Abstract: The blue-green algae spirulina has attracted a lot of interest lately because of its exceptional nutritional makeup and possible health advantages. Spirulina's high protein content (which includes all essential amino acids), essential fatty acids (especially gamma-linolenic acid), vitamins (like B vitamins, vitamin E, and beta-carotene), minerals (like iron, calcium, and magnesium), and strong antioxidants (like phycocyanin and chlorophyll) are all explored in this review. Studies indicate that spirulina has a number of health-promoting qualities, including as anti-inflammatory and immunomodulatory actions, as well as possible antiviral qualities. Spirulina has also been linked to enhanced cardiovascular health, glycemic management, and lipid metabolism. Its antioxidant components have demonstrated potential in oxidative stress mitigation and free radical scavenging, both of which are linked to a number of chronic illnesses.

In addition, spirulina is regarded as a sustainable food source because it requires less resources to cultivate than conventional crops, which makes it a desirable choice for resolving issues with global food security. All things considered, spirulina is a promising nutraceutical with a variety of possible health advantages and uses in functional meals and dietary supplements.

Introduction

Freshwater algae called spirulina comes from the natural world and is a valuable and fascinating plant. Throughout history, it has been valued as a food and medicine by numerous civilizations. Native Americans, for example, ate a lot of it. As science and technology have progressed, as well as as awareness of health and nutrition has grown, spirulina has become more well-known as a prominent nutritional supplement and pharmaceutical raw material. Spirulina is rich in many different nutrients, such as high-quality protein, a range of vitamins, and minerals. It is essential for maintaining human health and preventing a number of ailments. Spirulina also has a wide range of uses in the food, pharmaceutical, cosmetic, and other industries, demonstrating its potential. A variety of cultivation techniques, including natural culture, artificial culture, and continuous culture, are available to suit the need for spirulina. Among these, continuous culture is a frequently employed technique that raises spirulina production and development rate. Moreover, techniques like enzymatic hydrolysis and ultrasonic cell wall cracking are frequently used to remove the spirulina's active ingredients. Studies have shown that ultrasonic cell wall cracking is a successful extraction technique that keeps the antioxidants and nutrients in algal cells intact. Spirulina is used as food and medicine ingredient, but it also has a number of other possible uses. Researchers have found that spirulina metabolites have a significant economic value when used as raw materials for biofuels and biomaterials. Furthermore, research has demonstrated that spirulina can be used to mitigate environmental pollution issues by cleaning soil, wastewater, and air. Researchers have thoroughly examined the nutritional components, growing techniques, extraction processes, and applications of spirulina during the past 20 years, leading to substantial advancements in our understanding of the plant's nutritional value. Methods, as well as additional elements. Spirulina has a vast amount of promise for boosting health and curing illnesses, as evidenced by several research Researchers have been working to maximise the value of spirulina in order to spur a spike in the use of the material as a raw material for biofuels and biomaterials in recent years. In green businesses where microalgae are the main focus. This article provides an overview of the current research status and future possibilities of spirulina and attempts to delve into the nutritional value of spirulina and its applications in domains such as food, medicine, cosmetics, treatment, and biofuels. Examining the future development and use of spirulina in a time when this field of study has made significant strides not only advances our knowledge of its nutritional value and potential uses, but also highlights the need for more wholesome, environmentally friendly, and sustainable natural resources. Many research have examined the physiological characteristics of several important antioxidant or antiviral chemicals found in blue green algae Spirulina. Extracts from Spirulina platensis exhibit medicinal qualities, including the capacity to lower the risk of cancer and blood cholesterol levels, boost the immune system, lessen the nephrotoxicity of drugs and heavy metals, and shield the body from radiation's damaging effects. In the meanwhile, spirulina merits particular consideration due to its high protein content and health-promoting qualities.
Examination of the nutritional elements found in spirulina.

