SPIRULINA: THE SINGLE CELL PROTEIN

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ARTICLE INFO

Article history
Received 26/04/2014
Available online
07/05/2014

Keywords
Spirulina,
Antioxidant,
Whey Protein,
Cyanobacterium,
Arthrospira Platensis,
HIV.

ABSTRACT

The algae spirulina has been considered for use as a supplementary protein. It is a blue green algae having strong antioxidant activity and provokes a free radical scavenging enzyme system. The cyanobacterium Arthrospira platensis can be used to produce single cell proteins (SPN), fatty acids (which can be used for bioenergy), food and feed supplements, and biofixation of CO2. SPN regulate gene expression and counteract oxidative stress. Its impact on communities and individuals is more dramatic in Sub-Saharan Africa, where it is compounded by widespread poverty and generalized high prevalence of human immunodeficiency virus (HIV). SPN improve the nutritional status of malnourished HIV-infected patients and nutritional rehabilitation improves on immune status with a consequent drop in viral load. Spirulina can prevent the LPS induced decrease in NPC proliferation; probably spirulina protects by non-stem cell autonomous mechanisms. A diet enriched with spirulina and other nutraceuticals may help protect the stem/progenitor cells from insults. Spirulina maxima prevents fatty liver development induced by carbon tetrachloride (CCl4). It is concluded that the use of spirulina should be encouraged in patients suffering from malnutrition, immuno-suppression, hepatic and neural compromise, etc. although further investigations on the antiviral effects of this alga and its clinical implications are strongly needed.

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Please cite this article in press as Saurabh Kumar Deo et al. Spirulina: the Single Cell Protein. Indo American Journal Of Pharm Research.2014:4(04).

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INTRODUCTION

The algae spirulina has been considered for use as a supplementary protein to feed and food [1]. Spirulina is blue green algae with strong antioxidant activity and provoke a free radical scavenging enzyme system [2]. A chloroplast-type ferredoxin from *Spirulina platensis* crystallized in an orthorhombic system, space group C2221, has cell dimensions a=62.32, b=28.51, and c=108.08 Å [3]. Although several reviews are available on spirulina, we shall emphasize its practical applications in the real case scenario and attempt to project its future implications in health and disease.

Spirulina has been touted as functional food with a number of health benefits. The cyanobacterium *Arthrospira platensis* can be used to produce pigments, single cell proteins, fatty acids (which can be used for bioenergy), food and feed supplements, and biofixation of CO$_2$ [4]. Spirulina regulate the alteration of gene expression and counteract oxidative stress [2]. It is emphasized that malnutrition is a major global public health issue and its impact on communities and individuals is more dramatic in Sub-Saharan Africa, where it is compounded by widespread poverty and generalized high prevalence of human immunodeficiency virus (HIV). Spirulina improve on nutritional status of malnourished HIV-infected patients and nutritional rehabilitation improves on immune status with a consequent drop in viral load [5]. Spirulina is rich in micronutrients (Table 1) [6].

Table 1: Micronutrients found in spirulina.

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Essential amino acids</strong></td>
<td></td>
</tr>
<tr>
<td>Isoleucine</td>
<td>4.13%</td>
</tr>
<tr>
<td>Leucine</td>
<td></td>
</tr>
<tr>
<td>5.80%</td>
<td></td>
</tr>
<tr>
<td>Lysine</td>
<td></td>
</tr>
<tr>
<td>4.00%</td>
<td></td>
</tr>
<tr>
<td>Methionine</td>
<td>2.17%</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td></td>
</tr>
<tr>
<td>3.95%</td>
<td></td>
</tr>
<tr>
<td>Threonine</td>
<td>4.17%</td>
</tr>
<tr>
<td>Valine</td>
<td>6.00%</td>
</tr>
<tr>
<td><strong>Non-essential amino acids</strong></td>
<td></td>
</tr>
<tr>
<td>Alanine</td>
<td>5.82%</td>
</tr>
<tr>
<td>Arginine</td>
<td>5.98%</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td></td>
</tr>
<tr>
<td>6.34%</td>
<td></td>
</tr>
<tr>
<td>Cystine</td>
<td>0.67%</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>8.94%</td>
</tr>
<tr>
<td>Glycine</td>
<td>3.5%</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.08%</td>
</tr>
<tr>
<td>Proline</td>
<td>2.97%</td>
</tr>
</tbody>
</table>
Spirulina contains the yellow/orange pigments cryptoxanthine and beta-carotene from which vitamin A can be made. Spirulina contains 4,000 mg/kg carotenoids (Table 2) [6].

