

# Potential health benefits of spirulina microalgae\*

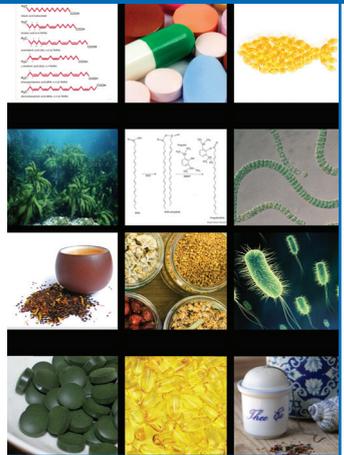
## *A review of the existing literature*

Bob Capelli,  
Gerald R. Cysewski,

Cyanotech Corporation

73-4460 Queen Kaahumanu Highway, Suite 102, Kailua-Kona, Hawaii, 96740, USA  
tel 808.326.1353 - fax 808.329.4533

email [bcapelli@cyanotech.com](mailto:bcapelli@cyanotech.com) - [gcysewski@cyanotech.com](mailto:gcysewski@cyanotech.com) - web [www.cyanotech.com](http://www.cyanotech.com)



### Key words

Spirulina  
Arthrospira platensis  
Immune system  
Cardiovascular system  
Anti-viral action  
Cancer prevention

## SUMMARY

The purpose of this paper is to first describe the species *Arthrospira platensis*, previously referenced as '*Spirulina platensis*' (commonly referred to as 'Spirulina'), and then to provide a review of the literature in regards to four main areas of Spirulina research: Immune system modulation; anti-viral activity; cancer preventive properties, and cardiovascular benefits. This paper focuses on research done since the year 2000, but references some important work completed before 2000 in certain cases. All citations are from published journals.

## INTRODUCTION

### Arthrospira platensis (Spirulina)

#### Description

*Arthrospira platensis* (hereafter referred to as 'Spirulina') is a uni-cellular microalgae which grows in fresh water, in salt water, as well as in brackish bodies of water. It grows best in a highly alkaline environment of pH 10-12. Such conditions currently exist in certain lakes in Sub-Saharan Africa and formerly in Mexico and Central America. 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.

#### Current Use

Spirulina has become popularly known as a superfood due to the great diversity and concentration of nutrients it contains. It is the most nutritious, concentrated whole food source found in nature. Spirulina is marketed throughout the world as a food supplement or as an

active ingredient in functional foods and beverages. It has attained considerable acceptance for the health benefits it bestows on consumers in Europe, North America, parts of Asia and Oceania. Spirulina's concentrated nutrition makes it an ideal food supplement for people of all ages and lifestyles.

#### Composition

Spirulina is about sixty percent complete, highly digestible protein; it contains all essential amino acids; Spirulina contains more beta-carotene than any other whole food; it is the best whole food source of gamma linolenic acid (GLA); it is rich in B vitamins, minerals, trace elements, chlorophyll, and enzymes; and it is abundant in other nutrients, such as carotenoids, sulfolipids, glycolipids, phycocyanin, superoxide dismutase, RNA, and DNA. Table 1 shows the typical nutrient content of a commercially available Spirulina product.

#### United Nations and NASA Interest

Due to its wealth of nutrients and health benefits reported by consumers, Spirulina has been subjected to research throughout the world. In 1974, the United Nations named Spirulina one of the best foods for the future. (1). The UN continues to study Spirulina's potential; in 2008 the UN Food and Agriculture Organization (FAO) report on Spirulina proclaimed that there is a need for both national governments and inter-governmental organizations to re-evaluate the potential of Spirulina to fulfill both their own food security needs as well as a tool for their overseas development emergency response efforts. (2) It is interesting to also note that 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 nutrient profile (3).

