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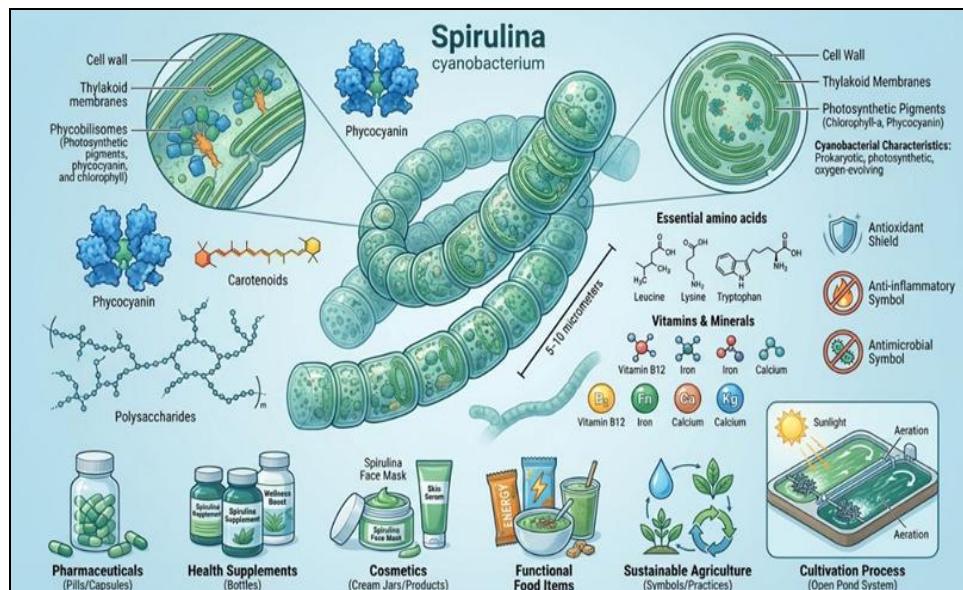
Spirulina: A multifunctional microalga with nutritional and therapeutic properties

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Abstract

Spirulina is a very helpful cyanobacterium that is rich in protein, essential amino acids, vitamins, minerals, and biologically active components like phycocyanin, carotenoids, and polysaccharides. Its strong antioxidant, anti-inflammatory, antimicrobial, antiviral, antidiabetic, and anticancer qualities are supported by these components, making it beneficial for use in pharmaceuticals and health supplements. *Spirulina* can be used in the pharmaceutical, cosmetic, functional food, and sustainable development industries due to its ease of cultivation and sustainability. Even though they are usually safe, quality control is essential to preventing contamination from toxins or heavy metals. All things considered, *spirulina* is a versatile microalga with significant therapeutic and nutritional advantages.



Keywords: GRAS Status, NASA, *Spirulina*, *Arthrospira Platensis*, nutritional composition, glucose metabolism, antioxidants

Introduction

A microscopic filamentous cyanobacterium, *spirulina* gets its name from the spiral or helical form of its filaments. It is said to have been used during the Aztec civilisation and has a long history as a food source. The drained biomass of *Arthrospira platensis*, an oxygenic photosynthesis-dependent bacterium found worldwide in fresh and marine waters, is referred to as *spirulina*. This algae is an important part of the human diet and has been used as an alternative source of vitamin and protein supplements with no discernible negative effects. It has a high protein content (up to 70%) and is also rich in minerals, especially iron, and vitamins, especially B12 and provitamin A (β -carotenes). Moreover, it is rich in γ -linolenic acid, tocopherols, and phenolic acids. *Spirulina* is easily digested because it lacks cellulose cell walls. *Spirulina* has been shown to be safe in numerous toxicological investigations.

