INTERNATIONAL JOURNAL OF ADVANCED BIOLOGICAL RESEARCH

www.scienceandnature.org

SPIRULINA AND AQUACULTURE: A NEW HOPE FROM EARTH TO SKY

[a]Brijesh Kumar Pandey, [b]Saket Jha, [a]Vipin Mishra, [c]Ravikant Singh, [b]Anupam Dikshit and [a*]Shashi Kant Shukla
[a]Anupam Rural Laboratory, Centre of Science and Society, University of Allahabad, Prayagraj, U.P. (India)-211002
[b]Biological Product Laboratory, Department of Botany, University of Allahabad, Prayagraj, U.P. (India)-211002
[c]Centre of Bioresource Innovation and Research (CBIR), Department of Biotechnology, Swami Vivekanand University, Sagar, M.P. (India)-470228
*Corresponding author E-mail: shashibplau@rediffmail.com

ABSTRACT
In the current global status, there is an urgent requirement to discover the alternative of fish food with maximum utility and sustainability. There are diverse feed materials available in the market with nutritional values only. For the conservation of existing resources, natural materials can play a vital role in the fulfillment of present demands with healthy environment; algae are one of them. Algae are divided into several classes among which blue-green algae are of commercial importance such as *Spirulina,* a filamentous blue-green microalga. Several studies have shown the high nutritional values of *Spirulina* which alternatively reflect in the positive growth and production of different fish species. The above mentioned alga is also known to increase the oxygen level of existing water bodies and decrease the level of pollution. *Spirulina* has occupied significant place in the human food also. In African countries this alga is commercially harvested and used as rich protein source in the human food. Moreover, *Spirulina* can be used in different industries such as fertilizers, medicine, poultry *etc*.

KEYWORDS- *Spirulina*, sustainable, blue-green algae, medicine, poultry etc.

INTRODUCTION

Spirulina are multicellular and filamentous blue-green alga belongs to class cyanophyceae. It has gained considerable popularity in the health food industry, pharmaceuticals, supplement to aquaculture diets as feeding material and various sectors. It is also consumed as high calorie capsule in space. Its growing demand is because of its high nutritive value as having higher source of vitamins, proteins and vital minerals. From ancient times, it was eaten as raw and even now several countries used it as raw food and processed food and capsules. *Spirulina* grows in fresh-water as well as in marine (Mohan *et al*., 2014).

The coiled shape of trichomes is characteristic feature of *Spirulina* and is maintained only in a liquid culture medium. The addition of gas filled vacuoles in the cells, together with the coiling of filament, it appears like floating mats on ponds/ lakes. The trichome of *Spirulina* ranges from 50-500 µm in length and thickness is about 3-4 µm. The fine structure and the chemical composition of the cell walls of cyanobacteria are similar to those of Gram-negative eubacteria, composed of peptide-glycan. They are lysozyme sensitive hetero-polymer that confers shape and osmotic protection to the cell, in addition to other material not sensitive to lysozyme. Sphaeroplasts produces by protoplast from several cyanobacteria even in *Spirulina.*

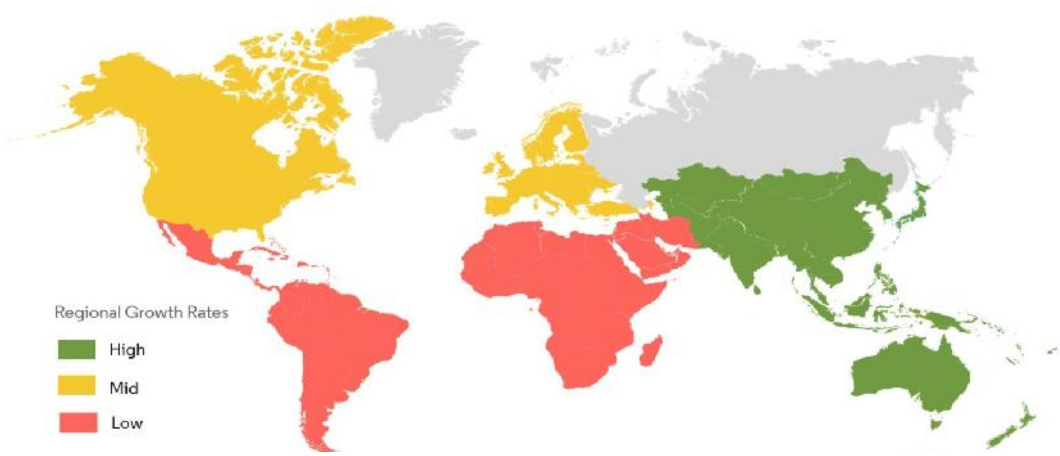

FIGURE 1. Geographical representation of Global Production of *Spirulina.*
Mordor Intelligence, 2020.

Protoplast was successfully isolated from *S. platensis*, treated with large amount of lysozyme at 30 °C and under illumination with 1450 lux/m^2/second (Abo-Shady *et al*. 1992). It was easily digested by lysozyme because of smooth, soft and without wall covering (Mohan *et al*. 2014). *Spirulina* contains maximum quantity of several amino acid and beta-carotene. *Spirulina* provides huge source of fatty and γ-linolenic acid which regulate to hormones and body functions (Habib *et al.* 2008). It is an agent of proteins, amino acids, polysaccharides, vitamins B_{12}, beta-carotene and several minerals with maximum iron (Lorenz. 1999). Some common *Spirulina* species are *S. maxima*, *S. platensis* and *S. pacifica*. The *S. platensis* is most predominant species and commercially cultivated worldwide whereas *S. maxima* is produced in the South and Central American regions (Belay 2002; Kebede and Ahlgren 1996). Major countries producing *Spirulina* are namely, USA, Canada, Mexico, Germany, France, Spain, Italy, UK, Netherland, India, China, Japan, Thailand, Australia, New Zealand and some other countries of Latin America (Figure 1 and 2) (Mordor Intelligence, 2020; Mishra *et al*. 2008).

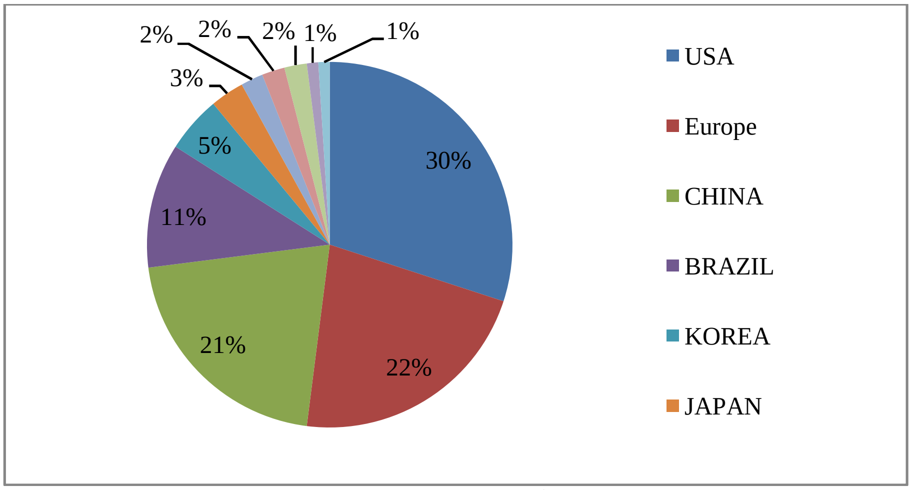

FIGURE 2. Global production commercially of *Spirulina*. Mishra *et al.* 2013.