\*An extensive compilation of published research on the potential health benefits of Spirulina is available from the authors. Please contact us at [info@cyanotech.com](mailto:info@cyanotech.com)

### Nutrient Levels

Besides basic nutrients such as amino acids, essential fatty acids, vitamins and minerals, Spirulina supplies many phytonutrients that are lacking in most of our diets. Moreover, Spirulina supplies common nutrients at high levels; comparing Spirulina with other foods shows its unusual nutrient profile (*Table 1*). A few examples:

### Nutrient profile of Spirulina vs other foods

- 180% more calcium than whole milk
- 670% more protein than tofu
- 3100% more beta carotene than carrots
- 5100% more iron than spinach
- more antioxidant and anti-inflammatory activity in 3 g of Spirulina than in five servings of fruits and vegetables (4).

### Diversity of Research

Research on Spirulina's health benefits has been far-ranging. The antioxidant and anti-inflammatory effects have been documented in the literature. Other areas of research on Spirulina are varied; among many potential health applications researched are the following:

- Protection of the liver and kidneys
- Improvement of blood quality and prevention of anemia
- Benefits for diabetes
- Removal of heavy metals from the body
- Control of allergic rhinitis

Recent research as a neuroprotective agent looks promising (5-7), but because of its still preliminary nature will not be reviewed here. The areas of potential health benefits for Spirulina that will be referenced for the purposes of this review, each with a significant body of research, will be limited to immunity; anti-viral properties; cancer prevention; and cardiovascular health.

## IMMUNE SYSTEM

The benefits of Spirulina in building immunity and improving resistance to viral infections are well documented. For decades, users have anecdotally reported a decrease in colds and flu from Spirulina use. (3,4) Several pre-clinical animal studies have shown good immunostimulatory effects in a variety of species. In humans, mammals, chicken and fish Spirulina produces an immunostimulating effect by enhancing the resistance to infections, the capacity of influencing hemopoieses, and stimulating the production of antibodies and cytokines. Spirulina has also been shown to activate macrophages, T and B cells. Sulfolipids derived from Spirulina have proved effective against HIV. Extracts from Spirulina biomass have also been found active against herpes virus, cytomegalovirus, influenza virus, etc. Spirulina extracts have also been shown capable of inhibiting carcinogenesis. (8).

**Table 1** Typical analysis per 100 grams for *Spirulina pacifica*<sup>®</sup>

Item	Amount
<b>General</b>	
Total Calories (Kcal)	333
Calories from Fat (Kcal)	50
Total Fat (g)	5
Saturated Fat (g)	2.2
Cholesterol (mg)	0
Total Carbohydrates (g)	16
Dietary Fiber (g)	7
Sugars (g)	0
Protein (g)	67
<b>Vitamins</b>	
Vit A (as Beta carotene) (IU)	375000
Vitamin E (IU)	7
Vitamin K1 (µg)	2000
Vitamin K2(µg)	500
Thiamin (B1) (µg)	117
Riboflavin (B2) (µg)	4667
Niacin (B3) (µg)	13333
Vitamin B6 (µg)	1000
Folate (µg)	200
Vitmain B12 (µg)	300
Biotin (µg)	<33
Pantothenic acid (µg)	150
<b>Minerals</b>	
Calcium (mg)	333
Iron (mg)	217
Phosphorous (mg)	1100
Iodine (µg)	500
Magnesium (mg)	500
Zinc (mg)	3
Selenium (µg)	30
Copper (mg)	0.7
Manganese (mg)	13
Chromium (µg)	1333
Sodium (mg)	1000
Potassium (mg)	2000
<b>Carotenoids &amp; Phytonutrients</b>	
Gamma Linolenic Acid (GLA) (mg)	1067
Zeaxanthin (mg)	300
Total carotenoids (mg)	500
Chlorophyll (mg)	1000
C-Phycocyanin (mg)	8000
Superoxide dismutase (units)	36000