**Table 2: The carotenoids found in spirulina.**

<table>
<thead>
<tr>
<th>Carotenoids</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha-carotene</td>
<td>Traces</td>
</tr>
<tr>
<td>Beta-carotene</td>
<td>1,700 mg/kg</td>
</tr>
<tr>
<td>Xanthophylls</td>
<td>1,000 mg/kg</td>
</tr>
<tr>
<td>Cryptoxanthin</td>
<td>556 mg/kg</td>
</tr>
<tr>
<td>Echinonene</td>
<td>439 mg/kg</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>316 mg/kg</td>
</tr>
<tr>
<td>Lutein</td>
<td>289 mg/kg</td>
</tr>
</tbody>
</table>
History

Spirulina has been used as a food source for centuries, and is still commonly consumed in Chad and surrounding countries in Africa; in fact, spirulina has served as the sole source of nutrition in some African communities in times of famine, during which entire native populations have existed eating only spirulina for over a month at a time [7]. Spirulina was used; cultivated, sold and eaten by Aztecs in the 16th century in the old Aztec capital city of Tenochtitlan, which is the site of modern day Mexico City. It was commonly used as a super food for increased energy and performance. The people of Chad that live near to Lake Chad – where spirulina grows naturally – continue to eat spirulina. They too, regard it as a nutritious whole food [7].

More recently, the United Nations (U.N.) in 1974 named spirulina ‘one of the best foods for the future’. The U.N. continues to consider spirulina to be an important food source and in 2008 the U.N. Food and Agricultural Organization report on spirulina, insisted that both national governments and inter-governmental organizations should consider spirulina [7]. Scientists from the US Space Program at NASA have studied spirulina as a potential food source for space travel and settlement of space stations due to its remarkable nutritional profile. The European Space Agency (ESA) has been exploring different methods of feeding spirulina to their astronauts, including spirulina pasta [7].

Functions

Spirulina is touted as functional food with a number of health benefits as discussed below:

Antioxidant activity:

Hassan et al reported that spirulina regulate the alteration of gene expression and counteract oxidative stress in rats during aflatoxosisis [2]. Eighty male Sprague-Dawley rats were divided into eight groups, which included the control group, the group fed with aflatoxins (AFs)-contaminated diet (2.5 mg/kg diet) for 30 day, the group treated orally with Whey protein coconentrate (WPC) (300 mg/kg b.w.), the group treated orally with spirulina (50 mg/kg b.w), the group treated orally with WPC plus SPN and the groups fed with AFs-contaminated diet and treated orally with WPC, SPN and/or WPC. Oxidative stress markers and gene expression were assayed in liver and testis and the damage of DNA was evaluated by DNA fragmentation and micronucleus tests. The results demonstrated that supplementation of spirulina and/or WPC reduced the oxidative stress induced by AFs as indicated by decreased lipid peroxidation level, increased glutathione content and up-regulated PHGPx gene expression. Both agents to inhibit DNA damage as indicated by the down-regulation of Fas gene expression, and decreased the percentage of DNA fragmentation and micronucleated erythrocytes. Moreover, WPC was found to be effective than spirulina and the combined treatment was more effective than the single treatment. [2].

