuronal development and protects the brain by reducing oxidative stress and antioxidants (Patil *et al.,* 2018; Tocher *et al.,* 2019). Abd Elkader *et al.* (2024) also suggested the presence of and its biologically active ingredients for neurological illnesses. They evaluated Spirulina and its active ingredients in neurodegenerative and neuropsychiatric illnesses. Daily ingestion of C-phycocyanin, an *S. platensis* phycobiliprotein, improves the quality of life of patients with MS. Disease-essential redox processes and myelination/demyelination undergo modulation (Bortolini *et al.,* 2022). Current research suggests that spirulina can improve mental wellness. Their antioxidant, neuroprotective, cognitive-enhancing and mood-regulating characteristics may improve brain health and reduce the risk of neurodegenerative diseases. However, to evaluate the optimal dosing, duration and long-term brain health effects of Spirulina supplementation, more research, particularly well-designed human clinical trials, are required (Kumar *et al.,* 2025).

**Antidiabetic effect and effects on metabolic disorders**

Dietary trends have emphasized the potential of Spirulina spp. as a beneficial adjuvant therapy, particularly for the treatment of osteoporosis and diabetes. Chromium, which binds to peptides that bind to insulin receptors, enhances the hypoglycemic properties of *S. platensis* (Ekeuku *et al.,* 2021). Taking *S. platensis* supplements, especially while pregnant or breastfeeding, has been shown to protect neurons from the bad effects of malnutrition, reactive gliosis and neurodegeneration (Sinha *et al.,* 2020), which controls expression levels. Furthermore, Spirulina has been found to decrease oxidative stress and blood sugar levels, which is likely attributable to the high concentration of ω-6 PUFAs (Guldas *et al.,* 2020).

**Antioxidant activity**

Reactive oxygen species (ROS) can destroy biological molecules and cause various illnesses. Oxidative stress contributes to hypertension, diabetes, atherosclerosis, ischemic illness and cancer. Oxidative stress from MDA and 4-hydroxynonenal is high (Yoshikawa and Naito, 2002). *In vitro* and *in vivo* studies have shown that spirulina reduces oxidative stress. Phycocyanins, β-carotene and other vitamins and minerals in spirulina have antioxidant and protective properties (Abdel-Daim *et al.,* 2013; Upasani and Balaraman, 2003).

*In vitro* research has shown that Spirulina or its extracts act as antioxidants (Qing *et al.,* 2003). Spirulina contains antioxidants, such as asolic acids, tocopherols and β-carotene. Studies have shown that Spirulina provides antioxidant protection *in vitro* and *in vivo* and that Spirulina methanolic extract contains antioxidant chemicals that can inhibit oxidation (Miranda *et al.,* 1998). Chromogenic and caffeic acids, which are phenolic components of Spirulina extract, are better antioxidants than lard acids (Marinova and Yanishlieva, 1992). Abd El-Baky *et al.* (2009) investigated whether *Spirulina platensis* cells grown in media with different hydrogen peroxide concentrations may increase the levels of chemicals. Researchers have linked higher $H_2O_2$ levels to higher levels of cellular lipophilic antioxidants (carotenoids and tocopherol) and hydrophilic antioxidants (glutathione and ascorbic acid).

**Anti-inflammatory activity**

Spirulina has well-documented benefits in boosting immunity and resilience against inflammation. It exhibits a highly promising anti-inflammatory effect in arthritis and colitis. An experimental model of colitis in rodents was the first to document the anti-inflammatory effects of phycocyanin (Gonzalez and Romay, 1999). Such components enhances the anti-inflammatory properties of Spirulina spp. Spirulina maxima lipid polysaccharide and protein isolates exhibited inhibitory effects against platelet aggregation induced by inflammatory and thrombotic mediators in the study conducted by Koukouraki *et al.* (2020). Therefore, researchers consider it a potential nutraceutical and food supplement that could aid in the treatment of thrombosis, inflammation and related conditions (Wu *et al.,* 2016).

**Immunomodulatory activity**

Recent speculation has linked Spirulina to regulation of the host immune system (Watanuki *et al.,* 2006). Spirulina is a potent immune stimulant, as demonstrated in animal studies. Spirulina polysaccharides primarily elicit immunostimulatory effects (Wu *et al.,* 2016). It augments the phagocytic activity of macrophages, promotes the accumulation of natural killer (NK) cells in tissues, activates and mobilizes T and B cells and stimulates cytokine and antibody production (Khan *et al.,* 2005; Mao *et al.,* 2000; Gad *et al.,* 2011). In a single study, researchers purified and characterized SP90-1 from *Spirulina platensis*, a novel heteropolysaccharide with immunostimulatory and antitumor properties. The authors further stated that further investigation of SP90-1 for immunomodulatory biomedical applications is possible (Cai *et al.,* 2022b). The various health benefits of Spirulina are depicted in Table 2.

## Use of spirulina in various food products

Several countries have certified Generally Recognized as Safe (GRAS) Spirulina. The FDA (Silver Spring, MD, USA) and ANVISA (Brasília, Brazil) have been used as food or supplements. Because Spirulina cultivation requires high pH, it prevents the growth of other organisms (Soni *et al.,* 2017). Many African countries continue to collect it from natural water, dry it and use it as a source of protein.

**Table 2:** Health benefits of Spirulina.

| Health Benefit | Mechanism | Description | References |
|---|---|---|---|
| Antioxidant activity | Scavenges free radicals, upregulates antioxidant enxymes (Superoxide Dismutase, Catalase, Glutathione Peroxidase) | Contains phycocyanins, β-carotene, vitamins and minerals that combat oxidative stress | Qing *et al.* 2003; Abd El-Baky *et al.* 2009 |
| Immunomodulatory effects | Activates macrophages, T-cells and NK cells; enhances cytokines (Interleukin-2, Interferon-γ) | Stimulates immune system and enhances cytokine/antibody production | Watanuki *et al.* 2006; Cai *et al.* 2022b; Wu *et al.* 2016 |
| Anti-inflammatory properties | Inhibits Cyclooxygenase-2 and pro-inflammatory cytokines (*e.g.*, Tumor Necrosis Factor-α, Interleukin-6) | Reduces inflammation in the body | Koukouraki *et al.* 2020; Wu *et al.* 2016 |
| Neuroprotective effects | Reduces reactive oxygen species, modulates neurotransmitter balance and prevents neuronal damage | May improve brain health by reducing oxidative stress | Patil *et al.* 2018; Tocher *et al.* 2019; Abd Elkader *et al.* 2024; Kumar *et al.* 2025 |
| Antidiabetic properties | Enhances insulin sensitivity, modulates glucose metabolism and inhibits α-glucosidase enzyme | Helps lower blood sugar levels and contains chromium | Sinha *et al.* 2020; Ekeuku *et al.* 2021 |
| Prebiotic effects | Provides polysaccharides that selectively support probiotic strains like Lactobacillus and Bifidobacterium | Promotes growth of beneficial gut bacteria | Gupta *et al.* 2017; Jamil *et al.* 2015; Ricigliano and Simone-Finstrom 2020 |
| Antitumor activity | Stimulates immune surveillance, induces apoptosis, inhibits angiogenesis | Boosts immunity and may suppress tumour cell growth | Hirahashi *et al.* 2002; Subramaiam *et al.* 2021 |

