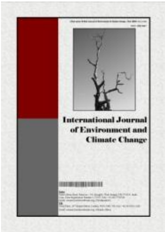

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Reducing the Carbon Footprint by Cultivating and Consuming Spirulina: A Mini-review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Increased carbon emissions have increased global warming resulting in tremendous changes in the climate factor. Climate change has brought drought, cyclones, floods, tsunami, irregular rainfall patterns threatening food security, cleanwater, etc. To reduce the impacts of global warming that are detrimental to humanity and the biosphere, global nations have agreed to reduce carbon emissions and go for a low carbon footprint in all industrial and commercial activities. This study analyzes the cultivation and consuming *spirulina (Arthospira platensis)* as a win-win situation for sustainable development in terms of GDP as well as carbon capture &storage (CCS).

Keywords: Sustainability; carbon capture; bluegreen algae; nutrient rich bioresource; phycocyanin.

1. INTRODUCTION

Natural ways of carbon sequestration are by vegetation in soil, forests, and in oceans as natural sinks. Artificial carbon capture can be done in Geological sinks that can hold thousands of gigatons of carbon in depleted oil and gas reservoirs, deep saline formations, and unminable coal seams. CO2 injection into geological formations for enhanced oil recovery (EOR) is a prominent technology that reduces the viscosity of heavy oil resulting in the release of trapped oil [1]. Phytoliths are silicified forms of plants that get accumulated in soils and

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sediments for hundreds to thousand years**.** Organic carbon present in phytoliths is mainly captured from atmospheric carbon di- oxide during photosynthesis. Phytolithic carbon sequestration in croplands, grasslands, forests, and bamboo lands can be an efficient measure for carbon capture [2]. Microalgae are recognized as the most productive biological systems for biomass production than terrestrial systems due to their short maturation cycle. Carbon di- oxide or bicarbonate capturing efficiencies in their cell structure make them apt for carbon capture from stationary point sources like cement kilns or power stations and nonpoint sources like atmospheric carbon [3]. Constructing algal ponds near industries is a necessary step followed by industries to reduce the carbon footprint [4]. *Spirulina* is a bluegreen algae with spiral filaments under the genus *Arthrospira*, and phylum Oscillatoriaceae. It is a cyanobacteria and contains two pigments green (chlorophyll) that does photosynthesis and fixes carbon di- oxide and blue (phycocyanin) in its cell structure. It is a unicellular micro algae growing in high alkaline conditions 10-12 pH introduced tomodern society by Kanembu tribes of Africa, near Lake Chad. In 1965, the botanist Jean Leonard confirmed that *dihe* consumed by the Kanembu tribe is made up of *spirulina*, and he cultured it in a sodium hydroxide production facility in laboratory conditions [5]. From that time till date *spirulina* is cultured and consumed by trillions of people as it is a GRAS level edible algae. This study involves the particular species *Arthospira platensis* biomass useful to humanity in infinite ways.

2. NUTRIENT PROFILE OF *Spirulina*

Spirulina is rich in exopolysaccharides (15-21%), fatty acids and easily digestible protein (60-70%). It contains a wide array of micronutrients and vitamins. GLA- gamma linolinic acid present in mother's milk is an important constituent that makes *spirulina* nature's mothers milk to humans. As it is rich in chlorophyll, a pigment resembling the structure of hemoglobin in the blood it can fight anemia. It is a rich vegetative source of vitamin B12, cyanocobalamin and is rich in other vitamins also. The micronutrients present are calcium, potassium, chromium, copper, iron, magnesium, manganese, phosphorus, selenium, sodium, zinc, molybdenum, chloride, germanium and boron. Phycocyanin the blue polypeptide present in *spirulina* regulates the production of white blood cells and stem cells thus imparting immuno regulatory nature to the microalgae. Phycocyanin also helps in the formation of blood- hematopoiesis. This versatile nutrient profile of *spirulina* has it approved by WHO as an efficient tool against malnutrition and anemia in children and women. Beta carotene an antioxidant is present that improves eye health and other antioxidants rich property helps to fight free radicals reducing cancer risk and heart attacks [6,7]. In this study compares conventional protein sources like egg and soybean with the nutritional benefits of bioactive peptides present in *spirulina* based on the reports of FAO [8]. All these qualities have given *spirulina* nutraceutical value making it the Great king of microalgal kingdom. Table 1 gives the aminoacid profile of *spirulina* [9].