**Protein**

The main protein in spirulina is called phycobilin, and it is made up of three proteins: phycocyanin, phycoglobin, and allophycocyanin. Spirulina's protein content was found by Leonard and Compere to be almost 50% of its dry weight. The main building unit of phycobilin, phycocyanin, is made up of and chain globulin subunit monomers that polymerize into hexamers and trimers, among other forms. With a molecular mass of 44–260 kDa and a maximum absorption wavelength of 610–620 nm, it demonstrates light absorption capabilities in the 550–630 nm range. The \( \alpha \) subunit of phycocyanin has a molecular weight of 12–19 KDa and two cysteine and two methionine residues. Conversely, the \( \beta \) subunit, which has a molecular mass of 14–21 KDa, has 3 cysteine and 5 methionine residues. There are 160–180 amino acid sequences in each subunit.

![Phycocyanin](image)

The molecular weight of phycocyanin is 44 kDa, its isoelectric point is 4.3 nm, and its maximum absorption wavelength is 620 nm. Additionally, research has shown that the \( \alpha \) subunits (or \( \beta \) subunits) of phycocyanin from various species have amino acid sequences that exhibit strong homology, as well as striking similarities in their structural structures. A protein with a variety of physiological functions, phytocyanin mainly aids in the absorption of proteins and has anti-inflammatory, anti-tumor, and antioxidant characteristics. Phycocyanin can also be used as a natural pigment in food and cosmetics and efficiently absorbs heat.

**Polysaccharide**

Spirulina platensis polysaccharide is a complex heteropolysaccharide with a 6% sulfate concentration. Among other things, its main constituents are D-mannose, D-glucose, D-galactose, L-rhamnose, and glucuronic acid. These constituents comprise roughly 14% to 16% of Spirulina's dry weight. It also has trace levels of other monosaccharides such as fructose, galactose, ribose, xylose, and galacturonic acid. Free radicals can be eliminated and the antioxidant system balanced by spirulina polysaccharides. Consequently, they have the ability to prevent oxidative damage in the body, raise serum insulin levels, improve the function of superoxide dismutase (SOD), and lower MDA levels—all of which contribute to the intended reduction of blood sugar.

**Lipids**

Fats Low-fat algae include spirulina, which has a fat level of about 6% to 9%. Nearly all of the essential amino acids and numerous significant unsaturated fatty acids required for human health are present in it body. Docosahexaenoic acid, eicosapentaenoic acid, and gamma-linolenic acid are examples of these unsaturated fatty acids. Remarkably, among autotrophs, spirulina is the only plant that has been found to be rich in gamma-linolenic acid. Gamma-linolenic acid has been proven in studies to have a number of health benefits, including lowering cholesterol, controlling blood pressure, and lowering blood lipid levels. It has drawn attention from all around the world due to its important function in the treatment and prevention of cardiovascular disorders. Gamma-linolenic acid also has antioxidant qualities, which can help whiten skin and postpone the effects of aging.

**Chlorophyll**

Marine Spirulina has a higher chlorophyll content than terrestrial plants. In addition to being a natural pigment and deodorant, chlorophyll is a naturally occurring bioactive chemical that can be used to cure a number of illnesses.
Chlorophyll A is made up of nitrogen and magnesium on four pyrrole rings and is usually seen as a dark green or dark green greasy or paste. It is the general word for pigments that are green and have a porphyrin structure. It is a naturally occurring, non-toxic fat-soluble pigment that dissolves readily in ethanol, acetone, and dimethyl sulfoxide but remains insoluble in water. Chlorophyll an is unstable and susceptible to light, heat, acids, and bases because of its structural makeup. Spirulina has a 1%–2% chlorophyll a level, which can be used as an indicator to assess the biomass and production of algae. Furthermore, like heme, chlorophyll has amazing physiological properties and has potential uses in the food, cosmetics, pharmaceutical, and other industries.