Spirulina is used for self-health in various places (Koli *et al.,* 2022). Given the high nutraceutical content of Spirulina biomass, research is shifting toward bioactive fortified functional foods, such as doughnuts, pasta, salad dressing, mayonnaises and gelled sweets.

**Pasta**

As a popular convenience food, pasta is valued for its good sensory properties, affordability and ease of preparation, versatility across cuisines and extended shelf life, making Spirulina-enriched variants a promising option for meeting modern dietary demands (Koli *et al.,* 2022). De Marco *et al.* (2014) demonstrated that incorporating Spirulina biomass into fresh pasta enhances its nutritional composition without compromising sensory, textural, or cooking quality. Similarly, Pagnussatt *et al.* (2014) highlighted that *Spirulina platensis* can be effectively used in commercial dry pasta while maintaining acceptable sensory and technological attributes.

Hussein *et al.* (2021) claimed that spirulina-enriched pasta is a significant source of antioxidants and protein. The enrichment of pasta resulted in a decrease in sensory scores as the addition level increased. The low concentrations of 2-pentylfuran and hexanal as aroma compounds may be the cause of this reduction. Ozyurt *et al.* (2015) formulated pasta using semolina and *Spirulina platensis* at three different concentrations (5, 10 and 15% w/w) to enhance its nutritional and sensory qualities. The study results indicated that the sensory evaluation of pasta enriched with 10% *S. platensis* yielded a favorable overall score, comparable to that of the control group. Similarly, De Marco *et al.* (2014) assessed the impact of Spirulina inclusion on the nutritional and technological qualities of dried pasta. The authors also reported that the incorporation of Spirulina resulted in an increase in protein content. However, the digestibility of protein decreased as the proportion of microalgae increased. In contrast to the control pasta, the spirulina-infused pasta exhibited a high level of antioxidant activity and phenolic compound content, which has the potential to improve the nutritional profile of the product.

Spirulina powder, incorporated at 2-15% concentrations into semolina-based pasta, enhanced its nutritional profile by significantly increasing protein, phenolic, flavonoid, iron and calcium content while retaining textural and sensory qualities. FAME analysis showed 2 to 2.5 times higher levels of $\gamma$-linolenic and docosahexaenoic acids with improved antioxidant activity. Nutrient retention after cooking and high sensory ratings, particularly for pasta with 12.5% Spirulina, highlight its consumer appeal. This green pasta, symbolizing health and vitality, offers a sustainable solution for addressing malnutrition, particularly in undernourished populations, making it a promising alternative for enhancing nutritional security and alleviating hidden hunger (Koli *et al.,* 2022).

**Dried / Powdered food**

Santos *et al.* (2016) developed a powdered product that resembled a chocolate shake and contained 750 mg of spirulina per 100 g of microalgal biomass. Based on their findings, cuisine had an average acceptance rate of 7.68 and 7.77, with 43.40% protein, 41.34% carbohydrates and 45.73% and 46.51% fat, respectively. Sharoba, (2014) developed and assessed complementary foods enhanced with spirulina for infants aged between one and three. These foods include cereals, legumes, fruits and other vegetables. The formulations were evaluated as biologically safe, sensory-acceptable, nutritionally appropriate, cost-effective and viable for domestic and industrial applications. In another study, the effect of incorporating 9% Spirulina platensis paste into dried noodles was assessed. The results of the study showed a significant increase in elasticity, protein (4x), β-carotene and sensory acceptability, all while meeting the Indonesian National Standards for protein, water and calcium content (Agustini *et al.,* 2017).

**Soup**

Lafarga *et al.* (2019) prepared broccoli soup by incorporating *Spirulina* sp., *Chlorella* sp., or *Tetraselmis* spp. at concentrations spanning from 0.5 to 2.0% (w/v). This led to an increase in the quantity of phenolics and antioxidants, as well as consumer acceptance, when combined in a suitable manner. Los *et al.* (2018) formulated dehydrated broths using flour derived from peach palm by-products (PPB), Spirulina platensis, or spinach. The authors also evaluated the composition of these formulations using physical, chemical, instrumental and sensory methodologies. A novel market niche was identified through sensory analysis and stews that contained PPB and S. platensis exhibited favorable acceptability. Spinach, Spirulina platensis and peach palm flour are effective alternatives for nutritionally enriching dehydrated soups with high protein, ash, fiber and antioxidant content.

**Cookies / Biscuits**

Batista *et al.* (2017) showed that the addition of *Spirulina platensis*, Chlorella vulgaris, Tetraselmis suecica and Phaeodactylum tricornutum to cookies at concentrations of 2% and 6% improved their antioxidant, functional and total phenolic content. Barakat *et al.* (2016) demonstrated that Spirulina algae contained a high level of protein (67.0±5.2% dried weight) and significant quantities of bioactive compounds with antioxidant activity, including phycocyanin (1254±23 mg/100 g) and β-carotene (85±5 mg/100 g). Additionally, researchers have reported an improvement in the organoleptic, chemical and nutritional properties of biscuit mixtures fortified with dried Spirulina algae at concentrations of 0.5, 1, 2 and 3%. The panel test organoleptically accepted the biscuit mixtures as soon as they demonstrated high nutritional values, bioactive content and protein and mineral content compared to the unfortified biscuit samples (control). Seema *et al.* (2025) demonstrated that cookies supplemented with up to 6% *Spirulina platensis* powder, in combination with wheat and bengal gram flour, were well accepted sensorially and showed enhanced protein and starch digestibility along with an improved nutrient profile.