Consequently, the US Food and Drug Administration has designated *Spirulina* as one of the substances that are Generally Recognised as Safe (GRAS) [1]. A type of cyanobacterium called *spirulina* is rich in proteins, polyunsaturated fatty acids, and bioactive compounds like C-phycocyanin, which has anti-inflammatory and antioxidant properties and may have an effect on the metabolism of fats and carbohydrates. This systematic review set out to assess *spirulina*'s effects on glucose metabolism and lipid profiles. Modifications in lifestyle and the use of medication serve as effective strategies for managing obesity and diabetes. Maintaining a suitable body weight, adhering to a nutritious diet, and engaging in physical activities that include endurance and high-intensity training are essential [2]. Data from various studies indicate its application in food formulations, particularly in sports supplements, baked goods, beverages, dairy items, snack foods, and confections. Additionally, it has been utilized by the National Aeronautics and Space Administration (NASA) for astronauts during space missions to the Moon and Mars [3]. Among the various types of *spirulina*, the species that have been most extensively researched include *Spirulina platensis* (Arthrospora platensis), *Spirulina maxima* (Arthrospora maxima), and *Spirulina fusiformis* (Arthrospora fusiformis). Numerous antioxidants, including the pigment beta-carotene, phycocyanin, tocopherols, micronutrients, and polyunsaturated fatty acids, particularly gamma-linolenic acid and phenolic compounds, are found in *spirulina*. It has a notably high concentration of macronutrients and micronutrients. Proteins, carbohydrates, vitamins like provitamin A, vitamin C, and vitamin E, and minerals like iron, calcium, chromium, copper, magnesium, manganese, phosphorus, potassium, sodium, and zinc make up 60-70% of its dry weight [4]. It also contains pigments like carotenes, phycocyanin, and chlorophyll a, as well as essential fatty acids like γ -linolenic acid (GLA). Applications for *spirulina* include wastewater treatment, pharmaceuticals, and cosmetics. Because the polysaccharides that make up its cell wall have an 86% digestibility rate, the human body can easily absorb it [5]. Its hypolipemic, antihypertensive, antidiabetic, neuroprotective, antianemic, anticarcinogenic, hepatoprotective, antibacterial, antiviral, and immunomodulatory properties are all supported by scientific data. Studies have demonstrated that *spirulina* can enhance macrophage phagocytosis and promote innate and cellular adaptive immunity [6]. Toxicological tests have shown that microalgae is safe and has no harmful effects at either acute or long-term concentrations [7]. Additionally, *spirulina* has shown good acceptance due to its organoleptic qualities, which could make it a potential food or nutrition supplement. It has also shown no signs of acute or chronic toxicity, making it safe for ingestion by humans [8]. Because of its powerful growth qualities and environmental flexibility, *spirulina* is considered an environmentally benign alternative to high-quality protein or bioactive elements for both humans and animals [9].

Chemical composition of *Spirulina*

A microalga known for its complex and nutrient-rich chemical makeup, *spirulina* is an important organism for a variety of uses in food, medicine, nutraceuticals, and animal feed. The primary characteristics of *spirulina*'s composition are its high concentrations of proteins, lipids, carbs,

vitamins, minerals, and pigments, all of which are important for its biological processes.

Proteins

Protein makes between 50-70% of the dry weight of *spirulina*, making it the most prevalent component. While *spirulina* comprises every one of the necessary amino acids, it is a complete protein supply that is equivalent to that found in animal products like meat and eggs, which makes its high protein concentration very noteworthy. Leucine (7.67%), lysine (4.37%), methionine (2.39%), phenylalanine (4.42%), threonine (4.88%), tryptophan (1.93%), and valine (6.37%) are the necessary amino acids that make up 38.81% of the total. Furthermore, the protein quality composition of *spirulina* is improved by the significant amounts of unnecessary amino acids, which comprise 61.19% and include alanine (7.52%), arginine (7.65%), glycine (5.24%), and serine (4.16%) [10]. One of the primary barriers to *spirulina*'s use as a protein source, particularly at greater incorporation levels in diets, is its stiff peptidoglycan cell wall. Because of this, the nutrients bioavailability, bioaccessibility, and digestibility are difficult [11].

Lipids

About 7% of *spirulina* is made up of lipids, which include several important fatty acids. The main components are linoleic acid and gamma-linolenic acid, which allow *Spirulina* to control blood cholesterol levels [12]. Saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) make up the lipid profile. *Spirulina* includes several unsaturated fatty acids that are essential for human health, such as omega-6: arachidonic acid (AA), gamma-linolenic acid (GLA), and omega-3: Docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). EPA and DHA are essential for foetal growth and have positive effects on the neurological and cardiovascular systems [13]. Although it might vary depending on growth conditions, the GLA content of *spirulina* typically ranges from one to two percent of its entire dry mass. Additionally, in contrast to GLA and other PUFAs, *spirulina* has lower quantities of omega-3 fatty acids, such as α -linolenic acid [14].