C-phycocyanin, a biliprotein pigment found in some blue green algae (Spirulina platensis) with nutritional and medicinal properties, was investigated for its efficacy on sodium oxalate-induced nephrotoxicity in experimentally induced urolithic rats. Farooq et al showed that phycocyanin protects the integrity of the renal cell by stabilizing the free radical mediated LPC and protein carbonyl, as well as low molecular weight antioxidants and antioxidant enzymes in renal cells. Thus, the antioxidant nature of C-phycocyanin protects the renal cell against oxalate-induced injury and may be a nephroprotective agent [8].

Enhance immunity:

According to the United Nations program on Acquired Immune Deficiency Syndrome (UNAIDS), about 68% of HIV-infected adults live in Sub-Saharan Africa [5,9]. Despite the fact that antiretroviral treatment (ART) has spectacularly prolonged the life expectancy among these patients infected with HIV, malnutrition remains a major complication of the disease and a public health problem in low income countries; its influence on the progression of HIV infection is frequently reported [10,11,12,13,14]. In Ghana for example, Tabi et al [15] reported that “most patients with HIV and AIDS die because of their poor nutritional status than from the disease itself”. Protein-calorie malnutrition impairs the anti-viral function of macrophages and is directly related to the severity of the HIV infection. Chronic infections generate a significant energy demand including protein catabolism for energy production via gluconeogenesis. This is worsened by protein intake deficiency. Besides, a range of metabolic abnormalities occur in HIV/AIDS patients on ART treatment, including dyslipidaemia, disorders of glucose metabolism, as well as changes in body composition [5,16,17,18,19]. All these are indications that the management of HIV-infected individuals should include an assessment of their nutritional status. WHO recommends that the diet of people living with HIV-AIDS should be supplemented with macronutrients and micronutrients [5]. Spirulina is generally considered safe for human consumption supported by its long history of use as food source and its favorable safety profile in animal studies [5].

Hepatoprotective effect:

Vadiraja et al reported the effect of C-phycocyanin (from Spirulina platensis) pretreatment on carbon tetrachloride and R-(+)-pulegone-induced hepatotoxicity in rats. Intraperitoneal (i.p.) administration (200 mg/kg) of a single dose of phycocyanin to rats, one or three hours prior to R-(+)-pulegone (250 mg/kg) or carbon tetrachloride (0.6 ml/kg) challenge, significantly reduced the hepatotoxicity caused by these chemicals. For instance, serum glutamate pyruvate transaminase (SGPT) activity was almost equal to control values. The losses of microsomal cytochrome P450, glucose-6-phosphatase and aminopyrine-N-demethylase were significantly reduced, suggesting that phycocyanin provides protection to liver enzymes. The level of menthofuran, the proximate toxin of R-(+)-pulegone was nearly 70% more in the urine samples collected from rats treated with R-(+)-pulegone alone than rats treated with the combination of phycocyanin and R-(+)-pulegone [20].
Spirulina maxima may prevent fatty liver development, induced in rats by a single intraperitoneal dose of carbon tetrachloride (CCl₄). Concentration of liver lipids did not differ in rats fed on a purified diet either without or with one of the fractions of spirulina, except for total cholesterol, which showed a slight increase in the group receiving the oil extract of spirulina. However, after CCl₄ treatment, liver total lipids and triacylglycerols were significantly lower in rats fed on a diet containing any fraction of spirulina (defatted or the oil fraction) than in rats without spirulina in their diet. Furthermore, the increased liver cholesterol values, induced by CCl₄ treatment, were not observed in rats receiving spirulina. In addition, rats receiving whole spirulina in their diet and treated only with the vehicle showed an increase in the percentage of HDL values. The changes in VLDL and LDL induced by CCl₄ treatment were not observed in the whole spirulina group. Furthermore, after CCl₄ treatment the values of the liver microsomal thiobarbituric acid-reactive substances were lower in the whole spirulina group than in the control group. These results support the potential hepatoprotective role of spirulina [21].