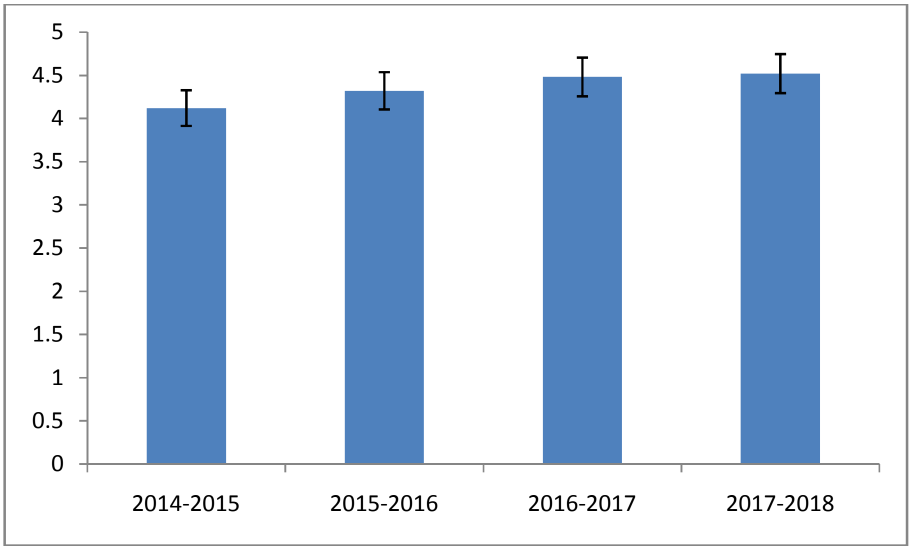

FIGURE 3. Global increasing demand of *Spirulina.* Mordor Intelligence, 2020.

1.1. Habitat and contrasting features

The largest *Spirulina* lakes are found in Central Africa, Texcoco, Chad, Niger and East Africa. *Spirulina* is mostly grows in alkaline lakes where the commonly growing micro-organisms is not able to survive (Kebede and Ahlgren 1996). Short supplies of nutrients usually alter the growth cycle of *Spirulina* in natural lakes. The growth rate of algal population is very fast and they die off when nutrients are worn out. A new seasonal cycle start when decay algae release their organic nutrients lead to increases the nutrients in the lakes.

Other then lakes, *Spirulina* also grows in soil, marshes, freshwater, brackish water, seawater and thermal flow. Good production of *Spirulina* is under alkaline, salt water (>30 g/l) with high pH (8.5- 11.0), particularly when optimum temperature. *S. platensis and S. maxima* grow rich in highly alkaline lakes of Africa and Mexico. Spirulina luxuriantly grows in lakes of Rift Valley of eastern Africa, where pH scale counts close to pH 11.0 and with high concentrations of sodium carbonate. Under control conditions, for the production of 1 litre of *Spirulina*, 85- 270 gm of salt is used (Kebede and Ahlgren

1996). *Spirulina* are capable to utilize ammonia even at high pH soil or water (Sasson, 1997). Mostly *Spirulina* is autotrophy (photosynthetic) and cannot survive in dark media containing organic carbon compounds. *Spirulina* help in reduces carbon dioxide in the light and yield particularly nitrates. The main yielding product of *Spirulina* during photosynthesis is glycogen (Sasson, 1997).

In laboratory, *Spirulina* is luxuriantly grown under 35°C-37°C. in natural conditions, it seems that an increase in temperature up to 39 °C for a few hours does not harm the blue-green alga, or its photosynthetic ability. Thermophilic or thermo-tolerant strains of *Spirulina* can be cultivated at temperatures between 35° C and 40° C. Such a property has the advantage of eliminating microbial mesophilic contaminants. The optimum temperature for *Spirulina* is 15° C (day) and less than 10° C (night) (Richmond *et al.* 1988). The resistance of *Spirulina* to ultraviolet rays seems to be rather high (Richmond *et al.* 1988). Both the species *i.e. S. platensis* and *S. maxima* is used worldwide and their production increases with their increase in demand in all major industries.

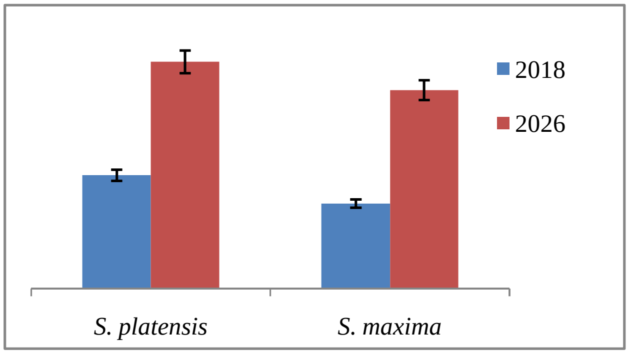

FIGURE 4. Global producing demands of the species of *Spirulina* reported by Kunsel and Sumant, 2019 Kunsel and Sumant, 2019).

2. Culturing methods of *Spirulina spp.*-

2.1. Natural production-

Basically commercial production of *Spirulina* cultures is combining with paddle wheel. Even, some species of *Spirulina* has been harvested commercially from naturally occurring populations. The use of soda water for cultivation and harvesting of *Spirulina* was done in Mexico. This process is called as "Semi-Natural cultivation" and after three days algal biomass is found maximum. After filtration, the algal biomass is spray-dried after homogenization and pasteurization (Olguín, 1986). In 1973, Sosa-Texcoco Ltd., USA invested US$ 5 million per year and continues till 1977 for the production of *Spirulina*. They successfully had grown the first pilot plant with production of 150 tones, and capacity of 300 tons per year 12.0 hectare of natural ponds. This technique solves the engineering problems arising from the increase in production and to run the toxicological tests indispensable before marketing the product (Olguín, 1986). Further this technique was used by many countries such as Myanmar for the production of *Spirulina*. In Twin Taung Lake, Myanmar the production of *Spirulina* was produced with larger quantity even more than 150 tones up to 10 year. From this lake, 60 % was harvested from Lake Surface and 40% was from outside the lake (Habib *et al.* 2008). *Spirulina* harvested with buckets and help of boats, when it reached the thick mat surface on lake in summer season (Habib *et al.* 2008). After harvesting, collected alga was dried and packed for the export to various areas like, pharmaceuticals, food industries, beverages *etc*.

2.2. Artificial cultivation-

For the artificial cultivation, eight major environmental factors influence the productivity of *Spirulina viz*., luminosity having 12 hour day and 12 hour night with intensity of 4 lux; temperature with 30 °C; inoculation size; stirring speed; dissolved solids (10–60 gm/ litre); pH in range of 8-10.5; water quality and macro- micronutrient (Ciferri, 1983; Ayala, 1998). The harvesting, processing and packaging of *Spirulina* has following stages:

1. Filtration and cleaning. For filter to need a nylon in water pond.
2. Pre-concentration: After collection of *Spirulina* is wash for decrease the amount salt content.
3. Concentration of *Spirulina*: Eradicate large amount of interstitial water present in the algal filament.
4. Neutralization: To neutralize the biomass with the addition of acid solution.
5. Disintegration: To break down trichomes by a grinder.
6. Spray-drying dehydration: It has a great money value which deals with approx. 25 $\pm$ 5 percent of total production cost.
7. Packing of *Spirulina*: Plastic bags are used for sealing the dried *Spirulina* to avoid hygroscopic actions.
8. Storage: Stored in fresh, dry, unlit, pest-free and hygienic storerooms to prevent *Spirulina* pigments from deteriorating (Ayala, 1998).