Carbohydrates

From fifteen to twenty percent of *spirulina*'s dry bulk is composed of carbohydrates. The majority of these carbohydrates are found as polysaccharides, which serve as the cyanobacterium's structural and storage components. Ten to fifteen percent of *spirulina* is made up of carbohydrates, mostly polysaccharides. About 50-70% of the body's energy needs are met by carbs, which are primarily responsible for providing energy (1 gramme of carbohydrates gives 4 kcal of energy). In addition to providing instant energy, carbohydrates are necessary for the heart, liver, central nervous system, and the contraction of muscles to operate at their best. Notably, *spirulina*'s sulphated polysaccharides are known by their bioactive properties, which include anti-viral, anti-inflammatory, and immune-boosting activities. The main monosaccharides found in *spirulina* [14] are glucose, rhamnose, xylose, mannose, and galactose. These polysaccharides form complex structures that maintain the integrity of the cell wall and may impact the organism's bioactivities. Additionally, sulfur-based polysaccharides like calcium-

containing spirulan (Ca-SP), a particularly unique sulfur-based polysaccharide, are present in its cell wall^[15].

Pigments

Spirulina contains phycocyanin along with other pigments such as carotenoids and chlorophyll, as well as vitamins B and E. *Spirulina*'s distinctive blue-green colour is a result of its high pigment concentration. Phycocyanin, a blue pigment-protein complex that can make up as much as 47% of the dry weight of *spirulina*, is the main pigment. In addition to being recognised for its potent antioxidant qualities, phycocyanin is essential to the light-harvesting complexes involved in photosynthesis. *Spirulina* can flourish in a variety of aquatic conditions because it contains large amounts of chlorophyll, which is necessary for photosynthesis. Naturally occurring lipophilic pigments called carotenoids are responsible for the red, yellow, and orange colours that occur in a variety of living things. In addition to serving as nutritional supplements, they are frequently used as colourants and flavour modifiers in food and feed^[16]. One of the unique characteristics of *spirulina* is its strong pigment concentration that gives it its distinctive blue-green color^[17]. The primary pigment in cyanobacteria is phycocyanin, a blue protein-pigment combination that can account for up to 47% of its dry weight. Phycocyanin is vital to the sunlight-capturing complexes of photosynthesis and is well-known for its potent antioxidant properties^[18].

Micronutrients

The mineral potassium, salt, and vitamin A are the three micronutrients that are most prevalent in *spirulina*. Potassium and sodium both support nerve impulses, contractions of muscles, and fluid homeostasis. For the heart, lungs, kidneys, liver, and other organs to remain healthy, vitamin A is necessary. It is also required for healthy vision, reproduction, and a strong immune system. Calcium and magnesium, which both maintain strong and healthy bones, assist modulate heart rhythm, and strengthen the immune system, are other important elements found inside *spirulina* that significantly improve health^[19]. *Spirulina* is rich in essential vitamins and minerals. It provides significant levels of B-complex vitamins, particularly thiamine (B1), riboflavin (B2), niacin (B3), and folate (B9), all of which are critical for energy metabolism and cellular activity^[20]. One of the most significant minerals in *spirulina* is iron. Given that its iron content can range from 28 to 50 mg per 100 g of dry weight, *spirulina* is an essential provider of iron, especially for people with iron deficiency anaemia^[21].

Secondary Metabolites

Polyphenols as well as phenolic acids, tocopherols, and linolenic acid are examples of bioactive secondary metabolites extracted from *spirulina*^[22]. Phenolic acids account for one third of all phenolic chemicals, whereas flavonoids constitute the remaining portion^[23]. Among other phenolic compounds, *spirulina* can include pyrogallol, gallic, chlorogenic caffeine vanillic, p-coumaric acid, naringin, hespardin, and rutin, querctetin, naringenin, catechin and hespirtin^[24]. Phenolic compounds, which are molecules having a benzene ring and more than one hydroxyl substituent, are the main class of bioactive chemicals found in plant-based products such algae^[25].

Activities of *Spirulina*

Anti-oxidant activity^[26].