Andaregie *et al.* (2024) investigated the factors that influence parents' willingness to purchase spirulina-fortified bread for primary school children in Ethiopia. Socioeconomic status, perception of benefits and acceptability significantly influenced the purchasing decisions, according to the results. These results bolster the promotion of spirulina-fortified consumables for children's nutrition through evidence-based dietary interventions and policy initiatives. The addition of microencapsulated Spirulina biomass into biscuits has yielded promising outcomes in terms of nutritional enhancement and sensory acceptance. da Silva *et al.* (2021) demonstrated that spray-dried microencapsulation facilitated the incorporation of 20% Spirulina biomass without significant sensory degradation, resulting in biscuits with a 40% increase in protein content and potential claims as a source of iron. Gun *et al.* (2022) reported that the inclusion of 4% *Spirulina platensis* improved the properties of biscuits, enhancing protein content by 56.92% and improving amino acid profiles. Furthermore, research on the addition of Spirulina powder to shortbread biscuits indicated increased hardness, a darker color, higher antioxidant activity and reduced oxidative changes during storage, all while maintaining consumer acceptability (Marcinkowska-Lesiak *et al.,* 2018).

**Snacks**

As per the study conducted by Lucas *et al.* (2018) spirulina-enriched snacks showed improved nutritional content (increased protein, lipids and minerals) without significantly affecting physical parameters, while maintaining sensory acceptance. The addition of Spirulina influenced color parameters and resulted in thin-walled microstructures. The protein, minerals and fat are increased by 22.60%, 46.40% and 28.10% respectively. In another study, spirulina-enriched snack foods showed that adding up to 10% Spirulina improved protein and ash content, as well as physical and textural properties, while ensuring microbiological safety. Snacks are cost-effective and suitable for domestic and export production (Morsy *et al.,* 2014).

**Dairy products**

The utilization of Spirulina in dairy products has been investigated in numerous studies, with a focus on its potential to enhance nutritional value, antioxidant activity and sensory attributes. Research indicates that the incorporation of *Spirulina platensis* into ice cream can augment antioxidant activity and polyphenol content (Rodrigues *et al.,* 2020). In vegan kefir, Spirulina fortification has been shown to improve prebiotic potential, bioactive quality and microbial counts (Sozeri Atik *et al.,* 2021). Traditional kefir supplemented with *Spirulina platensis* exhibited increased protein content, enhanced amino acid profile, elevated iron levels and improved antioxidant activities (Ustun-Aytekin *et al.,* 2022).

Investigations into yoghurt fortification with *Spirulina platensis* have favoured accelerated fermentation, improved water holding capacity and enhanced antioxidant activity (Barkallah *et al.,* 2017). The microalga has also shown promise in the development of functional Ricotta cheese, leading to increased protein, fat, ash, fiber and mineral contents, as well as improved antioxidant capacity. These findings suggest that Spirulina can be effectively employed as a natural ingredient to develop novel dairy products with enhanced nutritional and functional properties (Ismail *et al.,* 2023). Narayana and Kale, (2019) reported that supplementation of probiotic yoghurt with 1 g/L Spirulina enhanced the viability of *Bifidobacterium bifidum*, *Streptococcus salivarius* ssp. *thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* during storage, while maintaining acceptable pH and acidity, thereby supporting its potential in functional dairy product development.

**Other food products**

The addition of microalgae, specifically Spirulina and Chlorella, into bread and breadsticks has been demonstrated to enhance their nutritional profile, notably in terms of antioxidant capacity and mineral content, while also influencing physical attributes such as texture, rheology and color. Despite these modifications, consumer acceptability was largely preserved, suggesting the potential of microalgae as functional ingredients in baked goods. Hernandez-Lopez *et al.* (2023) and Uribe-Wandurraga *et al.* (2019) have documented that microalgae like Spirulina can be effectively incorporated into bakery products, providing both nutritional advantages and environmental sustainability, thereby creating innovative, nutrient-dense options for consumers.

El-Anany *et al.* (2023) found that the addition of spirulina powder to chicken mortadella enhanced its nutritional profile and antioxidant properties without adversely affecting its sensory attributes. The incorporation of vegetable oils into spirulina-based 'crostini' was shown to protect phycocyanin from degradation during cooking, likely due to the tocopherol content of the oils (Niccolai *et al.,* 2021).

**Other applications**

Solanki *et al.* (2023) optimized the cultivation of *Spirulina platensis* and found that Zarrouk's modified medium yielded the highest biomass, phycocyanin and carotenoid contents, indicating its superiority for enhancing growth and pigment production compared to other tested media. The study demonstrated that replacing 50-75% of fishmeal with Arthrospira platensis in the diet of Buenos Aires Tetra significantly improved growth performance, feed efficiency and carotenoid deposition in muscle and skin, highlighting its potential as a functional aquafeed ingredient (Rana *et al.,* 2024).

**Applications of spirulina in animal feeding: Impacts on growth, product quality and health**

Spirulina (*Arthrospira platensis*) has gained considerable attention as a functional feed ingredient in diverse animal production systems due to its high-quality protein, essential fatty acids, pigments, vitamins and bioactive compounds. In poultry, Peipei and Sumin, (2017) demonstrated that dietary supplementation with Spirulina powder (5-15 g/kg), in combination with traditional Chinese herbal medicines, improved yolk color, Haugh unit and iron content, while reducing cholesterol and triglycerides in eggs. Similarly, Naik *et al.* (2024) reported that broiler diets enriched with up to 1.5% Spirulina significantly enhanced body weight gain, feed conversion ratio (FCR), antioxidant status, immunity and beneficial gut microflora, with 1.5% proving most effective.

In mammalian models, Seyidoglu *et al.* (2019) found that oral Spirulina supplementation (500-1000 mg/kg body weight) in Wistar albino rats produced positive correlations between abdominal fat, growth and anthropometric indices without adverse effects on liver histopathology or serum enzymes. In rabbits, Khanna *et al.* (2024) observed that a 5% Spirulina-supplemented diet altered serum protein fractions, increasing albumin and reducing globulin levels, though growth performance and FCR were not significantly improved compared to controls.

Aquaculture studies have also highlighted Spirulina's potential as an alternative protein source. Sivakumar *et al.* (2018) reported that partial replacement of fishmeal with 42.8% Spirulina meal in Penaeus monodon diets resulted in superior growth, feed efficiency, survival and carcass composition compared to both control and higher-replacement diets. Likewise, Sowmiya *et al.* (2025) demonstrated that P. vannamei fed a diet containing 10% Spirulina achieved the highest growth rates, optimal feed utilization, improved body composition and enhanced resistance to Vibrio parahaemolyticus. Collectively, these findings underscore Spirulina's versatility as a feed additive, capable of enhancing growth, product quality, immune function and disease resistance across a range of animal species when incorporated at optimal inclusion levels.

