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Review article

SPIRULINA: THE BENEFICIAL ALGAE

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Abstract

Arthospira (spirulina) is a photosynthetic, spiral-shaped, multicellular and blue-green alga. Cell division occurs by binary fission. As it contains chlorophyll a, like higher plants botanist classify it as micro alga belonging to Cyanophceae class; but according to bacteriologists it is a bacterium due to its prokaryotic structure. Mexicans started using this microorganism as human food. Its chemical composition contains proteins (55%-70%), carbohydrates (15%-25%) and essential fatty acids (18%) vitamins, minerals and pigments like carotenes, chlorophyll and phycocyanin, pigments are used in food and cosmetic industries. Spirulina is considered as excellent food, lacking toxicity and have anticancer, antiviral, immunological properties and it also acts as a potent antioxidant. There has been a significant change in spirulina functions under stress conditions.

Keywords: Arthospira (spirulina), blue-green alga, pigments, potent antioxidant

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Introduction

Spirulina named as tecuitlatl by Aztecs (Mexicans) that means stone's excrement during 16th century. Later due to outbreak of contagious disease, new customs were adopted by people such as new food, religious and social changes and the topic of tecuitlatl came to an end [1]. *Spirulina*-"small cakes made of mud like algae, which has a cheese-like flavor, and that natives took out of the lake to make bread". They are dried into cakes called "Diha" or "Die".Some of the best worldwide known *Spirulina* producing companies are earthrise farms (USA), Cyanotech (USA), Hainan DIC microalgae co ltd (China) [2].

Morphology

Under light microscopy, the blue-green non-heterocystous filaments, composed of vegetative cells that undergo binary fission in a single plane, show easily visible transverse cross-walls. Filaments are solitary and free floating and display gliding motility. The trichomes, enveloped by a thin sheath, show more or less slightly pronounced constrictions at cross-walls and have apices either slightly or not at all attenuated [3] [4].

Microscopic view of microalgae Spirulina (Cyanobacteria) [4]

Spirulina is characterized by its regularly coiled trichomes. Under some conditions of temperature and pressure, its helical filaments can convert to abnormal morphologies, such as irregularly curved and even linear shapes, that are considered as a permanent degeneration that could not be reversed. However, the linear filaments of *Spirulina platensis* could spontaneously revert to the helical form with the same morphology as the original filaments. The ultra structural, physiological, and biochemical characteristics of linear filaments are different from those of the original filaments, whereas they are the same for the reverted and the original filaments [5].

Ultra-Structure

It is a prokaryotic organization with fibrils of DNA region. *Spirulina* has photosynthetic system, plucri-stratified cell wall, capsule, ribosome and numerous inclusions. Cell wall is made of four membered layers: L1, L2, L3, and L4 [6].

Life cycle

There are three fundamental stages: Trichomes fragmentation, Hormogonia cells enlargement and Maturation processes, and Trichome elongation. Then this mature trichomes get divided into filaments or hormogonia, cells in the hormogonia gets increased by binary fission, grows length wise and takes their helical form[7] [8].

Cultivation of *Spirulina*

Spirulina is a blue green micro alga. It is an excellent source of proteins, beta-carotene, B vitamins and minerals like iron. It is a wonder food especially for the undernourished people. Hence its cultivation is also encouraged in the domestic levels of the developing countries who are the worst victims of chronic malnutrition. *Spirulina* also proves to fetch them good amount of economy. *Spirulina* is a nutritious protein food supplement and is also used in the manufacture of several medicines, and cosmetics. Its cultivation on a commercial scale is slowly catching up with many farmers in India, particularly in Tamil Nadu. *Spirulina* is cultivated both for the commercial purpose as well for the domestic use in certain regions that are badly hit by chronic malnutrition and other deficiency diseases. The domestic house hold level cultivation of spirulina is very beneficial [8][9].

Domestic cultivation of *Spirulina*

The domestic cultivation method is well known as the "Mud Pot *Spirulina* Cultivation". This method requires mud pots of 35 to 40 liters capacity and an exposed but protected open area. The medium for the cultivation is the bio-gas slurry which is very cheap and easily available. Then, the sea-salt, Potassium dihydrogen Phosphate, Cooking Soda and Sodium Chloride, all this is mix for pure *Spirulina* culture. The method of working is very simple. All thees pots are buried till the neck in the ground. These are then filled with water and the slurry medium. Next the pure *Spirulina* culture is added to the pots. These are to be kept in sunlight and need to be stirred at least 4 times a day. After 3-4 days of maturation the *Spirulina* is ready. It is now filtered in clean cloth and then washed in fresh water. *Spirulina* can be immediately used for consumption or if a powdered form is desired it should be dried immediately [10] [11].

