IJP (2026), Vol. 13, Issue 1 **(Review Article)**

Received on 02 January 2026; received in revised form, 27 January 2026; accepted, 29 January 2026; published 31 January 2026

SPIRULINA: A MULTIFUNCTIONAL MICROALGA WITH NUTRITIONAL AND THERAPEUTIC PROPERTIES

Sanket B. Phirange [*1], Chanchal N. Raj [2], Shraddha V. Patil [2], Mayuri C. Prabhu [2], Tushar R. Pawar [3] and Aashish S. Jain [3]

Department of Pharmacognosy and Phytochemistry [1], Department Pharmacognosy and Phytochemistry [2], Shri. D. D. Vispute College of Pharmacy & Research Centre [3], Navi Mumbai - 410221, Maharashtra, India.

Keywords:

Spirulina, *Arthrospira platensis*, Nutritional Composition, GRAS Status, NASA, Glucose Metabolism, antioxidants

Correspondence to Author:
Sanket B. Phirange

Department of Pharmacognosy and Phytochemistry, Shri. D. D. Vispute College of Pharmacy & Research Centre, Navi Mumbai - 410221, Maharashtra, India.

E-mail: sanketphirange99@gmail.com

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 antioxidants, 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 prevent contamination from toxins or heavy metals. All things considered, spirulina is a versatile microalga with significant therapeutic and nutritional advantages.

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 alga 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).

QUICK RESPONSE CODE

DOI: 10.13040/IJPSR.0975-8232.IJP.13(1).13-23

Article can be accessed online on: www.ijpjournal.com

DOI link: https://doi.org/10.13040/IJPSR.0975-8232.IJP.13(1).13-23

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 contain 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, hespirdin, and rutin, quercetrin, 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-1β, IL-and responses induced by variety that will causing a age related to stimulate strong IL-1β, 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 beenbecause 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; vii) 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 $mgml^{-1}$ 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 apromising 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 *Arthrospira maxima, A. platensis,* and *A. fusiformis*. 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 CO_2 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 hypoglycemiaas a result of cyanobacteria. surgery is stress full 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.

ACKNOWLEDGEMENT: All individuals listed as authors have contributed substantially to the work and are required to indicate their specific contribution

Funding: The Preparation of this article was not supported by external Funding

Author's Contribution:

Conceptualization: Dr. Chanchal Navin Raj.

Data Curation: Sanket Bhau Phirange, Tushar Rangrao Pawar, Shraddha Patil, Mayuri Prabhu

Formal Analysis: Dr. Ashish Suresh Jain.

Validation: Dr. Chanchal Navin Raj.

Writing Original Draft: Sanket Bhau Phirange.

CONFLICT OF INTEREST: Authors Declare no Conflict of Interest.

REFERENCES:

1. Karkos PD, Leong SC, Karkos CD, Sivaji N and Assimakopoulos DA: Spirulina in clinical practice: evidence-based human applications. Evid Based Complement Alternat Med 2011; 2011(1). doi:10.1093/ecam/nen058.
2. Bohórquez-Medina SL, Bohórquez-Medina AL, Zapata VAB, Ignacio-Cconchoy FL, Toro-Huamanchumo CJ, Bendezu-Quispe G, Pacheco-Mendoza J and Hernandez AV: Impact of spirulina supplementation on obesity-related metabolic disorders: a systematic review and meta-analysis of randomized controlled trials. NFS J 2021; 25: 21–30. doi:10.1016/j.nfs.2021.09.003.
3. Ahmad NAMR, Intikhab NA, Zafar NS, Farooq NU, Shah NHBU, Akram NS, Abid NJ, Parveen NZ and Iqbal NS: Spirulina, an FDA-approved functional food: Worth the hype? Cell Mol Biol 2023; 69(1): 137–144. doi:10.14715/cmb/2022.69.1.24.
4. DiNicolantonio JJ, Bhat AG and O'Keefe J: Effects of spirulina on weight loss and blood lipids: a review. Open Heart 2020; 7(1): 001003. doi:10.1136/openhrt-2018-001003.
5. Soni RA, Sudhakar K and Rana RS: Spirulina – from growth to nutritional product: a review. Trends Food Sci Technol 2017; 69: 157–171. doi:10.1016/j.tifs.2017.09.010.
6. Trotta T, Porro C, Cianciulli A and Panaro MA: Beneficial effects of spirulina consumption on brain health. Nutrients 2022; 14(3): 676. doi:10.3390/nu14030676.
7. Chaouachi M, Vincent S and Groussard C: A review of the health-promoting properties of spirulina with a focus on athletes' performance and recovery. J Diet Suppl 2023; 21(2): 210–241. doi:10.1080/19390211.2023.2208663.
8. Gutiérrez-Salmeán G, Fabila-Castillo L and Chamorro-Cevallos G: Nutritional and toxicological aspects of spirulina (Arthrospira). Nutr Hosp 2015; 32(1): 34–40. doi:10.3305/nh.2015.32.1.9001.
9. Meka P, Geddada M, Chodipilli RD, Peddireddy LB, Khandavalli S and Boddani S: Spirulina: nutritional and therapeutic potential as a superfood. Int J Pharm Sci 2025; 3(11): 91–103.
10. Spínola MP, Mendes AR and Prates JAM: Chemical composition, bioactivities, and applications of Spirulina (*Limnospira platensis*) in food, feed, and medicine. Foods 2024; 13(22): 3656. doi:10.3390/foods13223656.
11. Coelho D, Lopes PA, Cardoso V, Ponte P, Brás J and Madeira MS: A two-enzyme constituted mixture to improve the degradation of *Arthrospira platensis* microalga cell wall for monogastric diets. Journal of Animal Physiology and Animal Nutrition [Internet] 2019; 104(1): 310–21. Available from: https://doi.org/10.1111/jpn.13239
12. AlghePAM. Nutritional Composition of Spirulina - AlghePAM - Alga *Spirulina italiana*. AlghePAM - Alga Spirulina Italiana. https://www.alghepam.it/nutritional-composition-spirulina/.
13. Podgórska-Kryszczuk I: Spirulina An Invaluable Source of Macro- and Micronutrients with Broad Biological Activity and Application Potential. Molecules 2024; 29(22): 5387. https://doi.org/10.3390/molecules29225387.
14. Wild KJ, Steingaß H and Rodehutscord M: Variability in nutrient composition and *in-vitro* crude protein digestibility of 16 microalgae products. Journal of Animal Physiology and Animal Nutrition [Internet] 2018; 102(5): 1306–19. Available from: https://doi.org/10.1111/jpn.12953
15. Pugh N, Ross S, ElSohly H, ElSohly M and Pasco D: Isolation of Three High Molecular Weight Polysaccharide Preparations with Potent Immunostimulatory Activity from *Spirulina platensis*, Aphanizomenon flos-aquae and

Chlorella pyrenoidosa. Planta Medica [Internet] 2001; 67(08): 737–42. Available from: https://doi.org/10.1055/s-2001-18358