The role of bioactive components in spirulina

Antioxidant action

As it grows, the nutrient-rich algae spirulina produces a variety of physiologically active secondary metabolites that make it a natural superfood. These secondary metabolites have a range of actions, including as immunological modulation, anti-tumor activity, antioxidation, and anti-inflammatory qualities. Consequently, they have substantial prospective uses in the fields of cosmetics, healthcare, medicine, and other industries. The spirulina secondary metabolites that have been found so far. Spirulina, a green algae with a remarkable high protein content, is thought to be a viable “cell factory” since it may synthesize bioactive peptides that have medicinal effects and serve as a source of nutrients for other organisms. Many investigations conducted in the past few years have shown that certain peptides released by Significant biological functions of hydrolysis include immunological modulation, blood pressure reduction, antioxidation, anti-inflammatory, and anti-cancer effects. spirulina proteolytic peptides’ biological activity and processes have been thoroughly reported in a variety of literature sources. An imbalance between oxidation and antioxidation in the body is called oxidative stress. Reactive oxygen species build up excessively in this situation, including hydrogen peroxide (H2O2), hydroxyl group (-OH), superoxide anion (-O2-), and other substances. Malondialdehyde (MDA), a product of cell peroxidation, changes the permeability of cell membranes and damages cells. One of the main causes of inflammation, liver damage, metabolic problems, cardiovascular diseases, and other illnesses is oxidative stress. Numerous age- and chronic condition-related illnesses, including diabetes, Parkinson's disease, Alzheimer's disease, hypertension, and hyperlipidemia. Owing to its profusion of bioactive components such as phycocyanin, carotenoids, and algal polysaccharides, spirulina can strengthen the body's antioxidant defenses. It helps to stop DNA damage, lipid peroxidation, and the elimination of free radicals.

The antioxidant properties of spirulina have been the subject of many investigations recently. Strong antioxidant enzyme activity seen in spirulina successfully prevents DNA damage and intracellular lipid peroxidation while also effectively removing free radicals. Additionally, by lowering oxidative stress, spirulina has particular protective benefits on the kidneys and neurological systems of animals. Spirulina is regarded as a promising agent for the prevention and treatment of cardiovascular disorders because of its strong antioxidant activity. Spirulina's strong antioxidant properties make it a good treatment for both skeletal muscle damage from vigorous exercise and chronic obstructive pulmonary disease, despite the paucity of human clinical trials on the subject.

Anti inflammatory Action

A protective reaction that happens after tissue damage or foreign material invasion is the inflammatory response. It forms the basis for the emergence of various illnesses. Often referred to as the "precursor" of cancer, chronic inflammation is detected to be present in 25% of cancers during the development and growth, based on epidemiological studies. Long-term inflammation is dangerous for cardiovascular health because it can cause thrombosis and atherosclerosis, which can lead to heart disease. Furthermore, it harms nerve tissue, raising the possibility of Alzheimer's. From localized inflammatory areas, severe inflammatory reactions can spread, leading to infections that may ultimately result in death by progressing to sepsis. Clinical anti-inflammatory medications that are currently widely used can have serious adverse effects, such as immunosuppression and harm to human tissues and organs. Thus, it is critical to design anti-inflammatory medications that are both highly effective and have few harmful side effects. Bioactive compounds found in spirulina include phycocyanin, spirulina polysaccharide, eicosapentaenoic acid, SOD, vitamins, and flavonoids. In large quantities. It is now a well-known area of study for researchers globally in the medical industry. Here has been much written about the medicinal potential of spirulina proteolytic peptides in the treatment of inflammation and related conditions. Phycocyanin, MMLDF, and LDAVNR are examples of peptides produced from macroporphyrin that have showed anti-inflammatory properties in animal models or in vitro. Phycocyanin peptides have a variety of anti-inflammatory properties, such as scavenging different types of oxygen free radicals, preventing lipid peroxidation, lowering TNF-α release, preventing histamine release from mast cells, and suppressing amino acid metabolism.
Researchers LEDON et al. examined the anti-inflammatory properties of phycocyanin, an extract from spirulina, and noted variations in prostaglandin E2 (PGE2) concentrations and the activity of phospholipase A2 (PLA2) when phycocyanin is present. Because phycocyanin inhibits the formation of PGE2 and PLA2 activity, the results showed that it has some anti-inflammatory potential. In comparison to indomethacin, extracts of two crude polysaccharides from spirulina showed better anti-inflammatory activity, according to Guzman S et al. In vitro experiments by Matsui MS et al. shown that Spirulina algina polysaccharide might prevent the development of erythema brought on by intense stimulation. It was discovered through in vitro research that the polysaccharide might prevent hemophilic cells from adhering and aggregating. It was discovered through in vitro research that the polysaccharide might prevent hemophilic cells from adhering and aggregating. Consequently, it's seen as anti-inflammatory topical medication. An experimental indicator was mouse ear edema, while a control was Dexamethasone. The findings demonstrated that dexamethasone could induce atrophy of the liver, spleen, and thymus in rats, and that the 0.3% spirulina group's rate of ear swelling inhibition was superior to that of the positive control medications. Compared to dexamethasone, spirulina had a stronger anti-inflammatory impact and no negative impact on the indices of the kidney, liver, thymus, or spleen.