A great deal of research has been done on Spirulina and extracts from Spirulina in Japan. A hot water extract of Spirulina has shown very promising effects on the human immune system. In one study done in Japan, blood analysis of volunteers given a hot water Spirulina extract showed significant improvement in immune markers. These Spirulina extracts potentiate the immune system leading to suppression of cancer development and viral infection. These researchers identified the mechanism of action for Spirulina's immune potentiating capacity:

They found that subjects given the Spirulina extract had higher levels of natural killer cells interferon gamma and more potent production of interleukin-12p40. Spirulina may be involved in signaling responses through toll-like receptors in blood cells even when orally administered. Toll-like receptors are a class of proteins that play a key role in the innate immune system. This may indicate that in humans, Spirulina acts directly on myeloid lineages and either directly or indirectly on NK cells (9).

In 2008, researchers in Copenhagen experimented with Immulina, a high-molecular-weight polysaccharide extract from Spirulina (10). They found that Immulina is between 100x and 1000x more active in activating monocytes *in vitro* than polysaccharide preparations that were being used at the time in clinical settings for cancer immunotherapy. This 100-1000 fold increase in activity is quite remarkable. They followed this up with two additional studies in 2006, one *in vitro* and one rodent study, both confirming their earlier conclusions in regards to immune system enhancement (11). The findings in the rodent study suggested that cells of the innate immune system were activated by oral consumption in mice (12).

The research on Immulina in Denmark included both *in vitro* experimentation and human clinical analysis. *In vitro*, Immulina was found to be strongly active against *Candida albicans* and tetanus toxoid. In healthy human volunteers consuming Immulina, blood immune markers tumor necrosis factor alpha, interferon gamma, and interleukin-6 were all significantly enhanced when tested at both 8 and 14 days of continuous consumption. Effects on other immune markers during 56 days of continuous consumption were tested, also with positive results. This research indicates an age-dependent, temporary enhancement of adaptive immune responses was caused by Immulina (13).

Phycocyanin is a water-soluble blue pigment found only in Spirulina and other species of blue-green microalgae. Phycocyanin is a potent antioxidant and possesses significant immune enhancing and anti-viral properties. Early work done in Japan on phycocyanin's anti-viral properties will be discussed later; a more recent study from Japan found a potent immunostimulatory effect and a reduction of allergic inflammation in rodents given phycocyanin. Results indicated an increase in resistance to infectious diseases and a significant effect on immunoglobulin E (IgE) antibodies. The researchers concluded that phycocyanin enhances biological defense activity against infectious diseases through sustaining functions of the mucosal immune system and reduces allergic inflammation by the suppression of antigen-specific IgE antibody (14).

M. Eric Gershwin has published two studies on Spirulina; one with positive results on allergic rhinitis (15) and another *in vitro* study that will be reviewed here on

the immunostimulatory potential of Spirulina (16). This study found several different mechanisms for Spirulina's effects on immunity, including stimulating the secretion of interleukin-1beta, interleukin-4 and interferon gamma by 2.9, 4.0 and 1.6 times respectively. However, Spirulina was much more effective in the generation of a Th1-type response. This *in vitro* study supports the potential therapeutic benefits of Spirulina on immune responses (16).

### Anti-Viral Properties

Certainly, a food, a nutritional supplement or a drug that has documented anti-viral activity as well as an ability to positively affect the immune response would be of considerable clinical interest. Based on the existing research, Spirulina shows great potential in both of these related areas of disease resistance. Unique nutrients found within Spirulina once again play an important role in Spirulina's function as an antiviral. In 1996, researchers in Japan isolated a sulfated polysaccharide found in Spirulina to research as an antiviral agent. They named this compound 'Calcium Spirulan.' These researchers published two studies in the 1990's demonstrating that Calcium Spirulan is effective against a variety of viruses. Calcium Spirulan inhibited the replication of enveloped viruses such as *Herpes simplex* type 1, human cytomegalovirus, measles, mumps, influenza A and HIV-1. Calcium Spirulan selectively inhibited the penetration of virus into host cells. (17) Their second study compared the antiviral activity of Calcium Spirulan with a well-researched antiviral called dextran sulfate. The two antiviral agents were tested against HIV-1 and *Herpes simplex* virus type 1. Calcium Spirulan was found to be a superior antiviral to dextran sulfate indicating that Calcium Spirulan is a potent antiviral agent against both HIV-1 and HSV-1. Even at low concentrations of Calcium Spirulan, an enhancement of virus-induced syncytium formation was not observed, as was observed in dextran sulfate treated cultures. The researchers concluded that Calcium Spirulan can be a candidate agent for an anti-HIV therapeutic drug that might overcome the disadvantages observed in many sulfated polysaccharides (18).