16. Chen W, Xu J, Yu Q, Yuan Z, Kong X and Sun Y: Structural insights reveal the effective *Spirulina platensis* cell wall dissociation methods for multi-output recovery. Bioresource Technology [Internet] 2019; 300: 122628. Available from: https://doi.org/10.1016/j.biortech.2019.122628
17. Marzorati S, Schievano A, Idà A and Verotta L: Carotenoids, chlorophylls and phycocyanin from Spirulina: supercritical CO_2 and water extraction methods for added value products cascade. Green Chem 2019; 22(1): 187–196. doi:10.1039/c9gc03292d.
18. Christaki E, Florou-Paneri P and Bonos E: Microalgae: a novel ingredient in nutrition. International Journal of Food Sciences and Nutrition [Internet] 2011; 62(8): 794–9. Available from: https://doi.org/10.3109/09637486.2011.582460
19. Chaiklahan R, Chirasuwan N, Srinorasing T, Attasat S, Nopharatana A and Bunnag B: Enhanced biomass and phycocyanin production of Arthrospira (Spirulina) platensis by a cultivation management strategy: Light intensity and cell concentration. Bioresource Technology [Internet] 2021; 343: 126077. Available from: https://doi.org/10.1016/j.biortech.2021.126077
20. Bortolini DG, Maciel GM, De Andrade Arruda Fernandes I, Pedro AC, Rubio FTV and Branco IG: Functional properties of bioactive compounds from *Spirulina* spp.: Current status and future trends. Food Chemistry Molecular Sciences [Internet] 2022; 5: 100134. Available from: https://doi.org/10.1016/j.fochms.2022.100134.
21. Liestianty D, Rodianawati I, Arfah RA, Assa A, Patimah N and Sundari N: Nutritional analysis of spirulinaspto promote as super food candidate. IOP Conference Series Materials Science and Engineering [Internet] 2019; 509: 012031. Available from: https://doi.org/10.1088/1757-899x/509/1/012031
22. Srivastava G: Spirulina - Nutrition, Health Benefits, Types, & Side Effects - HealthifyMe Blog. Healthifyme. https://www.healthifyme.com/blog/spirulina/
23. AlFadhly NKZ, Alhelfi N, Altemimi AB, Verma DK, Cacciola F and Narayanankutty A: Trends and technological advancements in the possible food applications of spirulina and their health benefits: a review. Molecules [Internet] 2022; 27(17): 5584. Available from: https://doi.org/10.3390/molecules27175584
24. Sinetova MA, Kupriyanova EV and Los DA: Spirulina/Arthrospira/Limnospira—Three names of the single organism. Foods [Internet] 2024; 13(17): 2762. Available from: https://doi.org/10.3390/foods13172762
25. Machu L, Misurcova L, Ambrozova JV, Orsavova J, Mlcek J and Sochor J: Phenolic content and antioxidant capacity in algal food products. Molecules [Internet] 2015; 20(1): 1118–33. Available from: https://doi.org/10.3390/molecules20011118
26. Alshuniaber MA, Krishnamoorthy R and AlQhtani WH: Antimicrobial activity of polyphenolic compounds from Spirulina against food-borne bacterial pathogens. Saudi Journal of Biological Sciences 2020; 28(1): 459–464. https://doi.org/10.1016/j.sjbs.2020.10.029.
27. Kumar A, Ramamoorthy D, Verma DK, Kumar A, Kumar N, Kanak KR, Marwein BM and Mohan K: Antioxidant and phytonutrient activities of *Spirulina platensis*. Energy Nexus 2022; 6: 100070. https://doi.org/10.1016/j.nexus.2022.100070.
28. Martínez-Sámano J, De Oca ATM, Luqueño-Bocardo OI, Torres-Durán PV and Juárez-Oropeza MA: *Spirulina maxima* Decreases endothelial damage and oxidative stress indicators in patients with systemic arterial hypertension: results from exploratory controlled clinical trial. Marine Drugs 2018; 16(12): 496. https://doi.org/10.3390/md16120496.
29. GJ: Discover the surprising benefits of spirulina for inflammation [Internet]. Health Benefits of Eating. 2025. Available from: https://healthbenefitsofeating.com/spirulina-anti-inflammatory-benefits/
30. Ali EA. I, Barakat BM and Hassan R: Antioxidant and Angiostatic Effect of *Spirulina platensis* Suspension in Complete Freund's Adjuvant-Induced Arthritis in Rats. PLoS ONE [Internet] 2015; 10(4): 0121523. Available from: https://doi.org/10.1371/journal.pone.0121523
31. S NP, R NV, Verma NR and Ayenampudi SB: Spirulina: a spotlight on its nutraceutical properties and food processing applications. Journal of Microbiology Biotechnology and Food Sciences [Internet] 2023; 4785. Available from: https://doi.org/10.55251/jmbfs.4785
32. Carbone DA, Pellone P, Lubritto C and Ciniglia C: Evaluation of microalgae antiviral activity and their bioactive compounds. Antibiotics [Internet] 2021; 10(6): 746. Available from: https://doi.org/10.3390/antibiotics10060746
33. Hayashi T, Hayashi K, Maeda M and Kojima I: Calcium Spirulan, an Inhibitor of Enveloped Virus Replication, from a Blue-Green Alga *Spirulina platensis*. Journal of Natural Products [Internet] 1996; 59(1): 83–7. Available from: https://doi.org/10.1021/np960017o
34. Chen YH, Chang GK, Kuo SM, Huang SY, Hu IC and Lo YL: Well-tolerated Spirulina extract inhibits influenza virus replication and reduces virus-induced mortality. Scientific Reports [Internet] 2016; 6(1): 24253. Available from: https://doi.org/10.1038/srep24253
35. Liang SXT, Wong LS, Dhanapal ACTA, Balu P and Djearamane S: Therapeutic applications of spirulina against human pathogenic viruses. Journal of Experimental Biology and Agricultural Sciences [Internet] 2021; 9(Spl-1-GCSGD_2020): 38–42. Available from: http://doi.org/10.18006/2021.9(spl-1-gcsgd_2020).s38.s42
36. Chaouachi M, Vincent S and Groussard C: A Review of the Health-Promoting Properties of Spirulina with a Focus on athletes' Performance and Recovery. Journal of Dietary Supplements [Internet] 2023; 21(2): 210–41. Available from: https://doi.org/10.1080/19390211.2023.2208663
37. Fayyad R, Ali A, Dwaish A and Arch AAAA: Anticancer activity of *Spirulina platensis* methanolic extracts against L20B and MCF7 human cancer cell lines 2019.
38. Anvar A and Bioact BNM: Bioactive properties of spirulina: A Review 2021; 4: 134–142.
39. Qamar H: Cyanobacteria as natural therapeutics and pharmaceutical potential: role in antitumor activity and as nanovectors. Molecules 2021; 26.
40. Ouhtit A, Ismail MF, Othman A, Fernando A, Abdraboh ME, El-Kott AF, Azab YA, Abdeen SH, Gaur RL, Gupta I, Shanmuganathan S, Al-Farsi YM, Al-Riyami H and Raj MHG: Chemoprevention of rat mammary carcinogenesis by Spirulina. Am J Pathol 2014; 184(1): 296–303.
41. Kaur K and Kaur S: Spirulina – a wonder nutraceutical against cancer: a review. Plant Archives [Internet] 2021; 21(1). Available from: http://doi.org/10.51470/plantarchives.2021.v21.no1.177