3. Applications of *Spirulina* sp.-

Spirulina comprises various fields and makes it most valuable species in the earth. Some various applications of *Spirulina* such as fish feed, fertilizer, food, space food, animal feed, additives, pharmaceuticals, anti-oxidant and anticancer, etc. are mentioned below (Figure 5 and 6).

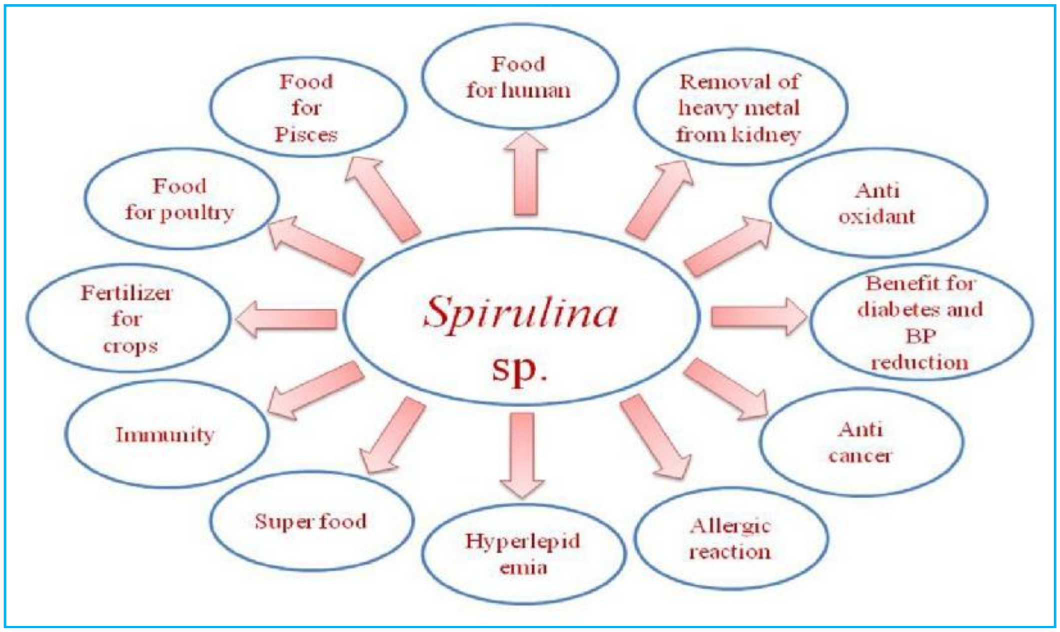

FIGURE 5. Various applications of *Spirulina*

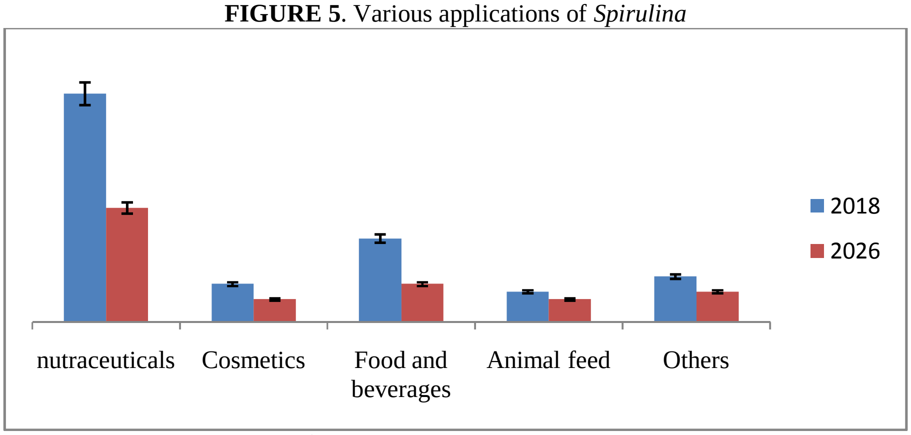

Figure 6. Growing demands of *Spirulina* in various industries (Kunsel and Sumant, 2019).

3.1. Use of *Spirulina* in Aquaculture-

Spirulina is low cost feed material compare to others of animal origin. In China *Spirulina* is use to aquaculture feed especially in Prawn (*Penaeus monodon*) for their boost for growth, immunity. *Spirulina* feed is used for decrease time of cultivation and mortality and increase shell hardness of scallop.

Feeding on *Spirulina* helped to improve disease resistance of high value fish resulting in an improvement in their survival rate from 15- 30% (Ghaeni, 2010). 37.7% survival rate of Abalone (*Haliotis midae*) fish help of *Spirulina* feeding material (Department of Food, 2011). It has been used as a supplement in green tiger prawn larvae diet (FAO, 2012). Also effect of *Spirulina platensis* meal has been evaluated as feed additive on growth and survival of *Litopenaeus schmitti* (shrimp) larva (Yoshimatsu and Hossain, 2014). Each year, the amount of fish produced around the world increases, which contributes to several environmental impacts such as the disposal of effluents without treatment in the environment (FAO, 2012).

The aquaculture is an activity that requires a large volume of water because every year millions tons of fishes are produced around the world by FAO, 2012 (FAO, 2012). Therefore, a considerable amount of residual waters is produced (Turcios and Papenbrock, 2014). Because it is an expanding activity, the aquaculture has caused several environmental problems, such as: soil and marine habitats degradations; chemical pollution; danger to biodiversity by the introduction of exotic species; reduction of the immune-biological resistance of the fishes; spread of diseases; mortality of aquatic organisms; several changes in water bodies; as well as economic damages in fishing industry (Turcios and Papenbrock, 2014). Fish is playing an important dietary animal protein source for human nutrition.

According to nutritionists, fish is an excellent substitute of protein for red meat, which contains all the essential amino acid (methionine, cystine, lysine, threonine, tryptophan, arginine, isoleucine, valine, histidine, phenylalanine *etc*.) and minerals *viz*., iodine, phosphorus, potassium, iron, copper and vitamin A and D in desirable concentrations (Sandhu, 2005). It serves as valuable source of protein to a healthy diet because of its low carbohydrate and unsaturated fat, especially Omega 3 contents (Razvi, 2006). Bangladesh became global fish producing giant with approximately 4.1 million metric tons. In an average, 28% inland water and 16 % was contributed by marine water (Department of Food, 2011). The main constrains in aquaculture are seed and feed. Fish feed generally constitutes 60-70% of the operational cost in intensive and semi- intensive aquaculture system (Singh *et al. 2006*). Fish meal (FM) for aquatic animals such as fishes, provide good source of high protein content with balanced amino acids, vitamins and vital minerals. From all these unique mixture makes the fish meal as a highly potential dietary which is easy to digest by the fishes (Tacon, 1993). The rapid growth of aquaculture has resulted in higher demand for FM and consequently its high price is expected to be further increased by continuous growth in its requirement (Hardy and Tacon, 2002). Furthermore, sustainability of FM production from wild fish is questionable (Naylor *et al*. 2000).

Spirulina provide the high nutritive feed material to fishes and aquatic animals which are very low cost and eco-friendly. This makes the *Spirulina* most valuable and affordable for aquaculture with its sustainable fish farming (Higg *et al*. 1996). And it has been found that the alga can be used as an alternative source of protein and can also be used to improve the color, flavor and quality of meat (Al-Badri, 2010; Nakagawa *et al*. 2007).