Chlorophyll, beta-carotene, phycoerythrin, and phycocyanin are among the natural pigments that make up this substance. *S. platensis* has demonstrated the capacity to scavenge free radicals and exhibit antioxidant activity. It also contains complexes of light-harvesting protein pigments called phycobilisomes^[27]. Phycocyanin, β-carotene, and other vitamins and minerals found in *spirulina* all contribute to the protective effects of antioxidants. DNA, RNA, proteins, and lipids are all harmed by reactive oxygen species (ROS), which can result in metabolic problems, tissue damage, and cell death. Many diseases, including hypertension, diabetes mellitus, atherosclerosis, ischaemic conditions, and cancer, are significantly influenced by oxidative stress and reactive oxygen species (ROS). DPPH method for estimating antioxidant activity^[28].

Anti-Inflammatory activity

Spirulina can lessen inflammation in arthritis for reasons other than its antioxidant properties. In rheumatoid arthritis models, *spirulina* has been shown to alter immune responses, promoting anti-inflammatory states and promoting bone and joint health and healing. *Spirulina*'s colourful pigment, phycocyanin, is crucial to its anti-inflammatory properties. It works by lowering pro-inflammatory molecules, assisting in immune response suppression, and significantly reducing arthritis-related pain and swelling. Gamma-linolenic acid, or GL because it controls inflammatory pathways, this essential fatty acid, which is found in *spirulina*, is crucial for joint health. It has been shown to have strong anti-inflammatory qualities, giving arthritis sufferers additional support^[29]. Studies have demonstrated that *spirulina* reduces inflammatory markers such as TNF-α, IL-6, COX-2, and VEGF in experimental models of rheumatoid arthritis. Animal studies have shown that *spirulina* improves survival rates and suppresses cellular and macroscopic indicators of arthritis with fewer gastrointestinal side effects when compared to traditional non-steroidal anti-inflammatory drugs (NSAIDs), like indomethacin^[30]. Studies have shown that *spirulina*-containing diets improved receptor function and decreased oxidative stress and inflammatory markers in the brains of aged rats. *Spirulina* reduces hepatic damage caused by heavy metal exposure, drug abuse, inflammation, cell deterioration, and anaphylactic reactions^[31].

Antiviral activity

Particularly against enveloped viruses like hepatitis C, influenza A, HIV, human cytomegalovirus, and herpes simplex virus^[32], *spirulina* has demonstrated antiviral properties. By preventing viruses from entering host cells, Ca-SP, a sulphated polysaccharide that is extracted from *spirulina*, has been shown to inhibit viral replication^[33]. Furthermore, phycocyanin has been demonstrated to possess antiviral qualities, possibly through influencing RNA synthesis *in vitro* and reducing viral replication rates. Because of its ability to stop viral entry, Ca-SP is a promising choice for antiviral therapies, especially in light of recently discovered infections with viruses. Additionally, *spirulina* extract has been described as a potential therapeutic agent because it lowers virus yields^[34]. The antiviral properties of *S. platensis* against enveloped viruses such as human cytomegalovirus (HCMV), HSV-1, measles

virus, mumps virus, HIV-1, and influenza virus are mainly attributed to calcium spirulan (Ca-SP), an acidic or sulphated polysaccharide that was extracted from *S. platensis* hot water extract. Furthermore, *S. platensis* demonstrated antiviral activity toward DNA and RNA enteric viruses that were not enveloped^[35].

Anticancer Activity

Given their extensive nutrient profile, which includes various vitamins, minerals, phenolic compounds, antioxidants, fatty acids, and bioactive components, choosing *Spirulina* species from the current forms of blue-green algae is advantageous^[36]. This filamentous genus of cyanobacteria is categorized by botany experts as a microalga that is a member of the Cyanophyceae family^[37]. When compared to chemotherapy, *Spirulina* spp. are a great option because toxicological studies on all *Spirulina* types have not revealed any detrimental effects on human health during or after exposure to acute or chronic dosages^[38]. The medicinal and biological qualities of ocean algae, including their efficacy as antitumor, antioxidant, and antibacterial agents, were thoroughly investigated. In order to extract bioactive substances that have been shown to have anticancer properties, these marine species include cyanobacteria⁸, also known as blue-green algae, which are prokaryotes that are widely distributed. Many naturally occurring compounds or their chemical counterparts have the ability to induce oxidative damage, affect mitochondrial function, halt the cell cycle, initiate apoptosis, and alter the activation of cell signaling, all of which can result in cell death and potentially eliminate a significant number of cancerous cells^[39, 40]. *Spirulina* extract showed cytotoxic and anti-proliferative effects on the A549 non-small-cell lung cancer cell line. Specifically, it caused these cells to go through apoptosis and stopped the cell cycle from moving on to the G1 phase. Furthermore, *spirulina* showed cytotoxicity against the colon carcinoma cell line HCT11641 and the hepatocellular cancer cell line HEPG2. Phycocyanin in a selenium-rich an effective antiproliferative agent is *spirulina* extract. These studies suggest that *spirulina* may produce novel, potentially beneficial natural anticancer products which can be improved either by itself or in conjunction with different compounds^[42].