An interesting paper (19) related to this antiviral research from Japan against HIV proposed that consumption of algae on a regular basis may inhibit the replication of HIV in consumers. They cite the literature demonstrating HIV inhibition by algae *in vivo* and *in vitro*, and also epidemiological evidence that populations with high algae consumption have correspondingly low rates of HIV infection. They point out that even within Africa where the highest rates of HIV infection are found, the rates vary dramatically between different countries and groups of people. Chad has a low reported rate of HIV/AIDS compared to the rest of Africa. A major tribal group in Chad, the Kanemba, eat Spirulina every day, consuming between 3 to 13 grams per day. The researchers drew a

correlation between the use of Spirulina in Chad and the low incidence of HIV/AIDS, concluding that the regular consumption of Spirulina could help prevent HIV infection and decrease viral loading of those infected (19).

Simple water extracts of Spirulina as well as dried Spirulina biomass have both also demonstrated antiviral activities. A study done by a group of researchers from both the Dana-Farber Cancer Institute and the Harvard Medical School demonstrated similar results to the Calcium Spirulan research cited above: The Spirulina water extract showed inhibition against HIV-1. When the virus was preincubated with the water extract prior to addition to human T-cells, the infectivity of HIV-1 was inactivated. When the water extract was fractionated, antiviral activity was found in both the polysaccharide fraction and the fraction depleted of polysaccharides and tannins. The researchers concluded that aqueous *Spirulina platensis* extracts contain antiretroviral activity that may be of potential clinical interest (20). This study is interesting in that it demonstrated that both the polysaccharide component of Spirulina (similar to Calcium Spirulan) and the remaining components of Spirulina extract after the polysaccharides have been removed both show antiviral properties. From this research we can deduce that Spirulina's anti-viral properties are not only derived from its polysaccharides; other components in Spirulina also play a role in its antiviral activity.

Additionally, a group of researchers in 2002 found a hot water extract of Spirulina to be effective against Herpes simplex virus types 1 and 2, pseudorabies virus and human cytomegalovirus (21). Finally, another study from 2002 on dried Spirulina's antiviral activity on the bacterial virus, bacteriophage T4, also showed promising results (22).

## CANCER PREVENTIVE POTENTIAL

Although there is not a great deal of human clinical research, there are numerous studies showing Spirulina's potential to prevent carcinogenesis and to shrink tumors in animal models. As early as 1987, researchers at Harvard University's School of Dental Medicine published evidence that a combination of Spirulina and Dunaliella microalgae extracts induced the regression of tumors in the mouths of rodents. Total tumor regression was found in 30% of the animals receiving the Spirulina and Dunaliella extracts, while partial tumor regression was found in all of the remaining 70% of the animals; meanwhile, in the control group, no tumor regression was found (23). The following year another study from Harvard showed that this same Spirulina and Dunaliella extract could prevent tumor development in rodent mouths (24). These two studies, although not on Spirulina alone, are very significant for the purpose of this review because they showed both a preventative and a curative potential for microalgae against cancer.