In recent years, food security is becoming serious issue with rapidly increasing world's population. The global population has increasing and, in order to maintain current level of per capita consumption of aquatic foods, the world will require an additional 23 million tons by 2020 (Haque and Gilani, 2005). This additional supply will have to come from aquaculture (FAO, 2012). Conventional agriculture has not the ability to supply enough food therefore, new alternative and unconventional food sources have to be searched to feed this much crowded world. Increasing practice of aquaculture can be solution for producing more fish meet up the protein requirement of this large population of the world. For that we need to produce more fish with less feed cost. It is suggested that the increased use of plant protein in fish diets can reduce the cost of FM and feeds (Lim and Lee, 2009).

Use as Bio-fertilizer-

In 1981 the FAO documented the possibilities of cyanobacteria replacing chemical fertilizers and rebuilding the structure of depleted soils (FAO, 1981.). In India, cyanobacteria are grown in shallow earthen ponds. After pond water evaporates, the dry algae are scooped and sell to rice farmers. Near about 22 % production of *Spirulina* was done in India. *Spirulina* is source of biological nitrogen with low cost compare to chemical fertilizer. These are also help in production of rice crop. An alga used in place of chemical fertilizer and it is benefits per 25 to 30 acre. Algae are used to reduction an equal amount of chemical fertilizer. *Spirulina* can be potent as well as low cost bio-fertilizer and can be used in several crops.

S. platensis with DAP and applied on tomato seedlings shown growth promotion much higher as compared with its singly treatments as well as control (Zeenat *et al*. 1990). Biological nitrogen is most important as compared to inorganic nitrogen because biological nitrogen also provides the other nutrients as well as carbon component directly to plant and help in its growth.

Spirulina contains 10% N w/w (high percentage), and other macro- and micro-nutrients which are slowly released under normal soil conditions, and increases fertility (Banerjee and Deb, 1996). *Spirulina* is used as bio-fertilizer in rice field (Prasanna *et al*. 2008). Yanni and Abd El-Rahman (1993) stated that rice performance (as assessed by plant height, productive tillers, grain and straw yields and their N-contents and fertilizer N-use efficiency) was enhanced by inoculation with *Spirulina platensis* along with urea fertilizer at 36 or 72kg N ha^{-1} rather than 108 kg N ha^{-1} without inoculation (Yanni and Abd El-Rahman, 1993). Ali and Mostafa (2009) showed that increasing grain and straw yield, plant height, number of capsule/ plant, number of branches/ plant, seed weight/ plant and 1000 seed weight of sesame plants when *Spirulina* algae was used as bio-organic fertilizer (Ali and Mostafa, 2009; Abd El-RheemKh *et al*. 2015).

Researchers also found that *Spirulina* helps in reducing the pollution in water and soil contaminated with DDT and several heavy metals (Figure 7). *Spirulina* growing singly as well as grown under stress of DDT showed significant growth (Kurashvili *et al*. 2018).

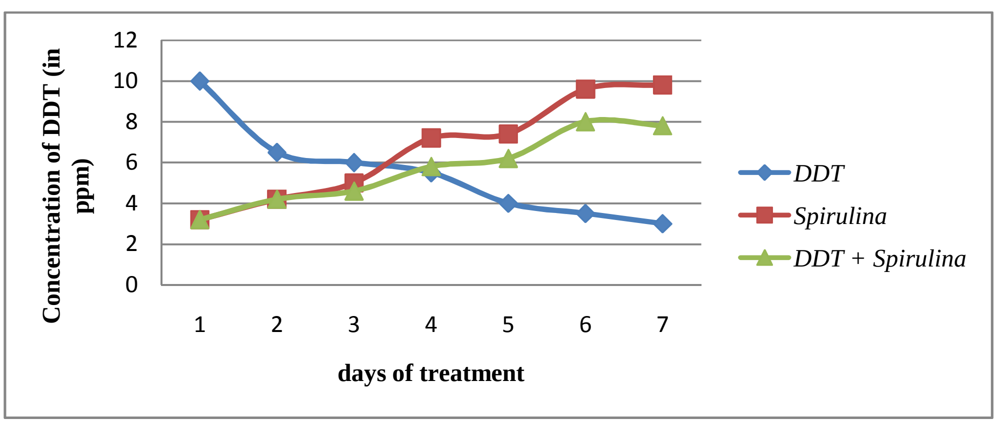

FIGURE 7. *Spirulina* helps in reducing water pollution (Kurashvili *et al.,* 2018).

3.2. Edible or food for human-

High amount of proteins, vitamins and minerals were found in *Spirulina* which help in biological active of living organism (Becker, 1994). Cell wall of *Spirulina* is made up of polysaccharide which digestibility of 86% directly absorbed by the human body. Both pills and capsules are made from dried *Spirulina*. For example in China, Wuhan

Botanical Institute, reported that the oral intake of *Spirulina* pills (10 gm/day) was able to increase the haemochrome level in females as well as lung capacity in juveniles. There were no effects found on males (Li, 1995). In Viet Nam, culturing was started in 1980 by Nguyen *et al.* (1980) and mass production was done by Kim (1990) (Nguyen *et al*. 1980; Kim, 1990). *S. platensis* powder and tablets were found to be increasing the lactation in mothers.

Another promising result was found that infants and children were cured from malnutrition when treated with *Spirulina* powder. It also helps in curing the arthritis, heart disease, obesity and zinc deficiency (Henrikson, 1989). An experiment was conducted on 20 males and 20 females in Coimbatore, India and found significant reduction in blood glucose levels due to supplementation in diet with *Spirulina* (Anuradha *et al*. 2001). *Spirulina* used in various food products such as granola bars, pastalina, candy, rich protein flour, soya milk, noodles, cheese, *etc*. (Vonshak. 1990). As little as 10 gm a day of *Spirulina* brings rapid recovery from malnutrition, especially in infants.

3.3. *Spirulina* as Super food-

Spirulina is truly an amazing food, full of nutritional wonders and can be used as a "Super food" in earth or in space (Moorhead *et al.* 2006). It is, therefore, a potential therapeutic agent for treating oxidative stress-induced diseases (Makhlouf and Makhlouf, 2012). Researchers found that the *Spirulina* have therapeutic properties such as reducing cholesterol level in blood, protect against some serious cancers, enhances the immune system, increasing the lactobacilli in intestine, reduction of nephro-toxicity by heavy metals and drugs, radiation protection, reduction of hyperlepidemia and obesity. Other *Spirulina* products are formulated for weight loss and also use as an aid for quitting drug-addictions (Choonawala, 2007). Because of these highly nutritive, *Spirulina* were widely used as space food in the form of capsules (Choonawala, 2007). Spirulina comprises all major nutritive contents which are needful for the development of human body. The major constituents which found on Spirulina are, Proteins; minerals, vitamins, poly-saccharides, glycogens and fatty acids (Figure 8).