### Emerging trends and future perspectives

*S. platensis*, in particular, is a type of spirulina that is highly nutritious, environmentally friendly and has exceptional curative properties. *Spirulina platensis* is gaining recognition for its high nutritional value and environmentally sustainable characteristics. It holds significant importance in the fields of medicine and technology. In the field of food science, researchers are incorporating Spirulina into plant-based meats, dairy alternatives and probiotic beverages to enhance their health benefits. In biotechnology, scientists are optimizing Spirulina to increase the production of valuable compounds such as phycocyanin and carotenoids through specialized techniques. In the field of immunology, the compounds found in Spirulina are being investigated for their potential to enhance the immune system, which could contribute to the development of vaccines and therapeutic interventions. In microbiology, Spirulina is being studied for its ability to promote beneficial gut bacteria while inhibiting harmful ones, thereby improving gut and immune health. In pharmacology, Spirulina is being explored for its potential to prevent cancer, reduce inflammation and combat viral infections. Some studies are examining its efficacy in the treatment of cancer, diabetes and viral infections.

## CONCLUSION

Spirulina has proven to be a reliable source of nutraceuticals and pharmaceuticals, which is especially advantageous in areas that struggle with social deficiencies, such as developing nations. Spirulina, a cyanobacterium-classified blue microalga, is notable for its abundant bioactive compounds, essential amino acids and unsaturated fatty acids. These compounds are crucial for maintaining basic human nutrition and serve as protein sources in diets free of animal products. Additionally, they contain colored compounds, including phenolic compounds, phycocyanins, carotenoids and chlorophylls, which function as natural antioxidants. Spirulina has the potential to be incorporated into functional diets. Spirulina's nutritional properties render it a promising candidate for functional foods, beverages and supplements. Spirulina has the potential to improve the nutritional value of bakery products, including bread and pastries. Additionally, we have the capacity to formulate nutraceuticals and capsules from Spirulina extracts. Additionally, this cyanobacterium may be employed in the development of active packaging and dressings in the field of biomedicine. Spirulina is an essential resource for sustainable nutrition owing to its ability to improve global health and combat malnutrition. Ongoing research and innovation in its production and application will further enhance its contribution to global health and wellness.

### Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

### Conflict of interest

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## REFERENCES


Abd El-Baky, H.H., El Baz, F.K. and El-Baroty, G.S. (2009). Enhancement of antioxidant production in *Spirulina platensis* under oxidative stress. *Acta Physiologiae Plantarum.* **31(5):** 623-631. https://doi.org/10.1007/s11738-009-0282-1.

Abd Elkader, H.T.A.E., Essawy, A.E. and Al-Shami, A.S. (2024). Bioactive compounds of the genus spirulina can prevent the progression of neurological diseases. *Neurochemical Journal.* **18(1):** 47-59.

Abdel-Daim, M.M., Abuzead, S.M. and Halawa, S.M. (2013). Protective role of *Spirulina platensis* against acute deltamethrin-induced toxicity in rats. *PLoS ONE.* **8(9):** e72991. https://doi.org/10.1371/journal.pone.0072991.

Agustini, T.W., Ma'ruf, W.F. and Wibowo, B.A. (2017, February). Study on the effect of different concentration of Spirulina platensis paste added into dried noodle to its quality characteristics. In *IOP Conference Series: Earth and Environmental Science* (Vol. 55, No. 1, p. 012068). IOP Publishing.

Andaregie, A., Sasaki, S., Shimura, H., Chikasada, M., Sato, S., Addisu, S. and Takagi, I. (2024). Promoting spirulina-enriched bread for primary school children in Ethiopia: Assessing parental willingness to purchase through information nudging. *Applied Food Research*. **4(1):** 100403.

Balkrishna, A., Dev, S.N.C., Joshi, B. and Mishra, R.K. (2023). Spirulina: A miraculous alga with pharmaco-nutraceutical potential as future food. *International Journal of Food*. **11(3):** 128-136.

Barakat, E.H., El-Kewaisny, N.M. and Salama, A.A. (2016). Chemical and nutritional evaluation of fortified biscuits with dried spirulina algae. *Journal of Food and Dairy Sciences*. **7(3):** 167-177.

Barkallah, M., Dammak, M., Louati, I., Hentati, F., Hadrich, B., Mechichi, T. and Abdelkafi, S. (2017). Effect of *Spirulina platensis* fortification on physicochemical, textural, antioxidant and sensory properties of yogurt during fermentation and storage. *LWT – Food Science and Tehnology*. **84:** 323-330.

Bashir, S., Sharif, M.K., Butt, M.S. and Shahid, M. (2016). Functional properties and amino acid profile of *Spirulina platensis* protein isolates. *Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences.* **59(1):** 12-19. https://doi.org/10.52763/pjsir.biol.sci.59.1.2016.12.19.

Batista, A.P., Niccolai, A., Fradinho, P., Fragoso, S., Bursic, I., Rodolfi, L. and Raymundo, A. (2017). Microalgae biomass as an alternative ingredient in cookies: Sensory, physical and chemical properties, antioxidant activity and *in vitro* digestibility. *Algal Research.* **26:** 161-171. https://doi.org/10.1016/j.algal.2017.07.023.

Begum, N., Qi, F., Yang, F., Khan, Q. U., Faizan, Fu, Q. and Zhang, W. (2024). Nutritional composition and functional properties of a. platensis-derived peptides: A green and sustainable protein-rich supplement. *Processes*. **12(11):** 2608.

Bohorquez-Medina, S.L., Bohórquez-Medina, A.L., Zapata, V.A.B., Ignacio-Cconchoy, F.L., Toro-Huamanchumo, C.J., Bendezu-Quispe, G. and Hernandez, A.V. (2021). Impact of spirulina supplementation on obesity-related metabolic disorders: A systematic review and meta-analysis of randomized controlled trials. *NFS Journal*. **25:** 21-30.

Bortolini, D.G., Barros, L., Maciel, G.M., Brugnari, T., Modkovski, T.A., Fachi, M.M., Pontarolo, R., Pinela, J., Ferreira, I.C.F.R. and Haminiuk, C.W.I. (2022). Bioactive profile of edible nasturtium and rose flowers during simulated gastrointestinal digestion. *Food Chemistry.* **381:** Article 132267. https://doi.org/10.1016/j.foodchem.2022.132267.

Bortolini, D.G., Haminiuk, C.W.I., Pedro, A.C., Fernandes, I.D.A.A. and Maciel, G.M. (2021). Processing, chemical signature and food industry applications of *Camellia sinensis* teas: An overview. *Food Chemistry: X,* **12:** 100160. https://doi.org/10.1016/j.fochx.2021.100160.

