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Review Article

Spirulina: A Miraculous Nutraceutical with Multifarious Biomedical and Biotechnological Applications

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Abstract

The present mini-review discusses *Spirulina*: A multifarious nutraceutical with biomedical and biotechnological applications. *Spirulina* is a blue-green microalgae with diverse biotechnological and biomedical applications. It has also been well known as Single Cell Protein (SCP) due to its multifarious nutraceutical properties, including in pharmaceuticals, food industry, agriculture, perfumery, cosmetics, tissue engineering, bio-refineries, therapeutic proteins, etc. Its wide applications in treating cancer, alleviating sinus-related problems, detoxification of heavy metal ions, diabetes mellitus, AIDS, and cancer are attributed to its various multifarious bioactive molecules such as beta-carotene, phycocyanin, chlorophyll-a, iron, and calcium. Spirulina is a promising agent through its antioxidant, anticancer, antimicrobial, anti-inflammatory, and other health-promoting and disease-preventive properties.

Keywords: *Spirulina*; blue-green algae; SCP; Nutraceutical; Biomedical applications

Introduction

Spirulina is a multicellular, filamentous blue-green algae i.e., Cyanobacteria belonging to the family Osellatorlaceae. It is a microalga, also known as phytoplankton, which refers to the aquatic autotroph that lives in suspension in the water column and the name encompasses several phyla which are mostly eukaryotes, including photosynthetic prokaryotes called cyanobacteria [1]. It is capable of deriving its energy from sunlight uses carbon dioxide as its carbon source [2], and obtains minerals from the inorganic sources of the environment like other cyanobacteria. *Spirulina* is gram-negative with a cell membrane, cell wall, and an outer membrane.

Nutritional composition of *Spirulina*

Spirulina is an excellent source of various food ingredients. It is rich in protein (70-55%), carbohydrates (30-25%), especially in polysaccharides, dietary fiber, polyphenols, carotenoids, minerals, vitamins, sterols, and essential fatty acids (18%) like the ω-3 PUFAs eicosapentaenoic acid and docosahexaenoic acid. Its nutritional contents vary from region to region due to various factors like tropical weather, strong sunshine, pure water resources, pollution-free environment, and growing conditions. Certain species of *Spirulina* such as Chlorella, Arthrospira, and Tetraselmiare are extensively used in food and feed industries owing to their rich nutrients like minerals, vitamins, antioxidants, (beta carotene, and phycocyanin) phenolic compounds and essential fatty acids [3], carbohydrates [4,5] (Table 1).

Table 1: Courtesy: Ankita and Priyanka, 2024.

	Minerals		Vitamins	
1.	Sodium (Na)	900	Provitamin A	2.330x103IU/Kg
2.	Potassium (K)	1400	(β-carotene)	140
3.	Calcium (Ca)	700	Thiamine	3.5
4.	Magnesium (Mg)	400	Riboflavin	4
5.	Phosphorus (P)	800	Pantothenic acid	0.1
6.	Manganese (Mn)	5	Vitamin B12	0.32
7.	Zinc (Zn)	3	Pyridoxin	0.7
8.	Iron (Fe)	100	Niacin	14
9.	Chromium	0.28	Biotin	0.005
10.	Copper	1.2	Folic acid	0.01
11.	Pigments		Tocopherol	20
12.	Chlorophyll	1	Vitamin E	100 α-tocopherol equiv
13.	Beta carotene	130	Vitamin K	2.2
14.	Phycocyanin	8	Inositol	35
15.	Total Carotenoids	0.35	Bioflavonoids	10

Uses of *Spirulina*

Spirulina has been in use for a long time, which is attributed to its various health-beneficial and disease-preventive bioactive components like protein, dietary fiber, β-carotene,γ-linolenic acid, etc., *Spirulina* is extensively used in the preparation of biscuits, cookies, candies, stylish noodles, beverages, chewing gums, etc. [6,7]. Apart from human food, it is also used to prepare livestock feeds such as poultry, prawns, exotic birds, carp, and canaries [8-10]. Added to these, various commercially available products of *Spirulina* have proved to have the potential to lower the lipid content of the blood, decreasing the WBC content after chemo and radiotherapy treatments [11,12]. *Spirulina* acts as an anti-arthritic, anti-atherogenic, tumor burden inhibiting, and cell degenerating agent [13-16].

Biomedical and biotechnological applications of *Spirulina*

Many studies have reported the biomedical and biotechnological applications of *Spirulina*. Owing to its attractive, health-promoting, and disease-preventive bioactives, it is widely used in food, feed, pharmaceutical, agriculture, cosmetics, and other such industries [4].

Anti-diabetic activity

Spirulina is reported to act as a potential adjunctive therapeutical agent in managing type 2 diabetes [17] and also exhibited its anti-diabetic activity by reducing the blood glucose level, and by improving the insulin level and type-2 diabetes in In vivo experimental rats [18].