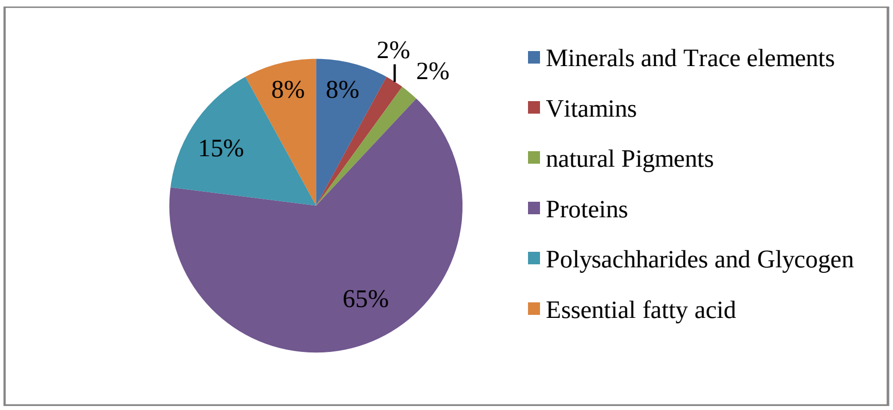

Figure 8. Major constituents in *Spirulina*. Mishra *et al*., 2013.

3.4. Medicinal use of *Spirulina*-

Research on *Spirulina* health benefits has been far-ranging. In addition to antioxidant and anti-inflammatory effects other potential health applications are: (a) protection of the liver and kidneys; (b) improvement of blood quality and prevention of anemia; (c) benefits for diabetes; (d) reduction in blood pressure; (e) removal of heavy metals from the body; (f) radioprotection; (g) prevention of liver and renal toxicity; (h) antioxidant action; (i) immune protection and (j) relief in allergic reactions (Capelli and Cysewski, 2010; Desai and Sivakami, 2004).

3.5. *Spirulina* as Antioxidant-

The specific character found in *Spirulina* is antioxidants which are help to reduce free radicals. Free radicals are harmful for health. Free radical is unstable products of cell, which is responsible for destroy and death to related cells. Oxidative stress directly or indirectly leads to various disorders like diabetes, atherosclerosis, rheumatoid arthritis, recurrentaphthous stomatitis, cancer, *etc*. (Lobner *et al*. 2008). *Spirulina* is a natural antioxidant together enlarge amount of protein. The optimum amount of beta-carotene and tocopherol were found in *Spirulina*. These antioxidants help to body protection for oxidative stress (Lobner *et al*. 2008).

Spirulina also have an iron chelating property. It can reduce the toxic amount of iron content in neuroblastoma cells under iron induced oxidative stress (Mittal *et al.* 1999). Geriatric patients administered *Spirulina* for 16 weeks showed a remarkable improvement in the antioxidant potential, as measured by the increased levels of antioxidant status in plasma of these individuals (Trushina *et al.* 2007). A double-blinded, placebo controlled study performed on individuals after exercise, showed decreased amount of creatine kinase, (an indicator of muscular breakdown) when they were supplemented with *Spirulina*. Moreover, their exhaustion time in the treadmill exercise increased by 52 seconds. This could be explained by the antioxidant potential of *Spirulina* (Trushina *et al*. 2007).

3.6. Role of *Spirulina* in Immunity-

Spirulina is protected and boost immunity and resistance to viral infections. *Spirulina* activates the cells of innate immune system which leads to enhance components of the mucosal and systemic immune system. Several pre-clinical animal studies have shown good immune stimulatory effects in a variety of species. Besides from human, *Spirulina* are able to induce the immune stimulations in chickens, mammals and fishes. It helps in enhancing the resistivity to several diseases as well as increases the haemopoieses capacity and production of antibiotics and cytokines. *Spirulina* has also been shown to activate macrophages T and B cells (Blinkova *et al.* 2001).

Spirulina releases the some sulfo-lipids which found effective against HIV, Herpes virus and influenza virus, *etc*. as well as also positively helps in inhibiting carcinogenesis (Khan *et al*. 2005). *Spirulina* is supplementary cure for many disease, these are proved by experiment (56 Batista *et al*. 2010). *Spirulina* is used for feed, human food and some biochemical products since 1980s. After chemotherapy and radiotherapy *Spirulina* capsules is used in lowering blood lipid level and maintain immune system (Vedi *et al*. 2013).

3.7. *Spirulina* used against Hyperlipidemia-

The antioxidant activity of *S. maxima* has been evaluated against lead acetate-induced hyperlipidemia and oxidative damage in the liver and kidney of male rats. It was found that *Spirulina* helps in prevention of lead acetate and decreases the level of heavy metal toxicity in liver and kidney followed by increasing the antioxidant activity (Batista *et al*. 2010). On the other hand, *S. maxima* succeeded to improve the biochemical parameters of the liver and kidney towards the normal values of the Control group (Sudha *et al*. 2011). It was observed that *Spirulina* helps in retarding the blood pressure and decreases the plasma lipid concentrations. It also decreases the lipoprotein cholesterol compounds in the blood and cell (Sudha *et al*. 2011). It has also been shown to indirectly modify the total cholesterol and high density lipoprotein cholesterol values. A water extract from *Spirulina* may inhibit the intestinal absorption of dietary fat by inhibiting pancreatic lipase activity (Ahsan *et al*. 2008).

3.8. *Spirulina* used as Anti-Cancer and Immune System Effects-

Chemotherapy is one of the main treatments used to cure cancer. Besides that, a group of drugs are used to kill or inhibit the growth of cancer cells (Thomas, 2010). These drugs are associated with toxicity, which at best is unpleasant and at worst may threaten life. Many side effects of chemotherapeutic drugs include hair loss, mouth sores, diarrhea, nausea and vomiting, loss of appetite and fatigue (Thomas, 2010). Hence new anticancer agents should be investigated from various resources.

Spirulina preparations increase phagocytic activity of macrophages and stimulate antibodies and cytokines production. It may also facilitate lipid and carbohydrate metabolism (Thomas, 2010). Researchers found that the *Spirulina* activated the NK cells, showed many advantages in which major role reported that these NK cells with combinations of BCG- cell wall skeleton enhanced the anti-tumor immunotherapy (Jimenez *et al*. 2003). As a result, in humans, *Spirulina* acts directly on myeloid lineages and either directly or indirectly on NK cells (Khan *et al*. 2005).

TABLE 1. Biological effects of *Spirulina* with its bio-active components

Biological Properties	Specific Effects	Bioactive Component	Ref (s).
Anticancer	Repairing of damaged DNA	Polysaccharides	(Lorenz. 1999)
	Selective Inhibition of Cyclooxygenase-2	C-phycocyanin	(Soheili and Khosravi-Darani . 2011)
	Helps in induction of G1 cell phase arrest, Apoptosis of MCF-7 breast carcinoma mediated by mitochondrial cells in human.	Selenium enriched *Spirulina*	(Demir and Tükel. 2010)
Antiviral	Blocking virus adsorption and penetration into vero cells	Calcium spirulan sulfated polysaccharide)	(Habib *et al.* 2008; Cohen. 1997; Parages *et al.* 2012).
	I Inhibition of the DNA polymerase activity	Sulfolipids	(Hayashi *et al.* 1996)
	Inhibition of enterovirus 71-induced cytophtic effect, viral plaque formation and viral-induced apoptosis	Protein- bound pigment allo-phycocyanin	(Gershwin and Belay. 2008)
Antibacterial		Fatty acids e.g. GLA	(Romay *et al.* 2003; Bermejo *et al.* 1997; Downham and Collins. 2000; McCarty. 2007; Clement. 1975).
Metallo-protective	Inhibiting lipid peroxidation, scavenging free radicals, enhancement of the activity of GSH peroxidase and superoxide dismutase	Antioxidant components	(Petkov and Furnadziev. 1988; Sharma *et al*. 2011; Watanabe and Miyamoto. 1991; Van-den-Berg *et al.* 1991; Kumudha *et al.* 2010).
Antioxidant	Metal-chelating activity, free radical scavenging activity	Carotenoids, vitamin E, Phycocyanin and chlorophyll	(Mosulishvili *et al.* 2002; Romaris-Hortas *et al.* 2011; Shaughnessy *et al.* 2002).
Immuno-stimulant			(Grawish. 2008; Reddy *et al.* 2000; Fournier and Gordon. 2000).