After tumor regression and also tumor prevention had been demonstrated by microalgae in animal models, a human clinical trial was conducted on pre-cancerous lesions in 1995. This study was conducted on pure Spirulina as compared to the previous animal trials which employed a combination of two species of microalgae. Subjects in the treatment group consumed a relatively low dose of Spirulina of 1 g per day for 12 months. Current dosages recommended for commercially sold Spirulina products are generally 1.5 g to as much as 5 g per day) This study was designed to examine the chemopreventive activity of Spirulina in reversing oral leukoplakia in subjects who chewed tobacco. (Leukoplakia is a condition with pre-cancerous lesions that develop on the inside of the cheek, the tongue or other parts of the oral cavity due to chronic irritation. It is quite common among chronic tobacco chewers.) The results of this study were quite promising: Complete regression of pre-cancerous oral lesions were seen in 45% of the 44 subjects consuming Spirulina, while only 7% of the 43 members of the placebo group experienced complete regression. Interestingly, within one year of discontinuing Spirulina supplementation, 9 out of 20 subjects who had previously been found to be in complete regression had developed recurrent lesions (25).

Since this early research, a great deal of investigation has taken place showing promise for Spirulina in the prevention and treatment of various cancers. Similar to our review of the literature on immunity and viruses above, the anti-cancer research has been conducted on pure Spirulina biomass as well as on 1) polysaccharides isolated from Spirulina; 2) hot water extracts of Spirulina biomass that has not been specifically isolated for a single active constituent; and quite notable and extensive research on 3) the blue pigment found only in Spirulina and in other species of blue-green microalgae called 'phycocyanin.' This research has grown since 2000, and has examined a variety of cancers in an assortment of different organs. Polysaccharide cancer research began in 1998 on Calcium Spirulan with a study examining its effects on three different types of cancers - carcinoma, melanoma and fibrosarcoma. Calcium Spirulan significantly inhibited the invasion of each of these tumor cells (26). Further research conducted on stem cell systems has also shown potential for Spirulina-derived polysaccharides. One such study from 2001 concluded, 'The polysaccharide of *Spirulina platensis* has chemo-protective and radio-protective capability, and may be a potential adjunct to cancer therapy' (27). A later study in the same area found that the polysaccharide extract from Spirulina significantly improved bacterial cell and increased the levels of interleukins 1 and 3 and tumor necrosis factor alpha (28).

Water extracts from Spirulina contain the water soluble pigment C-phycocyanin. There are several recent studies over the last few years that show cancer related benefits to both unrefined water extracts of Spirulina as well as

isolated C-phycoyanin. In fact, in just the last two years, water extracts of *Spirulina* have appeared in the literature three times showing such benefits. Two of these studies centered once again on oral cancer (29,30) while the third demonstrated an enhancement of antitumor natural killer cells through consumption of the extract. The third study is of particular interest-conclusions drawn found that orally administered *Spirulina* enhanced tumoricidal NK activation and inferred a potential for antitumor immunotherapy (31).

Research has been conducted in the last six years on phycoyanin's antitumoral effect. The results have proven very promising:

- 49% decrease in the proliferation of leukemia cell lines (32)
- 50% decrease in the proliferation of hepatocellular carcinoma (liver cancer) cell lines (33)
- significant decrease in HeLa cells *in vitro* compared to control cells (34) (HeLa cells are an immortal cancerous cell line extracted from cervical cancer cells in 1951)
- inducement of apoptotic features including cell shrinkage in these same HeLa cells (34)
- impedance of the reproduction of HeLa cells (35)
- in conjunction with selenium, phycoyanin was found to be a potent antiproliferative agent against human melanoma cells and human breast adenocarcinoma MCF-7 cells (36).

Many researchers find phycoyanin to be a truly exciting compound - described as a non-toxic fluorescent protein pigment with potent antioxidant, anti-inflammatory and anti-cancer properties (32); and this pigment is only found in *Spirulina* and other species of blue green algae.

An interesting study compared the activity of *Spirulina* with two other nutritional compounds - Vitamin E and germanium-132 - in pre-cancerous crypts in the colon. While the researchers found that all three compounds had some inhibitory effects, they pointed out that when tested after 9, 13 and 16 weeks, the number of aberrant crypts was significantly less in the *Spirulina* group as compared to the control group (37).