Cultivation of *Spirulina* for personal consumption

Spirulina Platensis can be cultivated for personal use in a basin. There are many ways of building an adequate basin depending on variables according to local conditions: out of plastic covers, hard clay, low walls. It is generally useful, to install a greenhouse or at least a roof on the basin to protect it from the bad weather to minimize the risk of contamination. The roof can be made of white or translucent plastic, or other solutions making it possible to let pass a part of the light. To cultivate *Spirulina* it is necessary to recreate the close culture medium in which the micro-algae grows naturally. The culture medium is a controlled salt solution in water that provides to *Spirulina* all the necessary chemical elements essential for its cultivation.
The pH of the culture medium should be between 8.0 and 11 (basic) [12].

Table 1. The composition of the culture medium or solution, for a basin of dimension 4m^2

The compositions of the culture medium or solution, for a basin of dimension 4m^2 (Chemical composition)		**Concentration (gm / liter)**
Sodium Hydrogen Carbonate	$NaHCO_3$	8
Sea salt	NaCl	5
Potassium Nitrate	KNO_3	2
Magnesium Sulphate	$MgSO_4.7H_2O$	0.16
Ammonium Phosphate (monobasic)	$NH_4PO_4.12H_2O$	0.08
Urea	$CO(NH_2)_2$	0.015
Iron Sulphate	$FeSO_4.7H_2O$	0.005

The material used for the cultivation of *Spirulina* is a basic stock of *Spirulina* that can be procured from scientific agencies or *Spirulina* farms. These stocks multiply in the culture medium by themselves also periodical control of the morphology of *Spirulina* may be necessary to exclude mutagen effect due to change in the chemical composition of the culture solution and because of the environmental factors. *Spirulina* are the carbon consuming micro-algae that consume carbon dioxide as in photosynthesis; one can increase the influx of Carbon dioxide, by composting under the greenhouse contiguous to the basin.

The ideal temperature for *Spirulina* Cultivation is between 35°C and 37°C.The water level of the basin should be controlled and it should be a minimum of 20 cm. Water should be added when necessary not impacting the chemical composition or pH of the culture medium. Agitation of the water of the basin is necessary to homogenize and ensure a good distribution of lighting among all the filaments of *Spirulina*. Agitation can be done manually with a clean brush or a wheel, 4 times per day, for 2 minutes. *Spirulina* is harvested by skimming the surface of the basin and to initially filter *Spirulina* in a filter such as a mosquito net. It is further filtered in a filter of dimensions of 60 microns. *Spirulina* collected after filtration and reduced in fine powder is stored in plastic bag/container. Though *Spirulina* can be consumed fresh, it can also be used after slight drying. It is better to consume *Spirulina* within 6 hours of its harvest but can be preserved for later consumption for a period of up to one year by drying it in the sun or in a solar drier. To store *Spirulina* for a much longer time, it is vacuum dried and packed air-tight where it sustains its nutritional qualities for five years [11] [13].

Commercial Cultivation

Spirulina is a simple, one-celled form of blue-green algae that gets its name from its spiral shape. The product is currently being hailed as the super food of the future because of its exceptional nutritional content. *Spirulina* is a better source of protein than either beef or soyabean. The process involves inoculation of *Spirulina* culture in tanks having mechanized agitators to oxygenate the water. About 20-25 gm of *Spirulina* grows in 1.0 sq. meter surface area of water in a day. The blue-green algae is removed from water surface and allowed to dry before purification and production of powder by spray drying process. It can be produced in very low cost and high cost depending upon the quality standard of infrastructure facility, production quality parameters and standardization of product followed .Internationally, customer are willing to pay for the product is premium price and so high end technology can equally viable as in the case low end. A lot of value added health drinks and products can be generated by using this alga. The

Spirulina that is to be used for the commercial purpose is cultivated in a different way. The commercial *Spirulina* is grown open-channel shallow artificial ponds. Here, the paddle-wheels are used to stir the water so as to accelerate the growth of *Spirulina*. The largest commercial production of *Spirulina* is carried out in United States, Thailand, India, Taiwan, China, Pakistan and Myanmar [13].