3.9. *Spirulina* used as Food Additives-

Since many of the existing blue-green algae species are known to produce toxin. It is very important to clarify the specific species used for human consumption as in all likelihood. There is a danger of species- substitution and/ or contamination of *Spirulina* with other cyanobacteria. *Spirulina* is used in many countries with various forms of food products and as additives. Several food items are soups, sauces, pasta, snack foods, instant drinks and other recipes completely made from powdered *Spirulina* (Syahril *et al*. 2011). For example, instant noodles, stylish noodles, nutritious blocks, beverages and cookies (Syahril *et al*. 2011). In addition micro-algal biomass has been studied in several food products oil-in-water emulsions, vegetable puddings, biscuits and pastas.

The effect of micro-algal concentration on the products color parameters was investigated, as well as its stability through the processing conditions and along storage time (Patro *et al.* 2011). Due to its blue green colour, many food items were sprayed with it to make attractive. It is also added to many food items such as shakes, jellies, biscuits or cakes (Nikodemusz *et al*. 2010). These cyanobacteria were mixed with wheat flour to make pasta with is delicious as well as highly nutritive (Nikodemusz *et al*. 2010).

3.10. Use of *Spirulina* in Poultry

About one third of the world consumes feed production for poultry. *Spirulina* as new green market creates major challenges to synthetic poultry feeds manufacturers to formulate feeds using high quality components (Ross and Dominy, 1990). *Spirulina* is one of the high quality natural feed additives that can be used in animal and poultry nutrition. Researchers found that hens fed with *Spirulina*, were enhanced in their egg productive and shown well organized reproductive performances as compared to control hens (Nikodemusz *et al*. 2010; Ross and Dominy. 1990.). Moreover, Takashi (2003) and others researchers found that egg yolk color was significantly improved by the addition of *Spirulina* to laying hen diets (Takashi. 2003; Chirasuwan *et al*. 2008).

4.0. CONCLUSION

Spirulina belongs to blue-green algae and can be identified by its helical filaments, used since Aztec civilization. It refers to the desiccated biomass of *Arthrospira* spp., being used in space mission by NASA. They are consumed as food material in a large scale by different organisms due to high nutritional value. In the present review, we tried to focus little about different potentials of *Spirulina*, its properties, aspects with their bioactive compounds. In nutshell it can be concluded that this cyanobacterium is having the capacity of ruling from earth to sky.

5.0. ACKNOWLEDGEMENTS

Authors are thankful to the Coordinator, Centre of Science and Society, Head, Department of Botany for lab facilities; to UGC for financial support.

6.0. REFERENCES

Abd El-RheemKh M, Sahar MZ and Entsar ME. 2015. The stimulant effect of the *Spirulina* Algae under Low Levels of Nitrogen Fertilization on Wheat plants Grown in Sandy Soils. International Journal of Chem. Tech. Research. 8(12): 87- 91.

Abo-Shady AM, Abou-El-Souod SM, El-Raheem A, El-Shanshoury R and Mahmoud YAG. 1992. Protoplasts from the cyanobacterium, *Spirulina platensis*. World J. Microbiol. Biotech. 8: 385- 386.

Ahsan M, Habib B and Parvin M. 2008. Department of Aquaculture Bangladesh Agricultural University, Mymensingh, Bangladesh Tim C. Huntington FAO Consultant Mohammad R. Hasan.

Al-Badri SHA. 2010. Effect of environmental factors and some pollutants on the chemical content and nutritional value of blue-green alga *Spirulina platensis* (Nordst.) Geilter (Doctoral dissertation, M. Sc. thesis, College of Education–University of Thi-Qar).

Ali KM and Mostafa S M. 2009. Evaluation of potassium humate and *Spirulina platensis* as bio-organic fertilizer for sesame plants grown under salinity stress. Egypt. J. Agric. Res. 87: 369- 388.

Anuradha V and Vidhya D. 2001. Impact of administration of *Spirulina* on the blood glucose levels of selected diabetic patients. Indian J. Nutri. & Dietetics. 38: 40- 44.

Ayala F, 1998. Guía sobre el cultivo de *Spirulina*. In Biotecnología de Microorganismos Fotoautótrofos. 3- 20.

Banerjee M and Deb M. 1996. Potential of fly ash and *Spirulina* combination as a slow release fertilizer for rice field. Cientifica Jaboticabal. 24: 55- 62.

Batista AP, Raymundo A, Bandarra NM, Sousa I, Empis J and Gouveia L. 2010. Healthier food products with naturally encapsulated functional ingredients. Microalgae.

Becker EW. 1994. Microalgae. In Nutrition. Cambridge. Cambridge Univ. P. 196- 249.

Belay A. 2002. The potential application of *Spirulina* (*Arthrospira*) as a nutritional and therapeutic supplement in health management. Jour. Ameri. Neutra. Assoc. 5(2): 27- 49.

Bermejo R, Talavera EM, Alvarez-Pez JM and Orte JC. 1997. Chromatographic purification of phyco-biliproteins from *Spirulina platensis.* High-performance liquid chromatographic separation of their α and β subunits. J. Chromatogr. A. 778: 441- 450.

Blinkova LP, Gorobets OB and Baturo AP. 2001. Biological activity of *Spirulina*. Zh Mikrobiol Epidemiol Immunobiol. 2: 114- 118.

Capelli B and Cysewski GR. 2010. Potential Health Benefits of *Spirulina* microalgae: A review of existing literature. Nutra. Foods. 9(2): 19- 26.

Chirasuwan N, Chaiklahan R, Ruengjitchatchawalya M, Bunnag B and Tanticharoen M. 2008. Anti HSV-1 activity of *S. platensis* polysaccharide. K. J. Nat. Sci. 41: 311- 318.

Choonawala A. 2007. *Spirulina* production in Brine Effluent from Cooling Towers, Durban University of Technology.

Ciferri O. 1983. *Spirulina*, the edible organism. Microbiol. Rev. 47: 551- 578.

Clement G. 1975. Production and characteristic constituents of algae *Spirulina platensis* and *S. maxima*. Ann. Nutr. Aliment. 29: 477- 487.

Cohen Z. 1997. *Spirulina platensis (Arthrospira)*: Physiology, Cell Biology and Biotechnology. Taylor and Francis: London. 175- 204.

Demir BS and Tükel SS. 2010. Purification and characterization of lipase from *Spirulina platensis*. J. Mol. Catal. B-Enzym. 64: 123- 128.

Department of Food. 2011. Fishery statistical year book of Bangladesh, Fisheries Resources Survey Systems, Department of Fisheries, Dhaka, Bangladesh. 113.

Desai K and Sivakami S. 2004. *Spirulina* the wonder food of the 21st century. Asia Pacific Biotech. News. 8(23): 1298- 1302

Downham A and Collins P. 2000. Colouring our foods in the last and next millennium. Journal of Food Science and Technology. 35: 5- 22.

FAO, 1981. Blue-green algae for rice production. *FAO Soils Bulletin*. Rome, 1981.

FAO. 2012. Report of the thirtieth session of the committee on fisheries. FAO Fisheries and Aquaculture Report. No. 1012. Rome: 75.