Anti-obesity effects

The protein hydrolysate of the *Spirulina* has shown its anti-obesity effects in mice [19]. *Spirulina* powder is investigated to explore its efficacy in combating obesity, diabetes, and inflammation [20]

Spirulina as an anti-oxidant agent

Several studies have revealed the potential anti-oxidant activity of *Spirulina*, which is exhibited by reducing nitric oxide levels, lipid peroxide, activity of mitochondria, and generation of free radicals, that were attributed to the action of β-carotene, tocopherol, and phenolic compounds, [21-23].

Anti-inflammatory effects

Spirulina has proven its anti-inflammatory properties by inhibiting the release of histamine from mast cells [24]. Phycocyanin and

β-carotene, bioactive compounds of *Spirulina* are reported to offer anti-inflammatory effects by blocking the molecules, which cause oxidative stress, and result in inflammation [25-26]

Anti-cancer properties

Several studies have proved the significant anti-cancer and anti-tumor properties of *Spirulina*. Renata et al.,[27] have shown the anti-proliferative effects of S. platensis and its components viz phycocyanobilin and chlorophyllin, and chlorophyll A on several human pancreatic cancer cell lines. The chemopreventive properties of *Spirulina* hs strongly supported its anti-cancer effects against lung cancer cells [28]. The polysaccharides from *Spirulina* have exhibited significant antitumor and anticancer properties by down-regulating the process of angiogenesis and partially controlling the production of interleukin-17 production in Glioma cells [29] (Figure 1).

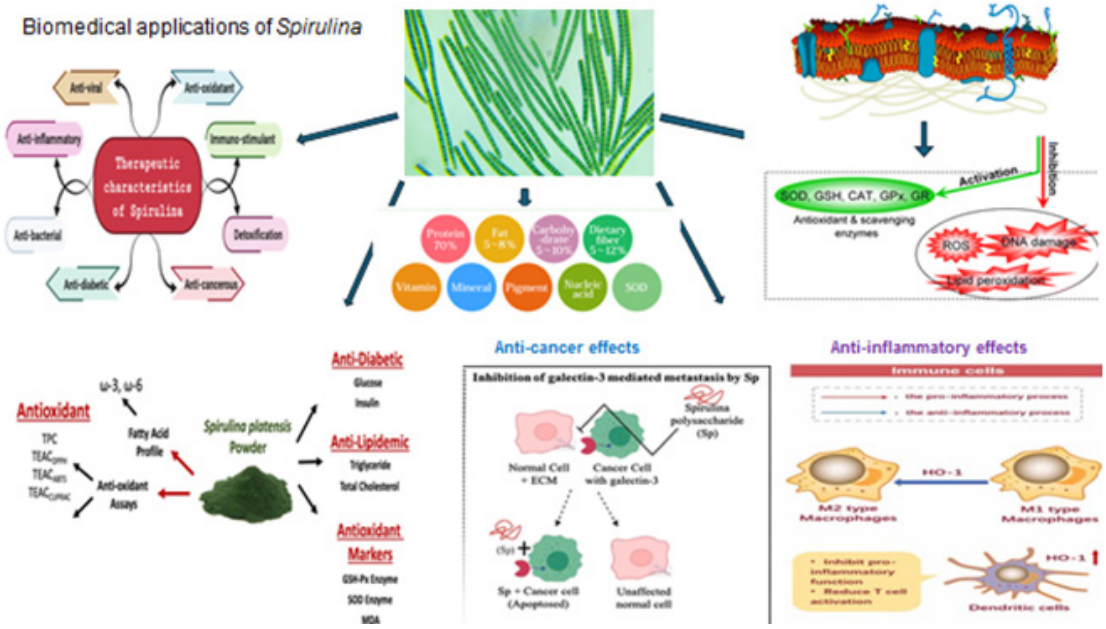

Figure1: Biomedical applications of Spirulina.

Immunomodulatory effects

In animals like humans and fish, *Spirulina* is reported to have significantly modulated the immune system by stimulating the cells of innate immunity, which improves resistance to infections, alters hematopoiesis, and induces antibody and cytokine synthesis [30-31]. Supplementation of *Spirulina* has demonstrated increased oxygen uptake and improved exercise in athletes [26].

Anti-aging effects

The current trend and growing interest of humans towards increasing life expectancy in a youthful appearance have overwhelmingly attracted the cosmetic market in search of anti-aging products [32]. Consequently, due to the health-promoting properties of *Spirulina*, it stands out as a rich source of active bioactive ingredients of diverse natural cosmetic products of luxury markets such as healthy sun-screen, moisturizing, antiwrinkles, antiaging and anti-acne creams [33-34].