Cai, B., Yi, X., Han, Q., Pan, J., Chen, H., Sun, H. and Wan, P. (2022a). Structural characterization of oligosaccharide from *Spirulina platensis* and its effect on faecal microbiota *in vitro*. *Food Science and Human Wellness.* **11(1):** 109-118. https://doi.org/10.1016/j.fshw.2021.07.012.

Cai, B., Zhao, X., Luo, L., Wan, P., Chen, H. and Pan, J. (2022b). Structural characterization and *in vitro* immunostimulatory and antitumor activity of an acid polysaccharide from *Spirulina platensis*. *International Journal of Biological Macromolecules.* **196(164):** 46-53. https://doi.org/10.1016/j.ijbiomac.2021.12.062.

Chaiklahan, R., Chirasuwan, N., Triratana, P., Loha, V., Tia, S. and Bunnag, B. (2013). Polysaccharide extraction from Spirulina sp. and its antioxidant capacity. *International Journal of Biological Macromolecules*. **58:** 73-78.

Chwil, M., Matraszek-Gawron, R., Terlecka, P., Skoczylas, M.M. and Terlecki, K. (2024). Comprehensive review of the latest investigations of the health-enhancing effects of selected properties of arthrospira and spirulina microalgae on skin. *Pharmaceuticals*. **17(10):** 1321.

Costa, J.A.V., Freitas, B.C.B., Rosa, G.M., Moraes, L., Morais, M.G. and Mitchell, B.G. (2019). Operational and economic aspects of *Spirulina*-based biorefinery. *Bioresource Technology.* 292. Article 121946. https://doi.org/10.1016j.biortech.2019.121946.

da Silva, S.P., do Valle, A.F. and Perrone, D. (2021). Microencapsulated Spirulina maxima biomass as an ingredient for the production of nutritionally enriched and sensorially well-accepted vegan biscuits. *LWT: Food Science and Technology.* **142:** 110997.

De Marco Castro, L., Arbeláez, M.I.R. and Garzón, C.M. (2019). Nutritional, functional and therapeutic properties of *Spirulina*: A review. *Food Bioscience.* **32:** 100508. https://doi.org/10.1016/j.fbio.2019.100508.

De Marco, E.R., Steffolani, M.E., Martínez, C.S. and León, A.E. (2014). Effects of *Spirulina* biomass on the technological and nutritional quality of bread wheat pasta. *LWT - Food Science and Technology.* **58:** 102-108. https://doi.org/10.1016/j.lwt.2014.02.054.

Demir, B.S., Tükel, S.S. (2010). Purification and characterization of lipase from *Spirulina platensis*. *Journal of Molecular Catalysis - B Enzymatic*. **64:** 123-8.

Desai, K., Sivakami, S. (2007). Purification and biochemical characterization of a superoxide dismutase from the soluble fraction of the cyanobacterium, *Spirulina platensis*. *World Journal of Microbiology and Biotechnology*. **23:** 1661-66.

Ekeuku, S.O., Chong, P.N., Chan, H.K., Mohamed, N., Froemming, G.R.A. and Okechukwu, P.N. (2021). Spirulina supplementation improves bone structural strength and stiffness in streptozocin-induced diabetic rats. *Journal of Traditional and Complementary Medicine.* https://doi.org/10.1016/j.jtcme.2021.07.010.

El-Anany, A.M., Althwab, S.A., Alhomaid, R.M., Ali, R.F. and Mousa, H.M. (2023). Effect of spirulina (Arthrospira platensis) powder addition on nutritional and sensory attributes of chicken mortadella. *Italian Journal of Food Science*. **35(4):** 1.

Elwakil, B.H., Eskandrani, A., El-Kady, H., Shahin, Y.H. and Awaad, A.K. (2024). *Spirulina platensis* as a super prebiotic to enhance the antibacterial effect of *Lactobacillus casei*. *South African Journal of Botany.* **173:** 417-429. https://doi.org/10.1016/j.sajb.2024.02.005.

FAO (2020). The State of World Fisheries and Aquaculture 2020. Food and Agriculture Organization of the United Nations. Assessed on 26 May, 2025.

Gad, A.S., Khadrawy, Y.A. and El-Nekeety, A.A. (2011). Antioxidant activity and hepatoprotective effects of whey protein and Spirulina in rats. *Nutrition.* **27(5):** 582-589. https://doi.org/10.1016/j.nut.2010.04.012.

Ge, Y., Kang, Y.K., Dong, L., Liu, L.H. and An, G.Y. (2019). The efficacy of dietary Spirulina as an adjunct to chemotherapy to improve immune function and reduce myelosuppression in patients with malignant tumors. *Translational Cancer Research.* **8(4):** 1065-1073.https://doi.org/10.21037/tcr.2019.06.13.

González, R., Rodríguez, S. and Romay, C. (1999). Anti-inflammatory activity of phycocyanin extract in acetic acid-induced colitis in rats. *Pharmacological Research.* **39(1):** 55-59. https://doi.org/10.1006/phrs.1998.0436.

Grosshagauer, S., Kraemer, K. and Somoza, V. (2020). The true value of Spirulina. *Journal of Agricultural and Food Chemistry.* **68(14):** 4109-4115. https://doi.org/10.1021/acs.jafc.0c00 085.

Guldas, M., Ziyanok-Demirtas, S., Sahan, Y., Yildiz, E. and Gurbuz, O. (2020). Antioxidant and anti-diabetic properties of Spirulina platensis produced in Turkey. *Food Science and Technology*. **41:** 615-625.

Gun, D., Çelekli, A., Bozkurt, H. and Kaya, S. (2022). Optimization of biscuit enrichment with the incorporation of Arthrospira platensis: Nutritional and sensory approach. *Journal of Applied Phycology*. **34(3):** 1555-1563.

Gupta, S., Gupta, C., Garg, A.P. and Prakash, D. (2017). Prebiotic efficiency of blue-green algae on probiotics microorganisms. *Journal of Microbiology and Experimentation.* **4(4):** 00120. https://doi.org/10.15406/jmen.2017.04.00120.

Habib, M.A.B., Parvin, M., Huntington, T.C. and Hasan, M.R. (2008). A review on culture, production and use of Spirulina as food for humans and feeds for domestic animals. Retrieved from https://www.fao.org/4/i0424e/i0424e00.pdf.