Immunomodulatory properties

Spirulina's aqueous extract was shown to have a significant impact upon the autoimmune system by stimulating NK cells and increasing macrophage phagocyte activity. Due to its positive effects on the generation of inflammatory compounds and antibodies, it also contributed to the activation and activation of T and B cells^[43]. This extract was also beneficial to the transplant community because it co-stimulates human T cells and inhibits CD28 to the same extent as drugs like cyclosporine, which have many side effects. Phycocyanin, a photosynthetic pigment, is involved in immune system inhibition. It has been shown to have an inhibitory effect on mast cell histamine ejection during the allergic inflammatory reaction^[45]. It has also been observed that *in vivo* and *in vitro* condition, it inhibited the proliferation of tumour cells, enhanced NK cell activity and stimulated the lymphocytes from spleen to generate TNF- α . In vivo activity of *spirulina* fusiformis on humoral immune responses, interferon- γ production and anti-inflammatory effects were studied in mice using different doses. In vitro

effects conversely, an inhibition of mitogen-induced T cell proliferative response were observed^[46]. Strong IL-1 β , IL- and responses induced by variety that will causing a age related to stimulate strong IL-1 β , IL-HHT in *Schistosoma mansoni* only dependently amplify are observed) do not give experiments revealed that spp. It was determined that *spirulina* was effective in enhancing the cell-mediated immunity via activation of Th-1 type response. According to the morphologic changes and morphological studies of liver in rats, we found that immune stimulating effect of microalgae was supported by NBT test of intraperitoneal macrophage^[47].

Antidiabetic Activity

Treatment of diabetes, *Spirulina* has been shown to improve the sensitivity to insulin and lower blood glucose levels in patients with diabetes^[48]. Within diabetes conditions, reactive oxygen species may be produced and it is likely associated in the progression of pancreatic cells abnormalities. Likewise, when the system goes through oxidative damage, the pancreatic cells may be sensitive for damage from the reactivity of the oxygen molecules because of the relatively insufficient synthesis of anti-oxidative enzymes like superoxide dismutase and catalase^[49]. The process which is responsible for the antidiabetic actions of naturally occurring nutrients remains uncertain, but multiple studies have identified the possible mechanisms of action: i) insulin sensitisation: *Spirulina* extracts have been found shown to improve the sensitivity to insulin in both animal models and human trials. The presence of polysaccharides such as and phycocyanin, which improve the uptake and application of glucose by cells, may be the reason for this effect., ii) suppression of the process of gluconeogenesis: *Spirulina* extracts have been reported shown to be able to inhibit hepatic gluconeogenesis, a mechanism by which the liver forms glucose from alternatives to carbohydrates. The inhibition could have been because of the abundance of the gamma together with other saturated fats that controls glucose metabolic processes. Protein content as well as biologically active peptides resulting from *Spirulina* has an excellent proteins composition (60-70% dry weight) as well as contains the presence of bioactive peptides that result from its protein content. These elements might be involved in *Spirulina*'s antidiabetic effects^[50]. The hypoglycemic effects of *spirulina* phycocyanin have been associated with a chromium-binding peptide that enhances insulin signalling and glucose absorption by activating insulin receptors; viii) microbiota of the gut modulation: Newly discovered evidence proposes that gut microbial acts a crucial part in glucose absorption and insulin resistance. *Spirulina* algae extracts have been discovered found to impact the breakdown of the microbes in the gut, potentially enhancing carbohydrate metabolism in animal models^[51].