Hypoglycemic action

The human body naturally maintains a blood sugar level of between 80 and 120 mg/dL in a dynamic balance. Numerous long-term issues can result from hyperglycemia, including diabetes, kidney failure, blindness, myocardial infarction, and cerebral infarction. Spirulina is a naturally occurring plant that has a superior hypoglycemic impact and less toxicity than traditional hypoglycemic medications. Spirulina predominantly affects glucose glycogen, largely by blocking its degradation or boosting its synthesis in the liver, according to research findings. Hozayen WG et al. discovered that spirulina can inhibit hexokinase activity in liver cells, enhance glucose-6-phosphatase activity in muscles, and decrease glucose absorption in the gut by observing the hypoglycemic impact of spirulina on diabetic rats. By decreasing hepatic glycogen synthesis and increasing insulin's hypoglycemic action, this encourages peripheral tissues to use glucose. OU et al. investigated how phycocyanin in spirulina affected diabetes brought on by tetrafluoracil and talked about the chemical process behind it. It has been shown that phycocyanin may stimulate the liver, pancreas, and pancreatic protein kinase and insulin signalling pathway, hence accelerating the breakdown of liver glycogen and lowering blood glucose levels. Rats that were fed biological substances containing spirulina and phycocyanin allowed Setyaningsih et al. to test the anti-hyperglycemic activity of the animals. The outcomes demonstrated that these compounds lowered mice's blood sugar levels. Proteins and polysaccharides from spirulina were separated and purified by Qi Qinghua et al. using hydrochloric acid precipitation method.

They discovered that the isolated polysaccharide from spirulina significantly reduced the symptoms of hyperglycemia in diabetic mice that had been given alloxouracil, indicating that it may have applications as a novel kind of functional food. Furthermore, sprints can lessen workout exhaustion by consuming spirulina polysaccharides in moderation to lower blood sugar and lipid levels, boost the body's antioxidant and anti-inflammatory capabilities, and improve antioxidant capacity. The outcomes show that hyperglycemia can be considerably improved by administering polysaccharide made from spirulina platensis efficiently blocks the absorption of glucose in the intestines of mice and successfully counteracts the effects of adrenaline on liver glycogenolysis in rats. Furthermore, it has been discovered that spirulina polysaccharides increase the antioxidant levels of mice with diabetes induced by alloxouracil and greatly reduce the symptoms of hyperglycemia. Sprints must keep a careful eye on their blood lipid and blood sugar levels. Upon examination of the results of the experiments, polysaccharide from Spirulina Algina can raise insulin sensitivity, improve the body's absorption of sugar, and as a result, lower the rate at which glucose is absorbed by muscle and fat tissue. Furthermore, Spirulina platensis polysaccharide can control the composition of serum fat, lower the expression of sterol regulatory element binding protein in liver tissue, and encourage the synthesis of damaged liver mitochondria, all of which effectively improve cell regeneration and have an anti-fatigue effect.