Promote stem cell genesis:

Adult stem cells are present in many tissues including, skin, muscle, adipose, bone marrow, and in the brain [22]. Neuroinflammation has been shown to be a potent negative regulator of stem cell and progenitor cell proliferation in the neurogenic regions of the brain. Recently we demonstrated that decreasing a key neuroinflammatory cytokine IL-1β in the hippocampus of aged rats reversed the age-related cognitive decline and increased neurogenesis in the age rats. We also have found that nutraceuticals have the potential to reduce neuroinflammation, and decrease oxidative stress. Spirulina protect the proliferative potential of hippocampal neural progenitor cells from an acute systemic inflammatory insult of lipopolysaccharide (LPS) (Fig. 1). To this end, young rats were fed for 30 days a control diet or a diet supplemented with 0.1% spirulina. On day 28, the rats were given a single i.p. injection of LPS (1 mg/kg). The following day the rats were injected with BrdU (50 mg/kg b.i.d. i.p.) and were sacrificed 24 hours after the first injection of BrdU. Quantification of the BrdU positive cells in the subgranular zone of the dentate gyrus demonstrated a decrease in proliferation of the stem/progenitor cells in the hippocampus as a result of the LPS insult. Furthermore, the diet supplemented with spirulina was able to negate the LPS induced decrease in stem/progenitor cell proliferation. In a second set of studies, the authors examined the effects of spirulina either alone or in combination with a proprietary formulation (NT-020) of blueberry, green tea, vitamin D3 and carnosine on the function of bone marrow and CD34⁺ cells in vitro. Spirulina had small effects on its own and more than additive effects in combination with NT-020 to promote mitochondrial respiration and/or proliferation of these cells in culture. When examined on neural stem cells in culture spirulina increased proliferation at baseline and protected against the negative influence of TNFα to reduce neural stem cell proliferation. These results support the hypothesis that a diet enriched with spirulina and other nutraceuticals may help protect the stem/progenitor cells from insults (Fig. 2) [22].

Neurogenesis is a life-long phenomenon that is limited to specific sites within the brain, i.e. subventricular zone (SVZ), and the subgranular zone (SGZ) of the hippocampus. The de novo production of new neurons in the hippocampus has been shown to be important for some forms of learning. Neurogenesis is physiologically relevant for cognitive function. Inflammation tightly regulates neurogenesis in the SGZ and cytokines do appear capable of regulating several phases of the neurogenesis process. At low concentrations, the proinflammatory cytokine TNF-α induces proliferation of neural progenitor cells (NPC), but at higher concentrations TNF-α results in apoptosis. TNF-α induced programmed cell death in the NPC is dependent on TNF receptor 1 (TNF-RI) which is constitutively expressed by NPC in culture. IL-1β can also directly suppress neurogenesis by blocking the production of cyclin dependent kinases. Inflammation also alters the way the new neurons integrate into the existing neuronal circuit [22]. Spirulina was able to prevent the LPS induced decrease in NPC proliferation. The LPS insult did not appear to have pronounced affects on microglial activation but did produce a measurable increase in astrogliosis. Pretreatment with spirulina also blocked the LPS induced astrogliosis. Probably, spirulina protects by non-stem cell autonomous mechanisms [22].

![Fig. 1: Spirulina protects against LPS induced decrease in cell proliferation](www.iajpr.com)
CONCLUSIONS

Herbal medicines continue to have a profound impact on health and disease [23]. Spirulina has a remarkable nutritional profile of natural vitamins, minerals, antioxidants and proteins. It has a diverse array of functions. More functions might be assigned to this single cell protein based on future research. The bottom line is that its use should be encouraged in patients suffering from malnutrition, immuno-suppression, hepatic and neural compromise, etc. Further investigations on the antiviral effects of this alga and its clinical implications are strongly needed.

REFERENCES