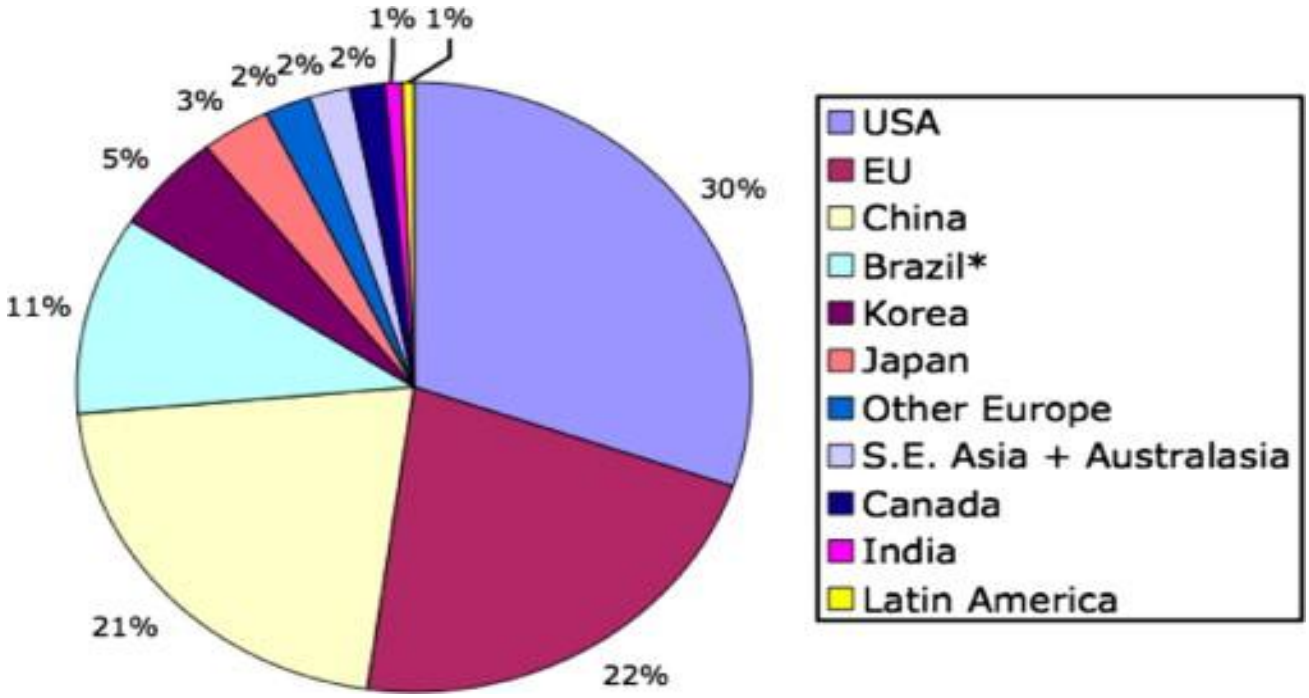

Fig. 1 Global assessment of research and development for algae biofuel production and its potential role for sustainable development in developing countries

Laboratory cultivation

Eight major environmental factors influence the productivity of *Spirulina*: luminosity (photo-period 12/12,4 luxes), temperature (30 °C), inoculation size, stirring speed, dissolved solids (10–60 g/liter), pH (8.5–10.5), water quality, and macro and micronutrient presence (C, N, P, K, S, Mg, Na, Cl, Ca and Fe, Zn, Cu, Ni, Co, Se) [14].

Small-scale commercial production of *Spirulina*

Spirulina cultivation has a number of advantages over traditional agriculture:

High yield

With around 60 percent protein content, *Spirulina*'s rapid growth means it yields 20 times more protein per unit area than soybeans, 40 times more than corn, and over 200 times more than beef.

Soil requirements: *Spirulina* culture does not require fertile land and can actually benefit from saline conditions.

Efficient water use: *Spirulina* uses less water per kilo of protein (approximately 2100 liter/kg protein) than other crops. Water can be recycled and the only significant water loss is through evaporation. *Spirulina* culture uses 25 percent of the water of soya, 17 percent of corn and 2 percent the water required for beef protein. As mentioned above, brackish or saline water can be utilized [14].

Efficient source of energy

Spirulina requires less energy input per kilo than soya, corn or beef, including solar and generated energy. Its energy efficiency (food energy output/kg/energy input/kg) is five times higher than soya, two times higher than corn, and over 100 times higher than grain-fed beef. The small-scale production of *Spirulina* is considered as a potential income-generating activity for households or village collectives. *Spirulina* might be also dried and processed for local consumption, especially where poor dietary regimes need to be supplemented. In addition, the extensive or semi intensive production of *Spirulina* for animal or aquatic feeds might be conducted for small-scale farming and aquaculture. As early as 1949, Spoehr and Milner (1949) suggested that the mass culture of algae would help to overcome global protein shortages. Ironically, in spite of the lamentably low per capita protein supplies in many parts of the world, mass cultivation of algae has received only casual interest. The United Nations Environmental Programme (UNEP) is emphasizing nitrogen fixation and nutrient recycling through a programme that will establish microbiological centers (MIRCENS), and it is hoped that this will stimulate interest in micro-algae technology as a component of an integrated recycling system for rural communities [14].