42. Schwartz J and Shklar G: Regression of experimental hamster cancer by beta carotene and algae extracts. J Oral Maxillofac Surg 1987; 45(6): 510–515.
43. Ismail MF, Ali DA and Fernando A: Chemoprevention of rat liver toxicity and carcinogenesis by Spirulina. Int J Biol Sci 2009; 5(4): 377–387.
44. Subhashini J, Mahipal SV, Reddy MC, Mallikarjuna Reddy M, Rachamallu A and Reddanna P: Molecular mechanisms in C-phycocyanin–induced apoptosis in human chronic myeloid leukemia cell line K562. Biochem Pharmacol 2004; 68(3): 453–462.
45. Sheahan S, Bellamy CO and Harland SN: TGF-β induces apoptosis and EMT in primary mouse hepatocytes independently of p53, p21^Cip1^ or Rb status. BMC Cancer 2008; 8: 191–201.
46. Maddaly R: The beneficial effects of spirulina focusing on its immunomodulatory and antioxidant properties. Nutrition and Dietary Supplements [Internet] 2010; 73. Available from: https://doi.org/10.2147/nds.s9838
47. Raffaella R, Marzia BG, Laura P and Elena M: Role of the p53/p21 system in the response of human colon carcinoma cells to doxorubicin. Int J Biol Sci 2009; 5(4): 377–387.
48. Mazokopakis EE, Starakis IK, Papadomanolaki MG and Ganotakis ES: The hypolipidaemic effects of Spirulina (*Arthrospira platensis*) supplementation in a Cretan population: a prospective study. J Sci Food Agric 2014; 94(3): 432-437.
49. Kajimoto Y and Kaneto H: Role of oxidative stress in pancreatic beta-cell dysfunction. Ann N Y Acad Sci 2004; 1011: 168-176.
50. El-Sakhawy MA, Iqbal MZ, Gabr GA, Alqasem AA, Ateya AAES and Ahmed FA: The mechanism of action of Spirulina as antidiabetic: a narrative review. Italian Journal of Medicine [Internet] 2023; 17(2). Available from: https://doi.org/10.4081/itjm.2023.1639
51. Feng W, Liu J and Cheng H: Dietary compounds in modulation of gut microbiota-derived metabolites. Front Nutr 2022; 9: 939571.
52. Zhao X, Chen L, Zhao L, He Y and Yang H: Antimicrobial kinetics of nisin and grape seed extract against inoculated Listeria monocytogenes on cooked shrimps: Survival and residual effects. Food Control [Internet] 2020; 115: 107278. Available from: https://doi.org/10.1016/j.foodcont.2020.107278
53. Chakraborty K, Lipton AP, Paulraj R and Chakraborty RD: *Guaiane sesquiterpenes* from seaweed *Ulva fasciata* Delile and their antibacterial properties. Eur J Med Chem 2010; 45(6): 2237-44.
54. Kaushik P and Chauhan A: *In-vitro* antibacterial activity of laboratory grown culture of *Spirulina platensis*. Indian J Microbiol 2008; 48(3): 348-52.
55. Chakraborty B, Jayaswal RP and Pankaj PP: Lovely faculty of Applied Medical Sciences, Lovely Professional University, Department of Zoology, *et al.* Antimicrobial Activity of Spirulina platensis Extract Against Gram Positive and Gram Negative Bacteria- A Comparative Study [Internet]. Vol. 6, International Journal of Current Pharmaceutical Review and Research 2015; 212–4.
56. Alshuniaber MA, Krishnamoorthy R and AlQhtani WH: Antimicrobial activity of polyphenolic compounds from Spirulina against food-borne bacterial pathogens. Saudi Journal of Biological Sciences [Internet] 2020; 28(1): 459–64. Available from: https://doi.org/10.1016/j.sjbs.2020.10.029
57. Shah MAR, Zhu F, Cui Y, Hu X, Chen H and Kayani SI: Mechanistic insights into the nutritional and therapeutic potential of Spirulina (Arthrospira) spp.: Challenges and opportunities. Trends in Food Science & Technology [Internet] 2024; 151: 104648. Available from: https://doi.org/10.1016/j.tifs.2024.104648