Fournier DB and Gordon GB. 2000. COX-2 and colon cancer: Potential targets for chemoprevention. J. Cell. Biochem. Suppl. 34: 97- 102.

Gershwin ME and Belay A. 2008. *Spirulina* in Human Nutrition and Health, CRC Press, Taylor and Francis Group, Boca Raton: London, New York. 1- 27.

Ghaeni M. 2010. The effect of *Spirulina* (fresh and dry) on some biological factors in and *Penaeus semisulcatus* larvae. Ismalic Azad University Science and research branch, PhD thesis, Tehran.

Grawish ME. 2008. Effects of *Spirulina platensis* extract on Syrian hamster cheek pouch mucosa painted with 7, 12-dimethylbenz α anthracene. Oral. Oncol. 44: 956- 962.

Habib MAB, Parvin M, Huntington TC and Hasan MR. 2008. A Review on Culture, Production and Use of *Spirulina* as Food for Humans and Feeds for Domestic Animals and Fish. FAO Fisheries and Aquaculture Circular No. 1034.

Habib MAB, Parvin M, Huntington TC and Hasan MR. 2008. A review on culture, production and use of *Spirulina* as food for humans and feeds for domestic animals FAO Fisheries and Aquaculture Circular. No. 1034. Rome, FAO. 33.

Haque SE and Gilani KM. 2005. Effect of ambroxol, *Spirulina* and vitamin E in naphtalene induced cataract in female rats. Ind. J. Phys. Pharmacology. 49(1): 57- 64.

Hardy RW and Tacon AG. 2002. Fish meal: historical uses, production trends and future outlook for sustainable supplies. Responsible marine aquaculture. 311- 325.

Hayashi T, Hayashi K, Maeda M and Kojima I. 1996. Calcium spirulan, an inhibitor of enveloped virus replication, from a blue-green alga *S. platensis.* J. Nat. Prod. 59: 83- 87.

Henrikson R. 1989. Earth food *Spirulina*. San Rafael, California, USA, Rancor Enterprises. Inc.

Higgs DA, Dosanjh BS, Prendergast AF, Beames RM, Hardy RW, Riley W and Deacon G. 1995. Use of rapeseed/ canola protein products in finfish diets. Nutrition and Utilization Technology in Aquaculture. 130- 156.

Jimenez C, Cossio BR, Labella D and Xavier NF. 2003. The feasibility of industrial production of *Spirulina* in southern Spain. Aquaculture. 217: 179- 190.

Kebede E and Ahlgren G. 1996. Optimum growth conditions and light utilization efficiency of *Spirulina platensis* (*Arthrospira fusiformis*) (Cyanophyta) from Lake Chitu, Ethiopia. Hydrobiol. 332: 99- 109.

Khan M, Varadhara S, Gansesa LP, Shobha JC, Naidu MU and Parmandi NL. 2005. C-phycocyanin protects against ischemia-reperfusion injury of heart through involvement of p38 and ERK signaling. Am. J. Physiol. Heart Circ. Physiol. 290(5): 2136- 2145.

Khan Z, Bhadouria P and Bisen PS. 2005. Nutritional and therapeutic potential of *Spirulina*. Curr. Pharm. Biotechnol. 6(5): 373- 379.

Kim DD. 1990. Outdoor mass culture of *S. platensis* in Vietnam. J. App. Phy. 2: 179- 181.

Kumudha SS, Kumar MS, Thakur GA, Ravishankar R and Sarada J. 2010. Purification, Identification and Characterization of Methylcobalamin from *Spirulina platensis*. Journal of Agriculture, Food and Chemistry. 58: 9925- 9930.

Kunsel T and Sumant O. 2019. *Spirulina* Market by Type (*Arthrospira* Platensis and *Arthrospira* Maxima), Application (Nutraceuticals, Cosmetics, Food and Beverages, Animal Feed, and Others), and Drug Formulation (Powder, Tablet & Capsule, Liquid, and Granule and Gelling Agent): Global Opportunity Analysis and Industry Forecast, 2019-2026, LS: Pharmaceuticals. 210.

Kurashvili M, Varazi T, Khatisashvili G, Gigolashvili G, Adamia G, Pruidze M, Gordeziani M, Chokheli L, Japharashvili S, Khuskivadze N. 2018. Blue-green alga *Spirulina* as a tool against water pollution by 1,1'-(2,2,2-trichloroethane-1,1-diyl) bis (4-chlorobenzene) (DDT). Annals of Agrarian Science. 16: 405- 409.

Li DM. 1995. *Spirulina* as a health food. Chinese Agro-technology Publication. 21- 28.

Lim SJ and Lee KJ. 2009. Partial replacement of fish meal by cottonseed meal and soybean meal with iron and phytase supplementation for parrot fish *Oplegnathus fasciatus*. Aquaculture. 290(3-4): 283- 289.

Lobner M, Walsted A, Larsen R, Bendtzen K and Nielsen CH. 2008. Enhancement of human adaptive immune responses by administration of a high molecular-weight polysaccharide extract from the cyanobacterium *Arthrospira platensis*. Journal of Medicinal Food. 11(2): 313- 322.

Lorenz RTA. 1999. Review of *Spirulina* and *Haematococcus* algae meal as a carotenoid and vitamin supplement for poultry. *Spirulina pacifica* Technical Bulletin. 53: 1- 14.

Makhlouf RA and Makhlouf I. 2012. Evaluation of the effect of *Spirulina* against Gamma irradiation induced oxidative stress and tissue injury in rats. International Journal of Applied Science and Engineering research. 1(2): 152- 164.

McCarty MF. 2007. Perspective Clinical Potential of *Spirulina* as a Source of Phyco-cyanobilin. Journal of Medicinal Food. 10(4): 566- 570.

Mishra T, Joshi M, Singh S, Jain P, Kaur R, Ayub S and Kaur K. 2013. *Spirulina*: The beneficial algae. International Journal of Applied Microbiology Science. 2(3): 21- 35.

Mittal A, Kumar PV, Banerjee S, Rao AR and Kumar A. 1999. Modulatory potential of *Spirulina fusiformis* on carcinogen metabolizing enzymes in Swiss albino mice. Phyto. Ther. Res. 13(2): 111- 114.

Mohan A, Misra N, Srivastav D, Umapathy D and Kumar S. 2014. *Spirulina*-The Nature's Wonder: A Review. Sch. J. App. Med. Sci. 2(4C): 1334- 1339.

Moorhead TW, Harris JM, Stanfield AC, Job DE, Best JJ, Johnstone EC *et al.* 2006. Automated computation of the Gyrification Index in prefrontal lobes: Methods and comparison with manual implementation. Neuro-image. 31: 1560- 1566.

Mordor Intelligence, 2020. https://www.Mordorintelligence.com/industry-reports/north-america-spirulina-extract -market.

Mosulishvili IM, Kirkesali EI, Belokobylsky AI, Khizanishvili AI, Frontasyeva MV, Pavlov SS and Gundorina SF. 2002. Experimental substantiation of the possibility of developing selenium- and iodine- containing pharmaceuticals based on blue green algae *Spirulina platensis*. Journal Pharm. Biomed. Anal. 30(1): 87- 97.

Nakagawa H, Sato M and Gatlin III DM (Eds.). 2007. Dietary Supplements for the Health and Quality of Cultured Fish, 1st ed. CABI Publisher. UK. 133- 167 and 168- 177.

Naylor RL, Goldburg RJ, Primavera JH, Kautsky N, Beveridge MCM and Clay J. 2000. Effect of aquaculture on world fish supplies. Nature. 405: 1017- 1024.