Table 1. "Aminoacids present in *Spirulina*"

Amino acid	Per 10 gm	% of total	Amino acid	Per 10 gm	% of total
Isoleucine	350 mg	5.6	Cystine	60 mg	1.0
Leucine	540 mg	8.7	Arginine	430 mg	6.9
Lycine	290 mg	4.7	Histidine	100 mg	1.6
Phenylalanine	280 mg	4.5	Threonine	320 mg	5.2
Tyrosine	300 mg	4.8	Proline	270 mg	4.3
Methionine	140 mg	2.3	Valine	400 mg	6.5
Glutamic acid	910 mg	14.6	Alanine	470 mg	7.6
Aspartic acid	610 mg	9.8	Glycine	320 mg	5.2
Tryptophan	90 mg	1.5	Serine	320 mg	5.2

3. SPIRULINA IN AQUACULTURE

Calcium-Spirulan is a unique polymerized sugar that does not allow a virus to penetrate the cell membrane to infect the cell and other polysaccharides of *spirulina* are involved in DNA repair mechanisms and enzymes synthesis in cells (Fig. 1).

Fig. 1. *Spirulina* culture

Thus supplementing *spirulina* as a feed, prevents the animal from viral attack increasing its immune system [5]. By using *spirulina* as fish feed reduces the major production cost which is the feed cost(40-60%) in aquaculture. It also improves the heath of the cultured species, makes the fish species more fit for human consumption by reducing antibiotics and hormones use in the culture, increase disease resistance, and the survival rate of the larvae. The *Spirulina* sp. LEB 18 was cultivated in aquaculture wastewater supplemented with 25% zarrouks medium to obtain biomass of T-25 assay with the highest concentrations of protein (65.73%), phycocyanin (16.60 mg/mL), PUFA (38.20%), and γ-linolinic acid GLA (23.29%). It also showed 90% bioremediation potential with the removal of COD, sulphate, phosphate, and bromine and proved to be ideal for biodiesel applications [10].

4. SPIRULINA AS ANIMALFEED

Spirulina is a promising new feed resource supporting rations of agriculturally significant animals like cattle, cows, pigs, rabbits, poultry showing improvements in productivity, health and product quality [11]. Approximately 20% of dietary *Spirulina* bypasses rumen degradation and is available for direct absorption within the abomasum and increases microbial crude protein production and reduces its retention time within the rumen [12]. This study observed *spirulina* powder supplement in feeds for 125 days culture of abalones and found enhancement in the shell size and protein content of abalones [13]. 3%*spirulina* supplementation along with high energy diet enhanced lipid metabolism, antioxidant capacity, and immune power in Hu lambs of two groups further divided to three subgroups [14]. In a 90days study in 32Najdi lambs divided into four groups aged 3months were fed with *spirulina* diet supplementation of 2ppm, 4ppm, 8ppm concentration. 8ppm concentration showed significance in meat composition, weightgain, nutritional digestibility, and nitrogen utilization [15].

5. SPIRULINA AS A BIOFERTILIZER

This study used *Chlorella vulgaris* and *Spirulina platensis* for sustainable agriculture reducing the use of chemical fertilizers polluting the environment to get 7-20.9% increased yield in rice crops by nitrogen fixation by the microalgae [16]. Cultivation of Spirulina sp. isolated from urban wastewaterfed lakes in outdoor rooftop batch cultures with concentrated wastewaters are a typical zero waste economy converting macronutrients C, N, P in the wastewater into algal biomass with 100% efficiency making them potential biofertilizers [17].