Antimicrobial Activity

Spirulina is a further significant organic preservative and antimicrobial substance used to combat harmful pathogenic microbes such as drug resistant microbes. *Spirulina* was historically known as a nutritional component, natural colourant as well as beneficial biological compound source that contain naturally occurring compounds^[52]. SP's water extract demonstrated potent antibacterial activity against *S. aureus*. Multiple drug resistance (MDR) has emerged. become widespread in the global population as a result of

the haphazard use of antibiotics. MDR organisms are thought to be lethal to humans because they cause life-threatening conditions through systematic infections [53]. The type of extract and its particular concentration affect its antibacterial activity. As previously reported, ethanol extract of SP at a dose of 1.6-1.9 mg ml⁻¹ produced clear ZOI against *Candida albicans* and *E. faecalis* [54]. Water, hexane, ethyl acetate, and dichloromethane extracts have also been shown to be efficient towards *S. aureus*. The inhibition zone against *S. aureus* and *S. typhimurium* was effectively determined by methanol and acetone extracts of SP at between 250 and 7000 parts per million [55]. The US Food and Drug Administration has classified *spirulina* as "generally recognised as safe" (GRAS), and the Intergovernmental Institution Against Malnutrition (IIMSAM) has also approved it (Mathur, 2018). Phenolic compounds which are involved in oxygen quenching, reducing reactions, and redox mechanisms are abundant in the biomass of *spirulina*. Still, these phenolic compounds' effectiveness to fight food pathogens [56].

Industrial and Neutraceutical application of *Spirulina*

All living things depend on food and nutrition to survive and thrive. Numerous issues pertaining to food, the environment, and financial health have arisen as a result of the fast growth of the human population and urbanisation. "Blue Food" is regarded as one of the innovative solutions to these problems. *Spirulina* is a multicellular, filamentous, nutrient-rich cyanobacterium that grows quickly, is non-toxic, and is easily adaptable. It is widely used in the pharmaceutical and functional food industries [57]. Protein, minerals, vitamins, beta-carotene, small amounts of elements like iron, and the rare necessary gamma-linolenic acid are just a few of the many vital nutrients found in *spirulina*. Additionally, it is beneficial for both humans and animals since it includes bioactive substances including polysaccharides and phycocyanin [58]. In the food business, *spirulina* has emerged as a promising sustainable option because to the growing need for nutritious foods and the growing awareness of health-conscious diets [59]. Since *spirulina* has been added to a variety of food products for commercial and colouring purposes, the number of goods containing it has increased tremendously in recent years. Recently, *spirulina* has grown into an essential development in the modern food industry, included into environmentally advanced items such as bread, pasta, snacks, yoghurt, and drinks. The majority of *spirulina* biomass is utilised as a nutritional supplement and comes in the form of capsules, granules, or dry particles [60]. The common species three main species of *spirulina* are *Arthospira maxima*, *A. platensis*, and *A. fusciformis*. Protein makes up nearly 60% of its dry weight, but beneficial components like phycobiliproteins, carotenoids, and chlorophylls can be used as natural food colouring agents with biotechnological uses [61]. Because of its nutritional value and growing demand, *spirulina* farming is acknowledged as a lucrative sector in the nutrition market for people as well as animal feed. China is home to the world's biggest producer of *spirulina* [62]. Its antioxidant, anti-inflammatory, and immunomodulatory qualities make it a useful food ingredient [63]. These characteristics promote both therapeutic outcomes and general human health. *Spirulina* is frequently utilised in industries other than food, for example cosmetics, energy production, wastewater treatment, and CO₂ reduction [64].