***Spirulina* indeed lends itself to simple technology**

Cultivation may be carried out in unlined ditches through which flow is low (e.g. 10 cm/second). Stirring may be provided by a simple device driven by wind energy or harnessed to humans. Harvesting mat be readily performed using some suitable cloth, and the biomass dehydrates in the sun. The quality of the *Spirulina* product obtained in this fashion would not be as high as what is attained in clean cultures, but product could serve well as animal feed. In Bangladesh, *Spirulina* was produced through a pilot project using paddle-wheel under transparent shade in the campus of BCSIR (Bangladesh Council for Scientific and Industrial Research) in 1980s. Later BCSIR established a system for the rural culture of *Spirulina*. In India, the Murugappa Chettiar Research Centre in Chennai has developed the technology and this has been successfully propagated on a large scale in the rural areas of Pudukottai district of Tamil Nadu. For instance, mud pot *Spirulina* production uses a medium consisting of biogas slurry, 2–3 g of sea salt or chemical medium (potassium dihydrogen phosphate, cooking soda and sodium chloride) and pure *Spirulina* culture [7] [9].

Production of *Spirulina* in organic nutrients including waste effluents may contest with the cost effectiveness. In Nigeria waste water is used for cultivation of *Chlorella* and *Spirulina.* Alternate use of organic nutrient source, waste water effluent available in rural source The fertilizer factory waste on an average contained phosphate-P (107–187 ppm), nitrate-N (3.0–4.0 ppm), sulfate SO4-2 (146–150 ppm), had a pH of 7.4–8.5 and electric conductivity of 700–2457 µmhos/cm. This physico-chemical status of fertilizer factory waste is suitable for the growth of *Chlorella* and *Spirulina*. Approximately, 11.0 percent (w/w dry matter) as no. of *Spirulina* was obtained when cultured in 50:50 mixture of effluent and filtered sea water (pH 8.30) after 21 days [9].

Commercial and mass cultivation

The main commercial large-scale culture of microalgae started in the early 1960s in Japan with the culture of *Chlorella*, followed by *Spirulina* in the early 1970s at Lake Texcoco, Mexico.

Spirulina is produced in at least 22 countries: Benin, Brazil, Burkina Faso, Chad, Chile, China, Costa Rica, Côte d'Ivoire, Cuba, Ecuador, France, India, Madagascar, Mexico, Myanmar, Peru, Israel, Spain, Thailand, Togo, United States of America and Viet Nam. The total industrial production of *Spirulina* is about 3000 tons a year [13].

Mass cultivation of *Spirulina*

Spirulina is usually carried out in shallow ponds, equipped with paddle wheels to mix the culture. Two types of open raceway ponds are typically used: the first is lined by concrete and is therefore expensive, the second is a shallow earthen tunnel lined with polyvinyl-chloride (PVC) or some other durable plastic material. Lining of the raceways increases the cost of production of algal biomass, hence the search for cheaper material and processes, such as low-cost clay sealing. The surface of commercial raceways varies from 0.1 to 0.5 hectares and culture depth is usually maintained at 15–18 cm. The paddle wheel, large (with a diameter up to 2.0 m and a speed of 10 rpm) or small (with a diameter of 0.7 m and a speed 2 to 3 times faster than 2.0 m diameter paddle wheel), is the most common stirring device. One difficulty of this paddle stirring is that the flow is not sufficiently turbulent to produce an optimum light pattern for single-cell algae. Thus, other means were used to increase turbulence in shallow ponds or raceways, and consequently photosynthetic efficiency [14].

Contamination by different algal species may present a severe problem for microalgal cultures grown in outdoor open ponds. In most cases, the steps that proved effective in prevention of *Chlorella* contamination were maintaining a high bicarbonate concentration (e.g. 0.2 M), taking precautions to maintain the dissolved organic load in the culture medium as low as possible, and increasing winter temperature by greenhouse heating. Development of grazers in the culture, mainly the amoebae type, was prevented by the addition of ammonia (2mm). Experience indicates that contaminating organisms do not present a serious difficulty as long as good growth is maintained in a mono-algal culture [15].

The whole process consists of eight steps (consisting harvesting, processing and packing):

1) **Filtration and cleaning**: A nylon filter at the entrance of the water pond is needed.
2) **Pre-concentration**: To obtain algal biomass which is washed to reduce salts content.
3) **Concentration**: To remove the highest possible amount of interstitial water (located among the filaments)
4) **Neutralization**: To neutralize the biomass with the addition of acid solution.
5) **Disintegration**: To break down trichomes by a grinder.
6) **Dehydration by spray-drying**: This operation has great economic importance since it involves about 20–30 percent of the production cost.
7) **Packing**: It is usually in sealed plastic bags to avoid hygroscopic action on the dry *Spirulina*.
8) **Storage**: Stored in fresh, dry, unlit, pest-free and hygienic storerooms to prevent *Spirulina* pigments from deteriorating [16] [17].