Fig. 2. Collection technique

Jadhav et al. [18] studied the enhancement of soya bean plant growth in terms of plant height, number of branches, and number of leaves by applying BGA fertilizer and obtained positive results. Dineshkumar et al. [19] applied *spirulina* and *chlorella* along with cowdung to the seeds of crops Maize, Onion, Green gram, Black gram, Tomato, and Paddy and concludes that shifting to organic agriculture is possible. Thus sustainable agriculture is close to our hands by using BGA biofertilisers. By applying *spirulina* fertilizer observed enhanced growth of Chinese Cabbage, Chinese broccoli, and Protea White Crown plants from seed germination [20]. Agricultural lands are degraded mostly due to extensive use of chemical fertilizers for the long term and also groundwater table going very low in certain areas causing salt water penetration.The study was conducted *with Triticum aestivum L.* against salinity concentrations of sea water 10% and 25%. Aliquots of 2% liquid extracts from *A.platensis*, stimulated an enhanced protein, antioxidants, carbohydrates and total phenols of the plant in both concentrations of the sea water.Thus *spirulina* biofertiliser can be effective against salinity stress in crop growth [21]. In this review discusses in detail about different mechanisms involved in applying *spirulina* biofertiliser for plant growth**.** Polysaccharides, longchain fatty acids and enzymes secreted by *A.platensis* are antagonistic to plant pathogens as a biocide. It can act as a biostimulant by secretion of growthpromoting phyto hormones like auxins. Various bioactive molecules and antioxidants secreted by the microalgae can act as stress tolerance boosters. The bioremediation potential of *spirulina* improves soil quality by chelating toxic metal ions and the presence of surplus micronutrients and P and nitrogenfixing capacity enhances plant growth. Improving *spirulina* biofertiliser using nanotechnology as algal biochar nanofertiliser is an upgrowing field that improves the phycoprospects of the fertilizer leading to sustainable agricultural practices [22]. (Fig. 2) shows collection techniques of *spirulina* culture.

6. SPIRULINA IN THE COSMETICS INDUSTRY

Ragusa et al. [23] in their detailed study of *spirulina* extracts in wide range of wound healing, antiageing, antiacne, skin care products concludes it as a booster in all products with no side effects. In beauty parlours *spirulina* face pack and lip balms are used as anti wrinkle agents. The biologically active metabolites in *spirulina* are interesting ingredients for nutricosmetic formulations and are important for skin care and antiageing [24]. Fifty healthy male and female participants were selected in the age group of 18-65 years from two hospitals in Bangladesh. The study was conducted for twelve months by applying the formulation containing *Spirulina* extract, after 28days found increase in stratum corneum water content and other skin tests revealed long-term benefits like hydration, oil control, skin protection making *spirulina* extract efficient in dermocosmetic formulations [25]. Vanillic acid present as the main phenolic component in the *spirulina* extract was the major cause for Tyrosinase enzyme inhibitor activity. In the ethanol extract, IC_{50}value was found to be 1.4×10^{-3} g/ml. Tyrosinase enzyme is the primary cause of melanin production which causes darkening. Hence *Spirulina* proves to be a potential whitening agent in the cosmetics [26].