Another study on pure *Spirulina* biomass measured the inhibition of tumors in skin and stomach. At *Spirulina* usage levels in rodents of 250 mg and 500 mg/kg body weight, inhibition of tumors was found in both the skin and stomach regions. The skin tumors in the *Spirulina* group reduced from 4.86 to 1.20% at the lower dose and from 4.86 to 1.15% in the higher dose group. In stomach tumors, the low dose group found a reduction from 3.73 to 2.05% and the high dose group found a reduction from 3.73 to 1.73% (38). Lastly, a recent study from 2008 showed once again a cancer preventative effect of pure *Spirulina* biomass. This research showed a protective effect of *Spirulina* in relation to induced genetic cell damage (39).

## CARDIOVASCULAR BENEFITS

The cardiovascular benefits of *Spirulina* use are described in many papers. A review published in 2009 noted several reports suggesting that *Spirulina* (*Arthrospira*) may have a beneficial effect in the prevention of cardiovascular diseases. Decreases in blood pressure and plasma lipid concentrations, especially triacylglycerols and low density lipoprotein-cholesterol have been demonstrated as a result of oral consumption of *Spirulina*. *Spirulina* has also been shown to indirectly modify the total cholesterol and high density lipoprotein-cholesterol values (40). A recent human trial validates the above referenced review in an open sample of the population. Results showed that total cholesterol and triacylglycerols were significantly decreased in the *Spirulina* group, and HDL levels saw a significant increase, while both systolic and diastolic blood pressure decreased. Again, *Spirulina* showed a hypolipidemic effect (41).

In Korea, a clinical trial was done on 78 elderly men and women, 60 to 87 years of age, to see the effects of *Spirulina* consumption on blood lipid profiles, as well as on immune markers and antioxidant capacity. As compared to placebo in this double blind, randomized trial, *Spirulina* users had lower cholesterol and increased interleukin-2 and decreased interleukin-6. *Spirulina* had a favorable effect on lipid profiles, immune variables, and antioxidant capacity in healthy, elderly males and females. The researchers concluded that *Spirulina* is suitable as a functional food. (42). This Korean study was done on random population, while the study described below was done on patients with hyperlipidemic nephrotic syndrome (nephrotic syndrome is damage to the kidneys). These researchers pointed out that essential fatty acids like GLA can prevent cholesterol from concentrating in the body, and noted that *Spirulina* has a considerable amount of GLA. The study included 23 subjects suffering from nephrotic syndrome who were divided into two groups. Group I was given medication for nephrotic syndrome alone, and group II was given medication for nephrotic syndrome plus 1 g of *Spirulina* per day for a period of two months. The researchers found significantly lower levels of total cholesterol, LDL-C and triglycerides in subjects supplementing with *Spirulina* than with those taking nephrotic syndrome medication alone. A comparison of the two groups found that total cholesterol decreased by 65% more with *Spirulina* consumption; LDL-C decreased by 54% more with *Spirulina* consumption; while triglycerides saw a decrease of almost 200% more with *Spirulina* consumption. The authors concluded that spray-dried *Spirulina* capsules, rich in antioxidants, GLA, amino acids and fatty acids, helped reduce the increased levels of lipids in patients with hyperlipidemic nephrotic syndrome (43).