58. Kumar N, Banerjee C, Negi S, Shukla P, Kumar N and Banerjee C: Microalgae harvesting techniques: updates and recent technological interventions. Critical Reviews in Biotechnology [Internet] 2022; 43(3): 342–68. Available from: https://doi.org/10.1080/07388551.2022.2031089
59. Gogna S, Kaur J, Sharma K, Prasad R, Singh J and Bhadariya V: Spirulina- An Edible Cyanobacterium with Potential Therapeutic Health Benefits and Toxicological Consequences. Journal of the American Nutrition Association [Internet] 2022; 42(6): 559–72. Available from: https://doi.org/10.1080/27697061.2022.2103852
60. Lafarga T, Mayre E, Echeverria G, Viñas I, Villaró S and Acién-Fernández FG: Potential of the microalgae Nannochloropsis and Tetraselmis for being used as innovative ingredients in baked goods. LWT [Internet] 2019; 115: 108439. Available from: https://doi.org/10.1016/j.lwt.2019.108439
61. Gogna S, Kaur J, Sharma K, Prasad R, Singh J and Bhadariya V: Spirulina- An Edible Cyanobacterium with Potential Therapeutic Health Benefits and Toxicological Consequences. Journal of the American Nutrition Association [Internet] 2022; 42(6): 559–72. Available from: https://doi.org/10.1080/27697061.2022.2103852
62. Khatoon N and Pal R: Microalgae in Biotechnological Application: A Commercial Approach. In: plant biology and biotechnology [Internet] 2015; 27–47. Available from: https://doi.org/10.1007/978-81-322-2283-5_2
63. AlFadhly NKZ, Alhelfi N, Altemimi AB, Verma DK, Cacciola F and Narayanankutty A: Trends and technological advancements in the possible food applications of spirulina and their health benefits: a review. Molecules [Internet] 2022; 27(17): 5584. Available from: https://doi.org/10.3390/molecules27175584
64. Chu WL: Biotechnological applications of microalgae. International e-Journal of Science Medicine & Education [Internet] 2012; 6(1): 24–37. Available from: https://doi.org/10.56026/imu.6.suppl1.s24
65. Wang H, Zeng C and Wu Z: Protein quality of Spirulina (*Arthrospira platensis*) and its application in functional food. Food Chem 2021; 347: 128840.
66. Carvalho MC: Effects of Spirulina biomass on soil erosion control and microbial activity. J Appl Phycol 2023.
67. Gitelson JI: Life support systems integrating algae-based oxygen and food production. Adv Space Res 2017.
68. Kt HR: Exploring the versatile applications of Spirulina: A comprehensive research review. International Journal of Advanced Biochemistry Research [Internet] 2024; 8(11): 87–93. Available from: https://doi.org/10.33545/26174693.2024.v8.i11sb.2799
69. Abu-Taweel GM, G AMM, Antonisamy P, Arokiyaraj S, Kim HJ and Kim SJ: Spirulina consumption effectively reduces anti-inflammatory and pain related infectious diseases. Journal of Infection and Public Health [Internet] 2019; 12(6): 777–82. Available from: https://doi.org/10.1016/j.jiph.2019.04.014
70. Musa MN, Jirgi GM, Zango ZU, Isah MN, Abdurrazak M and Adamu AA: A review on techno-economic assessment of Spirulina for sustainable nutraceutical, medicinal, environmental, and bioenergy applications. Bioresources and Bioprocessing [Internet] 2025; 12(1): 51. Available from: https://doi.org/10.1186/s40643-025-00888-3