Phytonutrients in *Spirulina*

Spirulina is a hard-core super food, non-toxic, absorbable nutrients and considered one of the most nutritious food on Earth [18] [19]. It is microscopic blue - green algae, often called as nature's perfect food because of its abundant nutritional profile. It is one of the most easily digestible and quickly assimilated sources of protein and also one of the richest food sources of protein, chlorophyll and beta-carotene. It also provides the benefits of vitamins and essential minerals from a whole food. *Spirulina* phytonutrients are extremely beneficial to the human body

as it can increase the immune system of the body. Phytonutrients are special compounds that are present in *Spirulina* that has different abilities to ensure good health to everyone. Dried *Spirulina* contains about 60% (51–71%) protein [7]. It is a complete protein source containing all essential amino acids, though with somewhat reduced amount of methionine, cysteine and lysine as compared to the proteins of meat, eggs and milk. It is superior to typical plant protein like legumes [2] [7] [20].

The main Pigments found in *Spirulina* are

Chlorophyll

The most visible pigment in *Spirulina* is chlorophyll. Chlorophyll is sometimes called green blood because of its similarity to the hemoglobin molecule found in human blood cells. Chlorophyll is known as the cleansing and detoxifying phytonutrients, increases peristaltic action and thus relieves constipation. It also normalizes the secretion of digestive acids. In addition, *Spirulina* soothes the inflammation and reduces the excess pepsin secretion associated with gastric ulcers. It has antiseptic qualities as it reduces swelling and promotes granulation- a process that regenerates new tissue over injuries, promotes regeneration of damaged cells and improves overall efficiency of cardiac work.

Carotenoids

Spirulina is the richest food source of beta-carotene which is a Vitamin A precursor. It has 21 times more beta carotene than raw carrots and with a spectrum of 10 mixed carotenoids, about half are orange carotene. These are alpha, beta and gamma. These components are half xanthophylls which work synergistically at different sites in our body to enhance healthy eyes and vision and antioxidant protection.

Phycocyanin

It is a brilliant blue polypeptide which is a source of biliverdin (a green pigment excreted in bile) which is most potent intra-cellular antioxidants and related to human pigment bilirubin and stem cells. Its components are important to healthy liver function and digestion of amino acids.

Porphyrin

Porphyrin is a red compound that forms the active nucleus of hemoglobin. It is essential for the formation of red blood cells. It is used as a chelator for heavy metal toxicity and circulation problems. Porphyrins have the ability to bind divalent metal ions due to the nitrogen atoms of the tetrapyrrole nucleus.

The central ion in chlorophyll is magnesium, which is freed from chlorophyll under acidic conditions permitting other metals to bind in its place. Toxic metals, such as mercury, lead and arsenic, are complexed first then excess amounts of other divalent metals, such as calcium, can be complexed by porphyrins. By increasing the porphyrin content, the heavy metal binding capability is also increased, providing clinicians with a natural, effective “chelating” tool.

Enzymes

Spirulina contains a number of enzymes. One of the most significant enzymes is superoxide dismutase (SOD), which is important in quenching free radicals and in retarding aging. This essential enzyme is crucial to the body’s ability to assimilate amino acids. Without SOD's presence in the body, we are unable to create the 10,000’s of long, complex chains of amino acids known as proteins. In fact, *Spirulina* is so high in enzyme activity that even after being dried (at 160 ºC) it will often start growing again if placed in the right medium, temperature and

sunlight. *Spirulina* has been scientifically demonstrated to increase reproduction of lacto-bacilli (bacteria that digests our food). It contains over 2000 different enzymes [21] [22].

Table 2:- Composition of phytonutrients of *Spirulina* [23]

Phytonutrients	
Alpha-carotene Xanthophylls Cryptoxanthin Echinenone Zeaxanthin Leutin	Traces 1000mg 556mg 439mg 316mg 289mg
Beta-carotene 9-cis Beta-carotene 13-cis Beta-carotene 15-cis Beta-carotene all-trans Chlorophyll Total carotenoids Phycocyanin Superoxide Dismutase	1.60 mg 0.51 mg 0.12 mg 7.80 mg 23.70 mg 14 mg 333 mg 2040 units

Nutritional Benefits of *Spirulina* Phytonutrients

Carotenoids, including zeaxanthin and beta-carotene

Support immune health, protect against age-related vision loss, protects skin from the effects of UV radiation [21]. *Spirulina* contains 4,000 mg/kg carotenoids.

Phycocyanin, (gives *Spirulina* its blue color)

Supports liver and kidney functions, key to detoxifying the body [19].

Bio-Chelated Iron

Prevents anemia, supports blood health [19].

B-Vitamins

Vitamin B, especially B-12 is essential for nerve health and healthy hair [21].