Hernandez-Lopez, I., Alamprese, C., Cappa, C., Prieto-Santiago, V., Abadias, M. and Aguiló-Aguayo, I. (2023). Effect of Spirulina in bread formulated with wheat flours of different alveograph strength. *Foods*. **12(20):** 3724.

Hirahashi, T., Matsumoto, M., Hazeki, K., Saeki, Y., Ui, M. and Seya, T. (2002). Activation of the human innate immune system by Spirulina: Augmentation of interferon production and NK cytotoxicity by oral administration of hot water extract of *Spirulina platensis*. *International mmunopharmacology.* **2(4):** 423-434. https://doi.org/10.1016/s1567-5769(01)00213-2.

Hussein, A., Ibrahim, G., Kamil, M., El-Shamarka, M., Mostafa, S. and Mohamed, D. (2021). Spirulina-enriched pasta as functional food rich in protein and antioxidant. *Biointerface Research of Applied Chemistry*. **11:** 14736-14750.

Ismail, H.A., El-Sawah, T.H., Ayyash, M., Adhikari, B. and Elkot, W.F. (2023). Functionalization of Ricotta cheese with powder of spirulina platensis: Physicochemical, sensory and microbiological properties. *International Journal of Food Properties*. **26(1):** 1968-1983.

Jamil, A.R., Akanda, M.R., Rahman, M.M., Hossain, M.A. and Islam, M.S. (2015). Prebiotic competence of Spirulina on the production performance of broiler chickens. *Journal of Advanced Veterinary and Animal Research.* **2(3):** 304-309. https://doi.org/10.5455/javar.2015.b99.

Jung, F., Krüger-Genge, A., Waldeck, P. and Küpper, J. H. (2019). Spirulina platensis, a super food?. *Journal of Cellular Biotechnology*. **5(1):** 43-54.

Khan, Z., Bhadouria, P. and Bisen, P.S. (2005). Nutritional and therapeutic potential of Spirulina. *Current Pharmaceutical Biotechnology.* **6(5):** 373-379. https://doi.org/10.2174/138920105774370607.

Khanna, S., Gulati, H.K., Kumar, S. and Kapoor, P.K. (2016). Effect of *Emblica officianalis* and *Spirulina platensis* on growth performance a nd serum biochemical parameters in rabbits. *Indian Journal of Animal Research.* **50(6):** 915-918. https://doi.org/10.18805/ijar.v0iof.6664.

Koli, D.K., Rudra, S.G., Bhowmik, A. and Pabbi, S. (2022). Nutritional, functional, textural and sensory evaluation of Spirulina-enriched green pasta: A potential dietary and health supplement. *Foods.* **11(7):** 979. https://doi.org/10.3390/foods11070979.

Koukouraki, P., Tsoupras, A., Sotiroudis, G., Demopoulos, C.A. and Sotiroudis, T.G. (2020). Antithrombotic properties of Spirulina extracts against platelet-activating factor and thrombin. *Food Bioscience.* 37. Article 100686. https://doi.org/10.1016/j.fbio.2020.100686.

Kumar, S., Saha, S., Singh, K., Singh, T., Mishra, A.K., Dubey, B.N. and Singh, S. (2025). Beneficial effects of Spirulina on brain health: A systematic review. *Current Functional Foods.* **3(1):** E120124225622.

Lafarga, T., Acién-Fernández, F. G., Castellari, M., Villaró, S., Bobo, G. and Aguiló-Aguayo, I. (2019). Effect of microalgae incorporation on the physicochemical, nutritional and sensorial properties of an innovative broccoli soup. *LWT -Food Science and Technology.* **111:** 167-174. https://doi.org/10.1016/j.lwt.2019.05.103.

Lafarga, T., Fernández-Sevilla, J.M., González-López, C. and Acién-Fernández, F.G. (2020). Spirulina for the food and functional food industries. *Food Research International.* 137. Article 109356. https://doi.org/10.1016/j.foodres.2020.109356.

Li, D. M. and Qi, Y.Z. (1997). Spirulina industry in China: Present status and future prospects. *Journal of Applied Phycology.* **9(1):** 25-28. https://doi.org/10.1023/A:1007901102546.

Li, Y., Lammi, C., Boschin, G., Arnoldi, A. and Aiello, G. (2019). Recent advances in microalgae peptides: Cardiovascular health benefits and analysis. *Journal of Agricultural and Food Chemistry*. **67(43):** 11825-11838.

Ljubic, A., Safafar, H., Holdt, S.L., Jacobsen, C. (2018). Biomass composition of *Arthrospira platensis* during cultivation on industrial process water and harvesting. *Journal of Applied Phycology.* **30(2):** 943-954. https://doi.org/10.1007/s10811-017-1237-x.

Los, P.R., Simões, D.R.S., Leone, R.D.S., Bolanho, B.C., Cardoso, T. and Danesi, E.D.G. (2018). Viability of peach palm by-product, Spirulina platensis and spinach for the enrichment of dehydrated soup. *Pesquisa Agropecuária Brasileira*. **53(11):** 1259-1267.

Lucas, B.F., de Morais, M.G., Santos, T.D. and Costa, J.A.V. (2018). Spirulina for snack enrichment: Nutritional, physical and sensory evaluations. *LWT - Food Science and Technology.* **90:** 270-276. https://doi.org/10.1016/j.lwt.2017.12.024.

Machu, L., Misurcova, L., Ambrozova, J.V., Orsavova, J., Mlcek, J., Sochor, J. and Jurikova, T. (2015). Phenolic content and antioxidant capacity in algal food products. *Molecule.* **20(1):** 1118-1133. https://doi.org/10.3390/molecules20011118.

Mao, T.K., Van De Water, J. and Gershwin, M.E. (2000). Effect of *Spirulina* on the secretion of cytokines from peripheral blood mononuclear cells. *Journal of Medicinal Food.* **3(3):** 135-140. https://doi.org/10.1089/jmf.2000.3.135.

Maoka, T. (2020). Carotenoids as natural functional pigments. *Journal of Natural Medicines*. **74(1):** 1-16. https://doi.org/10.1007/s11418-019-01364-x.

Marcinkowska Lesiak, M., Onopiuk, A., Zalewska, M., Ciepłoch, A. and Barotti, L. (2018). The effect of different level of Spirulina powder on the chosen quality parameters of shortbread biscuits. *Journal of Food Processing and Preservation*. **42(3):** e13561.

Marinova, E.M. and Yanishlieva, N. (1992). Inhibited oxidation of lipids. II. Comparison of the antioxidative properties of some hydroxy derivatives of benzoic and cinnamic acids. *Fat Science Technology.* **94:** 428-430.