71. Iwasa M, Takeuchi T and Harada E: Spirulina-associated hepatotoxicity. Am J Gastroenterol 2002; 97(12): 3212-3213.
72. Le TM, Knulst AC and Röckmann H: Anaphylaxis to Spirulina confirmed by skin prick test with ingredients of Spirulina tablets. Food and Chemical Toxicology [Internet] 2014; 74: 309–10. Available from: https://doi.org/10.1016/j.fct.2014.10.024
73. US National Library of Medicine. Blue-green alga.
74. Spirulina consumption: Concerns regarding contaminants and uncommon but possible adverse reactions and interactions Spirulina consumption: Concerns regarding contaminants and uncommon but possible adverse reactions and interactions. Ecronicon 2021.
75. Moulis G, Batz A, Durrieu G, Viard C, Decramer S and Montastruc JL: Severe neonatal hypercalcemia related to maternal exposure to nutritional supplement containing Spirulina. European Journal of Clinical Pharmacology [Internet] 2011; 68(2): 221–2.
76. Reddy CM, Bhat VB, Kiranmai G, Reddy MN, Reddanna P and Madyastha KM: Selective Inhibition of Cyclooxygenase-2 by C-Phycocyanin, a Biliprotein from *Spirulina platensis*. Biochemical and Biophysical Research Communications [Internet] 2000; 277(3): 599–603. Available from: https://doi.org/10.1006/bbrc.2000.3725
77. Antidiabetic property of spirulina. https://www.researchgate.net/publication/286971989Antidiabetic

How to cite this article:
Phirange SB, Raj CN, Patil SV, Prabhu MC, Pawar TR and Jain AS: ''Spirulina: a multifunctional microalga with nutritional and therapeutic properties. Int J Pharmacognosy 2026; 13(1): 13-23. doi link: http://dx.doi.org/10.13040/IJPSR.0975-8232.IJP.13(1).13-23.