Nguyen HT, Nguyen TC, Dang DK, and Dang HPH. 1980. The first results of investigations and cultivation of *S. platensis* in Vietnam. Rev. Hydrob. Bulg. Acad. Sci. 9.

Nikodemusz E, Paskai P, Toth L and Kozak J. 2010. Effect of dietary *Spirulina* supplementation on the reproductive performance of farmed pheasants. Technical; Articles- Poultry Industry. 1- 2.

Olguín EJ. 1986. Appropriate biotechnology systems in the arid environment. In: Doelle HW and Helén CG (Eds.). Applied Microbiology. Dordrecht, D. Reidel Publ. Com., Paris, UNESCO, Trends in Sci. and Res. 2: 111- 134.

Parages ML, Rico RM, Abdala-Díaz RT, Chabrillón M, Sotiroudis TG and Jiménez C. 2012. Acidic polysaccharides of *Arthrospira (Spirulina) platensis* induce the synthesis of TNF- Alfa in RAW macrophages. J. Appl. Phycol. 24: 1537- 1546.

Patro N, Sharma A, Kariaya K and Patro I. 2011. *Spirulina platensis* protects neurons *via* suppression of glial activation and peripheral sensitization leading to restoration of motor function in collagen-induced arthritic rats. In. J. Exp. Biology. 49: 739- 748.

Petkov GD and Furnadzieva ST. 1988. Fatty acid composition of acyl lipids from *Spirulina platensis*. C. Res. Bulg. Acad. Sci. 41: 103- 104.

Prasanna RP, Jaiswal YV and Singh PK. 2008. Influence of biofertilizers and organic amendments on nitrogenase activity and phototrophic biomass of soil under wheat. Acta Agronomica Hungarica. 56: 149- 159.

Razvi M. 2006. Lahore-absolutely fishy: Nutritional value. The Review, Dawn. 12- 13.

Reddy CM, Bhat VB, Kiranmai G, Reddy MN, Reddanna P and Madyastha KM. 2000. Selective Inhibition of Cyclooxygenase-2 by C-Phycocyanin, a Biliprotein from *Spirulina platensis.* Biochem. Biophysics Res. Co. 277: 599- 603.

Richmond A, Borowitzka MA and Borowitzka L. 1988. Micro-algal Biotechnology. Cambridge, Cambridge University Press. (Eds). 85- 121.

Romaris-Hortas V, Garcia-Sartal C, del-Carmen-Barciela-Alonso M, Dominguez- Gonzalez R, Moreda-Pineiro A and Bermejo-Barrera P. 2011. Bioavailability study using an *in vitro* method of iodine and bromine in edible seaweed. Food Chem. 124: 1747- 1752.

Romay C, Gonzalez R, Ledon N, Remirez D and Rimbau V. 2003. Phycocyanin: A Biliprotein with Antioxidant, Anti-Inflammatory and Neuroprotective Effects, Curr. Protein Pept. Sci. 4: 207- 216.

Ross E and Dominy W. 1990. The nutritional value of dehydrates, blue green algae (*Spirulina platensis*) for poultry. Poultry Science. 69(5): 794- 800.

Sandhu G.S. 2005. A text book of fish and fisheries. Dominant

Sasson A. 1997. Micro Biotechnologies: Recent Developments and Prospects for Developing Countries. BIOTEC Publication Place de Fontenoy, Paris. France. United Nations Educational, Scientific and Cultural Organization (UNESCO) 1/2542. 11- 31.

Sharma NK, Tiwari SP, Tripathi K and Rai AK. 2011. Sustainability and cyanobacteria (blue-green algae): facts and challenges. Journal of Applied Phycology. 23(6): 1059- 81.

Shaughnessy O, Kelloff JA, Gordon GJ, Dannenberg GB, Hong AJ, Fabian WK, Sigman CJ, Bertagnolli CC, Stratton MM, Lam SP, Nelson S, Meyskens WG, Alberts FL, Follen DS, Rustgi M, Papadimitrakopoulou AK, Scardino V, Gazdar PT, Wattenberg AF, Sporn LW, Sakr MB, Lippman WA and Von Hoff D SM. 2002. Treatment and prevention of intra-epithelial neoplasia: an important target for accelerate new agent development. Clinical Cancer Res. 8: 314- 346.

Singh PK, Gaur SR and Chari MS. 2006. Growth performance of *Labeo rohita* (H.) fed on diet containing different levels of slaughter house waste. J. Fish. Aqua. Sci. 1(1): 10- 16.

Soheili M and Khosravi-Darani K. 2011. The potential health benefits of algae and micro algae in medicine: a review on *Spirulina platensis*. Cur. Nutr. Food Sci. 7(4): 279- 285.

Sudha SS, Karthic R and Rengaramanujam NJ. 2011. Anti hyperlipidemic activity of *S. platensis* in Triton x-100 induced hyperlipidemic rats. Hygeia. J. D. Med. 3(2): 32- 37.

Syahril MZM, Roshani O, Hasyimah RN, Mohamad Hafiz MS, Sharida MD and Ahmed HY. 2011. Screening of anticancer activities of crude extracts of unicellular green algae (*Chlorella vulgaris*) and filamentous blue green algae (*Spirulina platensis*) on selected cancer cell lines. In: Proc. Inter. Conf. on Appl. Sci., Mathematics and Humanities.

Tacon AGJ. 1993. Feed ingredients for warm water fish meal and other processed feedstuffs. FAO, Fisheries Circular No. 856. Rome: 64.

Takashi S. 2003. Effect of administration of *Spirulina* on egg quality and egg components. Animal Husbandry. 57(1): 191- 195.

Thomas SS. 2010. The role of parry organic *Spirulina* in health management.

Trushina EN, Gladkikh O, Gadzhieva ZM, Mustafina OK and Pozdniakov AL. 2007. The influence of *Spirulina* and selen-*Spirulina* on some indexes of rat's immune status (Article in Russian). VoprPitan. 76(2): 21- 25.

Turcios AE and Papenbrock J. 2014. Sustainable treatment of aquaculture effluents-what can we learn from the past for the future? Sustainability. 6(2): 836- 856.

Van-den-Berg H, Brandsen L and Sinkeldam BJ. 1991. Vitamin B_{12} content and bioavailability of *Spirulina* and nori in rats. Journal of Nutr. Biochem. 2: 314- 318.

Vedi M, Kalaisel S, Rasool M and Sabina EP. 2013. Protective effects of blue green algae *Spirulina fusiformis* against galactosamine- induced hepatotoxicity in mice. Asian J. Pharm. Clin. Res. 6(3): 150- 154.

Vonshak A. 1990. Recent advances in microalgal biotechnology. Biot. Ad. 8: 709- 727.

Watanabe F and Miyamoto E. 1991. TLC Separation and analysis of vitamin B_{12} and related compounds in food. J. Liq. Chrom. Rel. Technol. 25(10-11), 1561-1577.

Yanni YG and Abd El-Rahman AAM. 1993. Assessing P fertilization of rice in the Nile delta involving nitrogen and cyanobacteria. Soil Biology and Biochemistry. 25: 289- 293.

Yoshimatsu T and Hossain MA. 2014. Recent advances in the high-density rotifer culture in Japan. Aquaculture International. 22(5): 1587- 1603.

Zeenat R, Sharma VK and Rizvi Z. 1990. Synergistic effect of cyanobacteria and DAP on tomato yield. Sci. and Culture. 56: 129- 131.