GLA Fatty Acid

GLA supports sexual and menstrual health, reducing symptoms of PMS. Also helps balance mood swings, and reduces inflammation [24].

Protein

Protein in *Spirulina* includes all essential amino acids which supports blood sugar levels and reduces appetite [12] [8].

Health benefits

This article is an attempt to introduce the basic composition of *Spirulina* and its biomedical applications. *Spirulina* spp. and its processing products are employed in agriculture, food

industry, pharmaceutics, perfumery and medicine. *Spirulina* has several pharmacological activities such as antimicrobial (including antiviral and antibacterial), anticancer, metalloprotective (prevention of heavy-metal poisoning against Cd, Pb, Fe, Hg), as well as immunostimulant and antioxidant effects due to its rich content of protein, polysaccharide, lipid, essential amino and fatty acids, dietary minerals and vitamins. For each application the basic description of disease, mechanism of damage, particular content of *Spirulina* spp. for treatment, *in vivo* and/or *in vitro* usage, factors associated with therapeutic role, problems encountered and advantages are given [7] [8] [13] [20].

***Spirulina* is the richest beta carotene food, with a full spectrum of ten mixed carotenoids**

About half are orange carotenes: alpha, beta and gamma and half are yellow xanthophylls. They work synergistically at different sites in our body to enhance antioxidant protection. Twenty years of research proves eating beta carotene rich fruits and vegetables give us real anti-cancer protection. Synthetic beta carotene has not always shown these benefits. Research in Israel showed natural beta carotene from algae was far more effective. Natural is better assimilated and contains the key 9-cis isomer, lacking in synthetic. As suspected, natural carotenoids in algae and vegetables have the most antioxidant and anti-cancer power [25].

***Spirulina* is an ideal anti-aging food**

Concentrated nutrient value easily digested and loaded with antioxidants. Beta carotene is good for healthy eyes and vision. *Spirulina*'s beta carotene is ten times more concentrated than carrots. Iron is essential to build a strong system, yet is the most common mineral deficiency. *Spirulina* is rich in iron, magnesium and trace minerals, and is easier to absorb than iron supplements. *Spirulina* is the highest source of B-12, essential for healthy nerves and tissue, especially for vegetarians [26].

Healthy Dieting with *Spirulina*

About 60% of *Spirulina*'s dry weight is protein which is essential for growth and cell regeneration. It is a good replacement for fatty and cholesterol-rich meat and dairy products in diet. Every 10 grams of *Spirulina* can supply up to 70% of the minimum daily requirements for iron, and about three to four times of minimum daily requirements for vitamins A (in the form of beta carotene), B complex, D, and K. But it does not contain vitamin C, but it helps maintain this vitamin's potency. *Spirulina* is rich in gamma-linolenic acid or GLA, a compound found in breast milk that helps in the development of healthier babies. Moreover, with its high digestibility, *Spirulina* has been proven to fight malnutrition in impoverished communities by helping the body to absorb nutrients when it has lost its ability to absorb normal forms of food. Another health benefit of *Spirulina* is that it stimulates beneficial flora like *lactobacillus* and *bifidobacteria* in the digestive tract to promote healthy digestion and proper bowel function. It acts as a natural cleanser by eliminating mercury and other deadly toxins commonly ingested by the body. *Spirulina* also increases stamina and immunity levels in athletes, and its high protein content helps to build muscle mass. At the same time, it can control hunger that may develop during the most demanding training routines. Thus, it indirectly acts as an effective way to maintain an athlete's ideal body weight [27].

The Disease Fighter

Spirulina contains other nutrients such as iron, manganese, zinc, copper, selenium, and chromium. These nutrients help to fight free radicals, cell-damaging molecules absorbed by the body through pollution, poor diet, injury, or stress. By removing free radicals, the nutrients help the immune system to fight cancer and cellular degeneration. *Spirulina* helps to reduce oral

cancer tumors in laboratory rats, and may thus provide a big medical breakthrough in cancer treatment. *Spirulina*'s ability to reduce the bad cholesterol LDL in the body helps to prevent the onset of cardiovascular diseases, such as hardening of the arteries and strokes. It also helps to lower blood pressure. While not clinically proven, *Spirulina* may also protect against allergic reactions and liver infection. Research confirms *Spirulina* promotes digestion and bowel function. It suppresses bad bacteria like E-coli and Candida yeast and stimulates beneficial flora like lactobacillus and bifido-bacteria. Healthy flora is the foundation of good health and it increases absorption of nutrients from the food we eat and helps to protect against infection. *Spirulina* builds healthy lactobacillus, aiding assimilation and elimination and relieving constipation [28].