Hypotensive action

A systemic illness known as hypertension is marked by high blood pressure and functional or organic alterations in the kidneys, brain, blood arteries, and heart, all of which are brought on by chronically elevated blood pressure. The main mechanism of action of the most widely prescribed synthetic antihypertensive medications, including captopril, enalapril, acapril, and LISINOLPRIL, is inhibition of the angiotensin-converting enzyme (ACE). By blocking ACE, angiotensin II is reduced and bradykinin, a vasodilator, is increased. These changes ultimately result in a drop in blood pressure. These synthetic medications do, however, have some negative side effects, including dry cough, taste disturbance, rash, and more, even when they successfully control blood pressure. For this reason, the creation of secure and efficient antihypertensive medications is crucial to the management and prevention of hypertension. Dietary proteins contain blood pressure-lowering peptides that are thought to be safer than manufactured antihypertensive
medications. For example, the suppression of ACE and renin may be responsible for the antihypertensive action of seaweed-derived active peptides. The renin-angiotensin system is essential for controlling blood pressure.

Renin is one mechanism through which angiotensin I, which is generated from angiotensinogen, is inhibited. The alternative method is competitively binding the ACE active site to stop angiotensin I from becoming angiotensin II, which inhibits kinin hydrolysis and stops vasoconstriction. According to ROJAS V et al., peptides that are active and have a molecular weight of fewer than two .The most potent ACE inhibitory action was shown by ku. In essential hypertensive rats (SHR), Liu Lichuang et al. discovered that pepsin hydrolysate, trypsin hydrolysate, and a complex hydrolysate containing spirulina protein greatly prevented the rise in blood pressure. Furthermore, the compound enzyme hydrolysate and trypsin shown encouraging therapeutic benefits on hypertension. Spirulina protein delivery by itself, however, showed no discernible effect on SHR hypertension, suggesting that the peptides produced under the three hydrolysis conditions possessed strong antihypertensive properties.

Immune regulation

The immune system's malfunction has a direct correlation to the onset and progression of diabetes, age-related illnesses, and cancerous growths. Spirulina's biological effects and immune mechanism have been well studied, and this indicates that spirulina may one day be used to prevent immune problem diseases. A number of active components found in spirulina, including phycocyanin, carotenoids, spirulina polysaccharides, and gamma-linolenic acid, help strengthen the immune system. Defence mechanisms. Its main mode of action is to stimulate bone marrow cell proliferation and the development of immunological effector cells, such as T cells, B cells, and macrophages. Furthermore, phytohemagglutinin, which stimulates lymphocyte transformation and enhances lymphocyte activity, can be promoted by phycocyanin. Polysaccharide from Spirulina algin has been shown by Lv Xiaohua et al. to have immunomodulatory effects and to improve peripheral blood monocyte proliferation in patients with chronic hepatitis B. The polysaccharide from Spirulina platensis can dramatically boost the quantity of antibody-producing cells and the activity of NK cells, according the research done by Xu Jiaohong et al. The findings imply that Spirulina platensis polysaccharide can boost mice's humoral immunity and NK cell function. By mainly boosting bone marrow cell proliferation and encouraging the development of immune effector cells including macrophages, T cells, and B cells, phycocyanin can improve immune function. Furthermore, in order to enhance lymphocyte activity and induce lymphocyte transformation, phycocyanin can support phytohemagglutinin.

Anti-cancer Action

Because cancer progresses gradually, it is appropriate to use natural, synthetic, or biological agents to reverse, slow, or prevent the formation of tumors and associated transition into malignant malignancies and to stop invasive or metastatic illnesses from happening. The key ingredient in spirulina, phycocyanin, is non-toxic, water-soluble, and has some stability. It has been thoroughly examined and used in numerous research projects. It was found by Bobbili et al. and Fan Min, respectively, that phycocyanin can kill free radicals and cause apoptosis in AK-5 tumor cells and Hela cells from human cervical cancer. Moreover, polysaccharide from Spirulina platensis has been shown to slow the growth of S180 transplanted tumors in mice and postpone the cell additionally, research has shown that lung cancer cells can undergo apoptosis when exposed to high phycocyanin concentrations. Research by MAHMOUD et al. demonstrated that spirulina significantly inhibited A-fetoprotein, increased survival rates, and had an impact on tumor regression.

Tumor markers, enhanced hepatocellular carcinoma biomarkers, and decreased hepatoma pathology. These results imply that spirulina may be a promising hepatocellular cancer treatment.