***Spirulina* in tissue engineering**

Spirulina polymers have intensively been used as raw materials for tissue engineering scaffolds, which can be used in making devices of bone joining, surgical sutures, vascular grafts, and artificial skin [35] Sang et al.,[36] have demonstrated the potential applications of *Spirulina* and nanofiber in cutaneous wound to facilitate skin regeneration.

***Spirulina* in biorefineries**

Spirulina drives the bio-energy sector extensively [37]. It is used as a raw material in biorefineries, which convert biomass into bio-products, value-added products, and energy [38] (Figure 2)

***Spirulina* in agriculture**

It is well documented by the FAO (Food and Agriculture Organization) in 1981 that chemical fertilizers can be replaced by *spirulina* (blue-green algae), which acts as a Biofertilizer to rebuild the structure of depleted soil. Shy et al.,[39] have reported that the *Spirulina* biomass produced from treatment of aquaculture wastewater can be used as agricultural fertilizers.

***Spirulina* as a nutraceutical**

In recent years, food biotechnology industries worldwide have shifted their focus towards *Spirulina* due to its food and feed production capability. *Spirulina* has extensively been used as food and feed additives owing to its richness in protein, carotenoids like β-carotene, essential fatty acids like γ-linolenic acid, fiber, antioxidants, etc. It has been as a "superfood" and used for the production of a wide range of nutraceuticals, functional foods, and value-added

products by fortifying *Spirulina* with dairy products, confectionaries, beverages, infant foods, bakery products such as biscuits, cookies, energy bars and extruded snacks [40], and commercially they are sold in various forms as tablets, capsules powder, flakes, bars and candies [41].

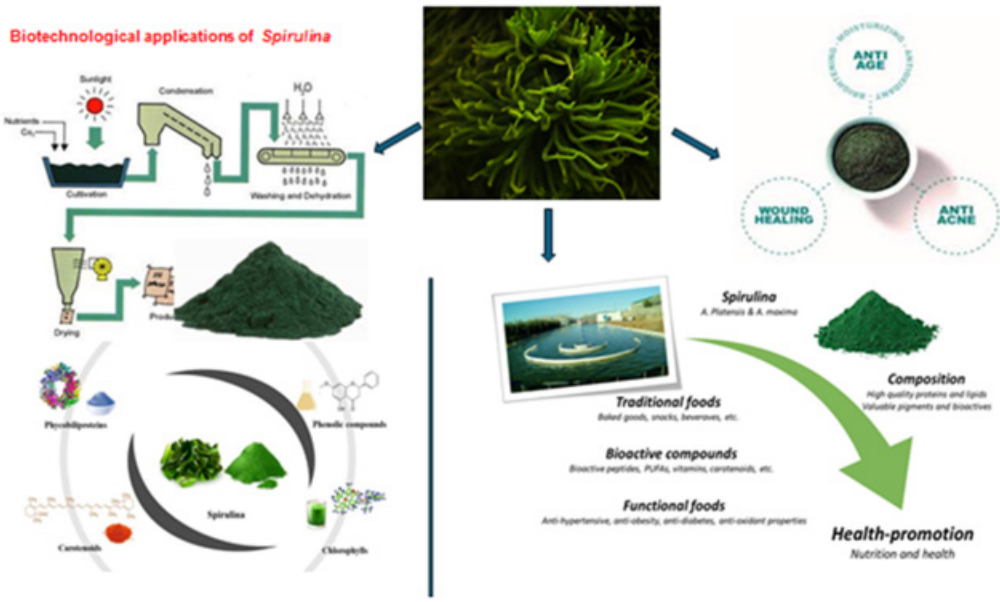

Figure 2: Biotechnological applications of Spirulina.

Conclusion

Spirulina is an excellent nutraceutical source of multifarious food bioactives of disease preventive and health-promoting properties. Its various biotechnological and biomedical applications such as anti-oxidant, anti-diabetic, anti-obesity, anti-cancer, anti-tumor, anti-aging, and immunomodulatory properties owing to its protein, peptides, β-carotene, γ-linolenic acid, phycocyanin, chlorophyll, fiber, vitamins, and minerals have intensively attracted the attention of food and pharmaceutical industries to produce innumerable forms of nutraceutical, functional foods and value-added products to achieve better health and to manage, treat and prevent different life-threatening diseases, including cancer. It is also widely applied in the fields of bio-refineries and renewable energy to produce biofuels and bio-fertilizers to reduce greenhouse gases and minimize the usage of chemical fertilizers, respectively, to prevent environmental pollution and promote health-beneficial effects. However, it still warrants more detailed research in the area of biomedical and biotechnology to enrich the knowledge of the users of its commercial products.

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Authors' Contribution

Authors AVJ & RJ drafted and wrote the manuscript while authors YM., SL & CMFP discussed the findings and supervised the process.

Conflict of Interest

All the authors of this review declare that they have no conflict of interest.

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