Mendhulkar, V.D., Shetye, L.A. and Khot, O. (2020). Modulation of the anti-cancer activity of sulfated polysaccharides, synthesized in spirulina platensis, due to varying degree of sulfation induced by nutrient and physical stress. *Journal of Biologically Active Products from Nature*. **10(4):** 275-284.

Miranda, M.S., Cintra, R.G., Barros, S.B.D.M. and Mancini-Filho, J. (1998). Antioxidant activity of the microalga *Spirulina maxima*. *Brazilian Journal of Medical and Biological Research.* **31(8):** 1075-1079. https://doi.org/10.1590/S0100-879X1998000800017.

Morsy, O.M., Sharoba, A.M., El-Desouky, A.I., Bahlol, H.E.M. and Abd El Mawla, E.M. (2014). Production and evaluation of some extruded food products using spirulina algae. *Annals of Agricultural Science*, *Moshtohor*. **52(4):** 329-342.

Mrowicka, M., Mrowicki, J., Kucharska, E. and Majsterek, I. (2022). Lutein and zeaxanthin and their roles in age-related macular degeneration-neurodegenerative disease. *Nutrients*. **14(4):** 827.

Naguib, Y.M.A. (2001). Pioneering astaxanthin. Nutrition Science News. February, 2001. Boulder CO. Available from: http://www.chiro.org/nutrition/FULL/Pioneering_Astaxanthin.shtml (Accessed 24 May 2025).

Naik, M., Sethy, K., Panda, N., Mishra, S.K. andhale, V.T. and Thakur, D. (2024). Dietary Spirulina supplementation enhanced performance, immune response and reduced oxidative stress in broiler chicken. *Indian Journal of Animal Research*. doi:10.18805/IJAR.B-5414.

Narayana, R. and Kale, A. (2019). Functional Probiotic Yoghurt with Spirulina. *Asian Journal of Dairy and Food Research*. **38(4):** 311-314. doi: 10.18805/ajdfr.DR-1472.

Niccolai, A., Venturi, M., Galli, V., Pini, N., Rodolfi, L., Biondi, N. and Tredici, M.R. (2021). Vegetable oils protect phycocyanin from thermal degradation during cooking of spirulina-based crostini. *LWT: Food Science and Technology*. **138:** 110776.

Ozyurt, G., Uslu, L., Yuvka, I., Gökdoðan, S., Atci, G., A., B. and Işik, O. (2015). Evaluation of the cooking quality characteristics of pasta enriched with *Spirulina platensis*. *Journal of Food Quality*. **38(4):** 268-272.

Pagnussatt, F.A., Spier, F., Bertolin, T.E., Costa, J.A.V. and Gutkoski, L.C. (2014). Technological and nutritional assessment of dry pasta with oatmeal and the microalga *Spirulina platensis*. *Brazilian Journal of Food Technology.* **17:** 296-304. https://doi.org/10.1590/1981-6723.0514.

Parages, M.L., Rico, R.M., Abdala-Díaz, R.T., Chabrillón, M., Sotiroudis, T.G., Jiménez, C. (2012). Acidic polysaccharides of arthrospira (Spirulina) platensis induce the synthesis of TNF in RAW macrophages. *Journal of Applied Phycology*. **24:** 1537-46.

Patil, J., Matte, A., Mallard, C. and Sandberg, M. (2018). Spirulina diet to lactating mothers protects the antioxidant system and reduces inflammation in post-natal brain after systemic inflammation. *Nutritional Neuroscience.* **21(1):** 59-69. https://doi.org/10.1080/1028415X.2016.1205619.

Peipei, L. and Sumin, Z. (2017). Effect of Spirulina-Chinese herbal medicine on quality of eggs and serum biochemical indexes of egg-laying hens. *Indian Journal of Animal Research.* **52(3):** 373-377. doi: 10.18805/ijar.v0iOF.9143.

Perera, C.O. and Yen, G.M. (2007). Functional properties of carotenoids in human health. *International Journal of Food Properties*. **10(2):** 201-230.

Petkov, G.D., Furnadzieva S.T. (1988). Fatty acid composition of acylolipids from *Spirulina platensis. C.R. Bulg. Acad. Sci.* **41:** 103-4.

Pulz, O. and Gross, W. (2004). Valuable products from microalgae: Commercial applications and perspectives. *Applied Microbiology and Biotechnology.* **65(6):** 635-648. https://doi.org/10.1007/s00253-004-1647-x.

Qing, R., Ye, H., Lan, L. and Fu, H. (2003). Study of the activity of two antioxidant enzymes of *Spirulina maxima* under excessive light stress. *Journal of Sichuan University.* **40(3):** 565-569.

Ramirez-Rodrigues, M.M., Estrada-Beristain, C., Metri-Ojeda, J., Pérez-Alva, A. and Baigts-Allende, D. K. (2021). *Spirulina platensis* protein as a sustainable ingredient for nutritional food products development. *Sustainability.* **13(12):** Article 6849. https://doi.org/10.3390/su13126849.

Rana, M., Das, M., Parvin, S. and Kabita, S. (2024). The effects of dietary supplement of *Arthrospira platensis* (Spirulina) as a fishmeal replacer on growth performance and carotenoid concentration in Buenos Aires Tetra (*Aphyocharax anisitsi*). *Agricultural Science Digest*. doi:10.18805/ag.D-5815.

Richmond, A. (1984). 'Spirulina' In: *Micro-algal Biotechnology*. Cambridge: Cambridge University Press, (M.A. Borowitzka and L.J. Borowitzka eds.) p. 85-121 (1984).

Ricigliano, V.A. and Simone-Finstrom, M. (2020). Nutritional and prebiotic efficacy of the microalga *Arthrospira platensis* (*Spirulina*) in honey bees. *Apidologie*. **51:** 898-910. https://doi.org/10.1007/s13592-020-00770-5.

Rodrigues, E.F., Vendruscolo, L.P., Bonfante, K., Reinehr, C.O., Colla, E. and Colla, L.M. (2020). Phycocyanin as substitute for texture ingredients in ice creams. *British Food Journal*. **122(2):** 693-707.

Rossetto, R., Maciel, G.M., Bortolini, D.G., Ribeiro, VR. and Haminiuk, C.W.I. (2020). Acai pulp and seeds as emerging sources of phenolic compounds for enrichment of residual yeasts (*Saccharomyces cerevisiae*) through biosorption process. *LWT-Food Science and Technology. 128.* Article 109447. https://doi.org/10.1016/j.lwt.2020.109447.