Uses of Spirulina

Use in dairy products

Utilization in dairy goods Yogurt's hardness can be improved and its water solubility decreased by the water-soluble protein phycocyanin. When spirulina powder is combined with yogurt during the preparation process, it produces yields a hard, curd-like yogurt that is vivid green in color and has a strong spirulina and frankincense scent. When making cheese, it's best to create the soft cheese in advance, add salt, and freeze it with 1% spirulina powder. After stirring the mixture, refrigerate it. Spirulina can lower moisture content, increase protein and beta-carotene content, and extend the shelf life of soft cheese.

Uses in spirulina in medicine

Utilizing spirulina in medical applications producing medication delivery systems. As a naturally occurring porous carrier, spirulina may be used to make medication carriers. Its potent drug adsorption ability is facilitated by the large
concentration of cell wall proteins, polysaccharides, amino acids, fatty acids, and other materials on its cell surface. By modifying elements like pore size, surface characteristics, and particle size, the spirulina-based drug carrier may successfully regulate the medication's release characteristics and rate of dissolution. Spirulina also has the ability to maintain the chemical and biological characteristics of medications, extend their half-lives in the body, and improve the efficacy of pharmacological therapy as a drug carrier. For the management of liver disease. Nutrients with anti-inflammatory and antioxidant qualities including beta-carotene and lutein are found in abundance in spirulina. These nutrients can protect liver cells from the damaging effects of inflammation and oxidative damage, preserving their health. Furthermore, the wide range of minerals and beneficial compounds included in spirulina can support general liver health by preventing liver problems such as cirrhosis and hepatitis. Research has demonstrated that spirulina-extracted polysaccharides hinder the hepatitis C virus's ability to replicate, indicating a possible use for these compounds as a hepatitis C treatment.

**Uses of spirulina in cosmetics**

Spirulina being used in cosmetics Carotenoids and vitamin E, two antioxidant-rich compounds that efficiently fend off free radicals, protect the skin from pollution and oxidative damage, and have anti-aging qualities, are abundant in spirulina. Moreover, spirulina has a wealth of naturally occurring moisturizing agents. Additionally polysaccharides, which support a supple and smooth complexion by preserving skin moisture. Spirulina's peptides promote the production of collagen, which makes skin firmer and more elastic. Furthermore, the sulfides in spirulina have some anti-inflammatory properties that help reduce skin irritation and inflammation. Additionally, lutein and carotenoids—natural whitening chemicals found in spirulina—effectively limit the manufacture of melanin, diminishing the appearance of dullness and dark patches.

**Spirulina used in biofuels and its application**

Spirulina in the production of biodiesel and its applications. With about 25 grams of oil extractable from every 100 grams of spirulina, spirulina has a high oil content. These oils are a prospective source of raw materials for the manufacturing of biodiesel because they are high in unsaturated fatty acids, which can be extracted and converted into the fuel biodiesel.

Generation of biogas. Spirulina produces a significant amount of oxygen and hydrogen during photosynthesis in the presence of light. These gases are renewable resources that can be used as clean energy sources found in a variety of gadgets, such as fuel cells. Furthermore, spirulina may be fermented into biogas in anaerobic environments, which makes it a competitive substitute for natural gas. Cut back on emissions of greenhouse gases. Spirulina is a very effective carbon dioxide absorber. It may successfully trap a significant quantity of carbon for the generation of biodiesel and biogas, as well as use carbon sources for growth. These fuels have reduced carbon emissions and help to mitigate climate change and environmental pollution. In conclusion, spirulina has a wide range of possible uses in biofuels.
Conclusion

These days, the growing global population, waste products from animal agriculture polluting the environment, and rising greenhouse gas emissions from animal agriculture eduction activities, a significant contributor to climate change worldwide

Since spirulina in particular is so nutrient-dense and has even been shown to be non-toxic, it is safe to eat and is advised for human consumption. We may draw the conclusion that consuming spirulina has a plethora of advantages, including far higher levels of important nutrients, bioactive substances, physiological health benefits, and non-toxicity, to mention a few. Therefore, it can be said that spirulina represents a promising substitute for feeding the world’s future and combating hunger and other nutritional problems.

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