The World Health Organization's suggestions for protein requirements are met by its amino acid composition. Encouraging its use as a premium protein supplement. Research shows that the net protein utilisation (NPU) is between 60% and 70% [65]. Because of its high protein content and nutrient density, *spirulina* helps with weight management. *Spirulina* is known for its abundance of bioactive substances that have anti-inflammatory, cardiovascular, immune-modulating, antidiabetic, and antioxidant properties properties. It is a promising option for alternative therapies because of significant components like phycocyanin, polysaccharides, and vital fatty acids. *Spirulina* is useful for treating wastewater due to its ability to remove metals, phosphorus, and nitrogen [66]. phycocyanin and β-carotene, counter oxidative stress from space radiation, enhancing cellular protection and recovery for astronauts Phycocyanin and β-carotene help astronauts recover and protect their cells from oxidative damage caused by space radiation. phycocyanin and β-carotene, counter oxidative stress from space radiation, enhancing cellular protection and recovery for astronauts [67]. *Spirulina* is an efficient biofertilizer because of its high nutrient content, especially in nitrogen, phosphorus, and potassium. A 2024 study published in Sustainability showed that applying *spirulina* increases microbial activity and soil organic matter, which improves cultivation and nutrient intake. phycocyanin and β-carotene, counter oxidative stress from space radiation, enhancing cellular protection and recovery for astronauts with 50-70% protein, vital amino acids, vitamins, and bioactive elements that improve health, *spirulina* is a useful addition to aquaculture and livestock feed. Immunity and growth. *Spirulina* improve animal health and reduce the use of antibiotics [68]. Because of their long-term sustainability, favourable effects on public health, environmental preservation, and food security, microalgal-based diets are regarded as excellent substitutes for plant and meat-based diets. The food's potential is attributed to its rich nutritional makeup [69]. Other vital nutrients that are required for sustaining a healthy diet can also be found in *spirulina* [70].

Safety and Limitations of *Spirulina*

While most healthy people can safely use *spirulina*, contaminated *spirulina* can have major negative health effects. This typically results from improperly farmed or non-lab-tested *spirulina*, which may contain Heavy metals such as arsenic, lead, or mercury Microcystins (toxins from contaminated blue-green algae) Pathogens or dangerous bacteria [71]. Although *spirulina*-based products are usually seen as safe, there is some evidence in the literature of mild side effects, like allergies. Before taking *spirulina* as a supplement, take into account the following potential contraindications [72]. Anaphylaxis can result from the initial ingestion of *spirulina*, according to a case report that describes a 17-year-old man who took a *spirulina* tablet and experienced an anaphylactic reaction [73]. Consuming *spirulina* while pregnant is generally regarded as potentially dangerous, and it is not advised for children. In order to prevent harmful toxins from reaching the infant via breast milk, nursing mothers should avoid *Spirulina* if contamination presumed [74]. The human body experiences hypoglycemia as a result of cyanobacteria. Surgery is stressfull procedure that influence glucose metabolism. *Spirulina* stimulates the immune system by increasing

natural killer cells. Medication is prescribed to individuals with autoimmune disorders in order to weaken the body's immune system. However, when these medications are taken together with products made from *spirulina*, the latter contributes to the first's effects [75]. Phycocyanin blocks COX-2, it interferes with blood clot formation [76]. The clotting process can be altered by cyanobacteria. Herbal products like cloves, garlic, red clover, turmeric, as well as and ginkgo have effects that are comparable to those of *spirulina* because *spirulina* inhibits the synthesis of fat by downregulating NADPH and NADH, it is antihyperglycemic. Additionally, it increases hexokinase activity, which aids in the liver cells' absorption of glucose from the blood [77].

Future Prospectives

The potential of *spirulina* to treat metabolic disorders, support neuroprotection, aid in anti-cancer therapy, and improve athletic performance is being highlighted by ongoing research. These advantages are largely due to its abundant antioxidant and biologically active profile. Genetic modifications to increase valuable compounds like phycocyanin and carotenoids are made possible by biotechnology advancements, opening the door for more potent therapeutic and nutraceutical uses. *Spirulina* is also a promising option for climate-resilient agriculture and sustainable food production due to its quick growth, low resource requirements, and capacity to flourish in harsh conditions.

Conclusion

Since contain its abundance of proteins, vital vitamins, minerals, and a variety of bioactive substances like phycocyanin and polysaccharides, *spirulina* is a nutritious microalga known for its wide therapeutic potential. Its potent antioxidant, anti-inflammatory, therapeutic, and metabolic health effects are attributed to these components, which make it advantageous for conditions involving oxidative stress, impaired immunity, and metabolic imbalance. Its use as an energy source and dietary supplement is supported by a number of experimental and clinical studies, but the available data is still constrained by small sample sizes and brief study durations. Therefore, to definitively confirm its therapeutic efficacy, ascertain the ideal dosage, and guarantee long-term safety across various populations, well-designed, extensive clinical trials are required.

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Conflict of Interest

Authors Declare no Conflict of Interest.

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