Santos, T.D., de Freitas, B.C.B., Moreira, J.B., Zanfonato, K. and Costa, J.A.V. (2016). Development of powdered food with the addition of *Spirulina* for food supplementation of the elderly population. *Innovative Food Science and Emerging Technologies*. **37:** 216-220. https://doi.org/10.1016/j.ifset.2016.07.011.

Seema, Jood, S. and Saharan, V. (2025). Effect on sensory evaluation, starch and *in vitro* protein digestibility in cookies supplemented by spirulina platensis powder. *Asian Journal of Dairy and Food Research*. **44(2):** 246-250. doi: 10.18805/ajdfr.DR-1794.

Seyidoglu, N., Inan, S. and Gunes, N. (2019). Dose dependent effects of *Spirulina platensis* on liver health in rats. *Indian Journal of Animal Research.* **54(3):** 349-353. https://doi.org/10.18805/ijar.B-1055.

Sharoba, A.M. (2014). Nutritional value of spirulina and its use in the preparation of some complementary baby food formulas. *Journal of Food and Dairy Sciences*. **5(8):** 517-538.

Singh, S.K., Shukla, L., Yadav, N., Singh, P.K., Singh, S.M., Yadav, M.K. and Kumar, A. (2023). Spirulina: From ancient food to innovative supernutrition of the future and its market scenario as a source of nutraceuticals. In Cyanobacterial Biotechnology in the 21st Century. Singapore: Springer Nature Singapore. (pp. 51-61).

Sinha, S., Patro, N., Tiwari, P.K. and Patro, I.K. (2020). Maternal *Spirulina* supplementation during pregnancy and lactation partially prevents oxidative stress, glial activation and neuronal damage in protein-malnourished F1 progeny. *Neurochemistry International.* 141. Article 104877. https://doi.org/10.1016/j.neuint.2020.104877.

Sivakumar, N., Sundararaman, M. and Selvakumar, G. (2018). Evaluation of growth performance of *Penaeus monodon* (Fabricius) fed diet with partial replacement of fishmeal by *Spirulina platensis* (Sp) meal. *Indian Journal of Animal Research.* **52(12):** 1721-1726. https://doi.org/10.18805/ijar.B-3438.

Solanki, N., Chouhan, G., Soni, P., Shekhawat, G.S., Singh G.P. and Parihar Suman (2023). Evaluation of nutrient dependent growth of spirulina platensis for pigment-proteins production. *Indian Journal of Agricultural Research*. **57(4):** 513-518. doi: 10.18805/IJARe.A-6082.

Soni, R.A., Sudhakar, K. and Rana, R.S. (2017). *Spirulina*-from growth to nutritional product: A review. *Trends in Food Science and Technology.* **69:** 157-171. https://doi.org/10.1016/j.tifs.2017.09.001.

Sotiroudis, T.G. and Sotiroudis, G.T. (2013). Health aspects of *Spirulina (Arthrospira)* microalga food supplement. *Journal of the Serbian Chemical Society.* **78(3):** 395-405. https://doi.org/10.2298/JSC121016013S.

Sowmiya, C., Ahilan, B., Vijay Amirtharaj, K.S., Sivasankar, P., Lingaprabu, D., Anix Vivek Santhiya, A. and Ruby, P. (2025). Evaluation of dietary supplementation of algae *Spirulina platensis* on growth performance and disease resistance in white leg shrimp challenge study against *Vibrio parahaemolyticus*. *Indian Journal of Animal Research*. https://doi.org/10.18805/IJAR.B-5632.

Sozeri Atik, D., Gurbuz, B., Boluk, E. and Palabıyık, I. (2021). *Development of vegan kefir fortified with Spirulina platensis. Food Bioscience.* **42:** *101050*.

Subramaiam, H., Chu, W.L., Radhakrishnan, A.K., Chakravarthi, S., Selvaduray, K.R. and Kok, Y.Y. (2021). Evaluating anticancer and immunomodulatory effects of *Spirulina (Arthrospira platensis)* and gamma-tocotrienol supplementation in a syngeneic mouse model of breast cancer. *Nutrients.* **13(7):** 2320. https://doi.org/10.3390/nu13072320.

Thevarajah, B., Nishshanka, G.K. S.H., Premaratne, M., Nimarshana, P.H.V., Nagarajan, D., Chan, J.S. and Ariyadasa, T.U. (2022). Large-scale production of *Spirulina*-based proteins and c-phycocyanin: A biorefinery approach. *Biochemical Engineering Journal.* 185. Article 108541. https://doi.org/10.1016/j.bej.2022.108541.

Tocher, D. R., Betancor, M.B., Sprague, M., Olsen, R.E. and Napier, J.A. (2019). Omega-3 long-chain polyunsaturated fatty acids, EPA and DHA: Bridging the gap between supply and demand. *Nutrients.* **11(1):** 89. https://doi.org/10.3390/nu11010089.

Upasani, C.D. and Balaraman, R. (2003). Protective effect of *Spirulina* on lead-induced deleterious changes in lipid peroxidation and endogenous antioxidants in rats. *Phytotherapy Research.* **17(4):** 330-334. https://doi.org/10.1002/ptr.1131.

Uribe-Wandurraga, Z. N., Igual, M., García-Segovia, P. and Martínez-Monzó, J. (2019). Effect of microalgae addition on mineral content, colour and mechanical properties of breadsticks. *Food and Function*. **10(8):** 4685-4692.

Ustun Aytekin, O., Coban, I. and Akta, S.B. (2022). Nutritional value, sensory properties and antioxidant activity of a traditional kefir produced with *Arthrospira platensis*. *Journal of Food Processing and Preservation*. **46(3):** e16380.

Wang, Y.Y., Xu, B.L., Dong, C.M. and Sun, Y.Y. (2023). The nutritional value of Spirulina and utilization research. *Life Res*. **6(3):** 15.

Watanuki, H., Ota, K., Malina, A.C., Tassakka, A.R., Kato, T., Sakai, M. (2006). Immunostimulant effects of dietary Spirulina platensis on carp, *Cyprinus carpio*. *Aquaculture*. **258:** 157-163.

Wu, Q., Liu, L., Miron, A., Klímová, B., Wan, D. and Kuèa, K. (2016). The antioxidant, immunomodulatory and anti-inflammatory activities of *Spirulina*: An overview. *Archives of Toxicology.* **90(8):** 1817-1840. https://doi.org/10.1007/s00204-016-1744-5.

Yoshikawa, T. and Naito, Y. (2002). What is oxidative stress? *Japan Medical Association Journal.* **45(7):** 271-276.