Removing Toxins

In 1994, a Russian Patent was awarded for *Spirulina* as a medical food to reduce allergic reactions from radiation sickness. 270 Children of Chernobyl consuming 5 grams a day for 45 days (donated by Earthrise Farms), lowered radionucleides by 50%, and normalized allergic sensitivities. *Spirulina* has a completely unique combination of phytonutrients including chlorophyll, phycocyanin and polysaccharides, which can help to cleanse our body [29].

For beautiful skin

Spirulina is one of the best anti-ageing agents. It nourishes the skin very well. You have to simply add 1 spoon of *Spirulina* to your fruit juice or smoothie. But before eating it out just apply a little bit on your face. Let it dry and then rinse off, then tone and moisturize. See the magic in just 3 weeks. *Spirulina* is loaded with vitamin A (in the form of beta carotene), the antioxidant widely recognised to maintain healthy skin. Beta carotene helps slow the aging of the skin which is caused by UV-radiation. It also helps protect the skin from sunburn. *Spirulina* is also a powerful source of the antioxidant, super oxide dismutase (SOD), that helps oxygenate the skin and helps protect the skin from UV-induced damage. Furthermore, *Spirulina* contains unusually high levels of the polyunsaturated fatty acid *i.e.* gamma linolenic acid (GLA) that contributes to optimal skin elasticity. Eat a good amount of *Spirulina* everyday along with carrots, sprouts, oatmeal, oranges, lemons, pumpkin, parsley, purified water and herbal teas. [29].

Anticancer Effects

It has been argued that the combined antioxidant and immune modulation characteristics of *Spirulina* may have a possible mechanism of tumor destruction and hence play a role in cancer prevention. While there are many animal and in vitro studies, there has been only one trial with human subjects. This study looked specifically at the effects of *Spirulina* on oral carcinogenesis, in particular leukoplakia. It is not surprising that few human studies exist to date as cancer prevention trials with lower cancer incidence as an endpoint have logistic problems, rendering them essentially impossible to conduct for most malignancies. The study conducted by Mathew *et al*., (1995) on a cohort of 77 patients originates from previous trials on hamsters that showed tumor regression after topical application or intake of *Spirulina* extract. They reported that 45% of their study cohort showed complete regression of leukoplakia after taking *Spirulina* supplements for 1 year. The authors also reported that there was no rise in the serum concentration of retinal β-carotene despite supplementation and concluded that other constituents within *Spirulina* may have been responsible for the anticancer effects. Even as their results appear promising, it was an unblinded, non-randomized trial and as such cannot be regarded as evidence of a positive effect [30].

Chronic Arsenic Poisoning: A Randomized Trial

Millions of people in Bangladesh, India, Taiwan and Chile are consuming high concentration of arsenic through drinking water and are at risk of chronic arsenic poisoning for which there is no specific treatment. A placebo-controlled, double-blind study was conducted to evaluate the effectiveness of *Spirulina* extract plus zinc in the treatment of chronic arsenic poisoning. Forty-one patients with chronic arsenic poisoning were randomly treated by either placebo (17 patients) or *Spirulina* extract (210mg) plus zinc (2mg) (19 patients) twice daily for 16 weeks. Each patient was supplied with arsenic-safe drinking water by installing a locally made water filter at household level. Effectiveness of *Spirulina* extract plus zinc was evaluated by comparing changes in skin manifestations (clinical scores) and arsenic contents in urine and hair, between the placebo and *Spirulina* extract plus zinc-treated groups. Results showed that *Spirulina* extract plus zinc twice daily for 16 weeks may be useful for the treatment of chronic arsenic poisoning with melanosis and keratosis [31].

Antioxidant and Antiproliferative activity: Treatment for Liver Cirrhosis

Liver fibrosis is a chronic liver disease that will develop to cirrhosis if severe damage continues to form. A potential treatment for liver fibrosis is to inhibit the activated hepatic stellate cell (HSC) proliferation or by inducing apoptosis of HSC. It was shown that spirulina inhibit the proliferation of HSC at the G2/M phase by its antioxidant activity [32]. The main component of spirulina which play antioxidant role is C-phycocyanin. This study was shown on HepG2 cells (Human liver cancer cells)[33].

***Spirulina* and Chronic Fatigue**

Spirulina has been promoted as “the food of the future" with “exceptional constituents" that contribute to high energy levels. A few of these constituents such as polysaccharides (Rhamnose and Glycogen) and essential fat (GLA) are absorbed easily by human cells and help in energy release. *Spirulina* increases healthy lactobacillus in the intestine enabling the production of Vitamin B6 that also helps in energy release. Despite this promotion, the only available placebo-controlled randomized trial showed that the scores of fatigue were not significantly different between *Spirulina* and placebo. *Spirulina* administered at a dose of 3g day^{-1} did not improve fatigue more than the placebo in any of the four subjects and possibly it has no effect on chronic fatigue [34] [35].