7. SPIRULINA IN THE PIGMENTS INDUSTRY

Ciferri et al. [27] *Spirulina* contains two biliproteins with high economical value: c-phycocyanin and allophycocyanin with absorption maxima at 615-620nm and 650nm in the visible region respectively. The chromophore is phycobilin, an open tetrapyrrole. Lina blue is commercialized by Dainippon Ink & Chemicals of Japan which constitutes of spirulina Phycocyanin. It is used as a food colorant in the coloring of candy, ice cream, dairy products and soft drinks as well as in cosmetics like eye shadow, eyeliner, and lipstick and textiles such as natural blue [28]. Ranjitha et al. [29] used phycocyanin pigments from *spirulina* as a natural photosensitizer for biosensitized solarcells (BSSC). Silverdoped TiO2 nanoparticles were prepared by sol-gel technique and along with pigments of phycocyanin extracted from *A.platensis* fabricated in solarcells to obtain high efficiency making this combination ideal for future BSSC applications. Sustainability in the textile industry leads us to shift in the use of phycocyanin blue from *A.platensis* to chemical and traditional dyes. The pre-mordanted cotton and bleached wool with phycocyanin-rich extract, representing the sustainable blue dye were tested for color characterization and fastness. The results validated the sustainable character of spirulina-based phycocyanin in the dyeing process yielding low oxygen demanding effluent waste according to the international standards thus less polluting the environment [30]. The authors observed photocatalytic degradation of organic dye Malachite green of concentration 25ppm by phycocyanin extracts of *A.platensis* in sunlight. After 3hours, 100% of the dye was degraded which is confirmed by UV absorbance studies which showed no peak in 620nm proving dye degradation [31]. The light-harvesting pigment phycocyanin of *spirulina* residue was converted into biochar by pyrolysis at 900 degrees and it is activated by peroxydisulfate to obtain an efficient long durable carbo green catalyst for wastewater treatment that showed marvelous bactericidal properties on *Escherichia coli* [32]. The major pigments present in *spirulina* are Phycocyanin (Blue): 14%, Chlorophyll (Green): 1% , Carotenoids (Orange/ Red): 47% [33].

Enhanced benefits of *spirulina* as food additive is given in Table 2.

8. SPIRULINA VS GLOBAL WARMING – THE CONCLUSION

Global algal biodiesel market is approximately USD 6.95 billions in the year 2020 with an annual growth rate of 8%. Dueto the richness of nutrients, *Spirulina* can be used as a prominent substrate for industrially important biomolecules production. The ease of production and its capacity to harvest sun's energy makes this microalgae a renewable source of energy. As a biofertiliser, it enhances agricultural productivity, and its metal binding nature and presence of longchain fatty acids, hold it a special place in water treatment methods (Fig. 3).

Thus one species of this microalgae can achieve seven sustainable development goals -7SDGs like sustainable agriculture yielding food security, clean water(used in WWT),clean energy production, upgrading degraded land (heavy metal removal and salt tolerance),Clean air (carbon sequestration& mitigation of climate change),good health (nutraceutical value), eradicating poverty by an improved economy.

Table 2. "Spirulina as food additive"

S. No	Spirulina as Food additive	Added benefits	Literature
1	Pasta, cookies, yogurt	Enhanced protein profile	AlFadhly et al. [34]
2	Pomegranate juice	Hepatoprotective effect	El-Beltagi et al. [35]
3	Vegan Kefir	Increased prebiotic potential	Atik et al. [36]
4	Icecream	Improved nutrient profile, natural light green color	Malik et al. [37]
5	Green tea	Complete nutrient compounds	Marzieh et al. [38]
6	Dairy products	Extended shelf life	Marzieh et al. [38]
7	Nectar with dates and spirulina	Improved health properties	Aljobair et al. [39]
8	Egyptian cookies	Added vitamins, nutrients to children snack	El Nakib et al. [40]
9	Chocolate milk	Good stability and proteins; reduced lipids	Oliveira et al. [41]
10	Milk chocolate	Nontoxic phycocyanin natural blue food colorant	Kalenik et al. [42]

Fig. 3. Role of *Spirulina* in different sectors

Spirulina production in larger quantities is done by methods like symbiosis and coculturing techniques with other microorganisms like Rhodotorula yeast, Pseudomonas stutzeri, Azospirillum brasilense, and Lactobacillus plantarum, which enhances the yield manifolds so that it reaches every human hand at a low cost. The literature says 1 gram of spirulina biomass uses 0.4-2 grams of carbon di-oxide. In other words, one acre of algae can remove 2.7 tonnes of carbon di-oxide which is 10-50% more efficient than terrestrial plants. If we follow the footprints of SPIRULINA in anyone of the above aspects, it will reduce the carbon footprint which is our prior duty to mother EARTH.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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