Allergy, Rhinitis, and Immunomodulation

It has been well documented that *Spirulina* exhibits anti-inflammatory properties by inhibiting the release of histamine from mast cells. In randomized, double-blind placebo-controlled trial, individuals with allergic rhinitis was fed daily, either with placebo or *Spirulina* for 12 weeks. Peripheral blood mononuclear cells were isolated before and after the *Spirulina* feeding and levels of cytokines (interleukin-4 (IL-4), interferon-γ (IFN-γ) and interleukin-2(IL-2)), which are important in regulating immunoglobulin (Ig) E-mediated allergy, were measured. Results showed that high dose of *Spirulina* significantly reduced IL-4 levels by 32% demonstrating the protective effects of this microalga toward allergic rhinitis. *Spirulina* has on IgA levels in human saliva and demonstrated that it enhances IgA production, suggesting a pivotal role of microalga in mucosal immunity. A Japanese team identified the molecular mechanism of the human immune capacity of *Spirulina* by analysing blood cells of volunteers with pre- and post-oral administration of hot water extract of *Spirulina platensis*. IFN-γ production and Natural Killer (NK) cell damage were increased after administration of the microalga extracts to male volunteers. In a recent double-blind, placebo-controlled study from Turkey evaluating the effectiveness and tolerability of *Spirulina* for treating patients with allergic rhinitis, *Spirulina*

consumption significantly improved the symptoms and physical findings compared with placebo including nasal discharge, sneezing, nasal congestion and itching. It is well understood that deficiency of nutrients is responsible for changes in immunity, which are marked as changes in production of T-cells, secretory IgA antibody response, cytokines and NK-cell activity [36].

Antiviral Applications: In Vitro Studies

There are no *in vivo* studies providing strong evidence supporting the possible antiviral properties of *Spirulina*. The active component of the water extract of *S. platensis* is a sulfated polysaccharide *i.e.* calcium spirulan (Ca-Sp). According to Hayashi *et al*., (1990) Ca-Sp (calcium spirulan) inhibits the *in vitro* replication of several enveloped viruses including Herpes simplex type I, human cytomegalovirus, measles and mumps virus, influenza A virus and human immunodeficiency virus-1 virus (HIV-1) [37].

In vitro study by K. Ishii *et.al.* (1999) showed that an aqueous extract of *S. platensis* inhibited HIV-1 replication in human T-cells, peripheral blood mononuclear cells and Langerhan cells. The advantage of using herbs and algal products with proven antiviral properties in fighting certain viruses is that they can be used through immune-modulation even when the infection is established [37].

Cholesterol-Lowering Effects and Effects on Diabetes

Cardiovascular disease remains the first cause of death in developed countries, despite increased awareness and high cholesterol is one of the most important risk factors in atherosclerosis. nakaya *et.al*. (1988) in the first human study, gave 4.2g day^{-1} of *Spirulina* to 15 male volunteers although there was no significant increase in high-density lipoprotein (HDL) levels, they observed a significant reduction of low-density lipoprotein (LDL) cholesterol after 8 weeks of treatment. The atherogenic effect also declined [38].Rama moorthy and Prema kumari (1996) in a more recent study administered *Spirulina* supplements in ischemic heart disease patients and found a significant reduction in blood cholesterol, triglycerides and LDL cholesterol and an increase in HDL cholesterol [39]. Mani. *et.al.*, (2000) in a clinical study, found a significant reduction in LDL: HDL ratio in 15 diabetic patients who were given *Spirulina*. However, this study suggested that small *Spirulina* can be recommended in diabetes [40].

Thus positive effects of *Spirulina* in allergic rhinitis are based on sufficient evidence but larger trials are required. The anticancer effects of *Spirulina* are perhaps derived from β-carotene (antioxidant); however, the link between β-carotene level and carcinogenesis cannot be regarded as reason of carcinoma. There are some positive studies on the cholesterol-lowering effects of *Spirulina* but larger studies are required before any definitive conclusions can be made. Finally, there are no high-level evidence trials on the role played by *Spirulina* in chronic fatigue and in antiviral applications. At the moment, the literature suggests that *Spirulina* is a safe food supplement without significant side-effects but its role as a drug remains to be seen [41] [42] [43] [44].

Antiinflammatory activity of Spirulina

In vivo as well as *in vitro* studies on spirulina have shown anti-inflammatory activity which is because of C-phycocyanin (C-PC) a biliprotein. C-Pc shows this anti-inflammatory activity by inhibiting pro-inflammatory cytokine formation. Further it was shown that not merely proinflammatory cytokine has to be inhibited but rather along with them inducible nitric oxide synthase (iNOS) and cyclooxygeanase-2 (COX-2) expression has to be inhibited for anti-inflammatory activity of spirulina [45].

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