Similar to other areas reviewed here on immunomodulation and cancer prevention, in the reviewing of *Spirulina*'s benefits for the cardiovascular system we find

supporting pre-clinical animal trials as well as studies on water extracts and phycocyanin. All of these studies add to the critical mass of evidence that Spirulina is a preventative tonic for the heart and cardiovascular system. One study from Japan in 2005 established a mechanism of action for Spirulina's action on blood lipids. This work was done both *in vitro* and in rats. *In vitro*, Spirulina showed a significantly higher bile acid-binding capacity than the control substance casein. Cholesterol solubility and uptake by Caco-2 cells was significantly lower in the presence of Spirulina as compared to casein. In rats, excretion of cholesterol and bile acids was significantly greater in rats fed Spirulina than in rats fed casein. Both serum and liver cholesterol levels were lower in the Spirulina-fed rats. The researchers concluded that Spirulina's hypocholesterolemic action may be due to the inhibition of cholesterol absorption and bile acid reabsorption. A hypocholesterol protein had yet to be found among algal proteins. However, this study reports the discovery of a hypocholesterolemic effect in the novel protein C-Phycocyanin. This study provides direct evidence that C-phycocyanin, can positively influence serum cholesterol concentrations (44).

Around the same time, other researchers reported evidence that both Spirulina alone and C-phycocyanin extracted from Spirulina can have a preventive effect on drug-induced cardiac side effects as well as a protective effect during heart attacks (45-47). In the first two studies, in a mouse model, they tested first Spirulina and then phycocyanin isolated from Spirulina as protectants against the adverse cardiac side effects of the common chemotherapy drug doxorubicin. This drug can produce several different cardiac side effects including congestive heart failure when used at higher doses. They concluded that Spirulina significantly protected the mice from cardiotoxic effects (45). In the second study they found a similar effect in pure C-phycocyanin. The positive results led them to what they referred to as a 'crucial role of the antioxidant nature of C-phycocyanin in cardioprotection' (46). The final study in this series measured the ability of both isolated phycocyanin and pure Spirulina in solution to protect rat hearts from damage during heart attack and help with recovery from the heart attack. Both substances showed good results, with the concentrated phycocyanin showing even greater benefits than pure Spirulina. Consumption of phycocyanin or Spirulina enhanced recovery of heart function as evident by decreased infarct size, attenuated lactate dehydrogenase and creatine kinase release, and suppressed ischemia-reperfusion induced free radical generation (47). This series of animal trials showed how promising Spirulina and phycocyanin can be for a leading cause of death.

Recent research on water extracts of Spirulina, on Sodium Spirulan, a novel polysaccharide isolated from Spirulina, and on a combination of phycocyanin from Spirulina with selenium have all showed cardioprotective

qualities. Summaries of these findings show:

- A water extract from Spirulina may inhibit the intestinal absorption of dietary fat by inhibiting pancreatic lipase activity (48)
- The sulfated polysaccharide Sodium Spirulan significantly inhibits vascular endothelial cell proliferation (49)
- Sodium Spirulan is a potent inhibitor of arterial smooth muscle cell proliferation (50)
- Selenium-rich phycocyanin extracted from Spirulina prevents the development of atherosclerosis (51).

## CONCLUSIONS

Spirulina is highly nutritious and shows great diversity and higher concentrations of nutrients compared to other food sources. In fact, it is among the most nutritious, concentrated whole food sources found in nature, contributing to its being known as a superfood. In this review, we have examined several areas of research showing the potential of Spirulina as a food supplement. Research on this uni-cellular, blue-green microalgae began in the 1970's, and has increased in the last ten years. We have examined a series of published studies, most of which were published since the year 2000. Many studies investigated benefits from pure Spirulina biomass, but some also researched extracts of Spirulina or isolated compounds from Spirulina (primarily C-phycocyanin, the blue-green pigment found only in Spirulina and other species of blue-green microalgae). From this review it may be concluded that:

- Spirulina shows potent immune stimulating effects
- Spirulina shows anti-viral activity against a variety of harmful viruses
- Spirulina shows promise as a cancer preventative agent and in the treatment of tumors
- Spirulina shows far ranging cardiovascular benefits including improvement of blood lipid profiles, prevention of atherosclerosis, and control of hypertension.

The potential of Spirulina and its constituent pigment C-phycocyanin in the four areas reviewed encourages further research and encourages considering daily supplementation with Spirulina.

## REFERENCES

- 1 **United Nations World Food Conference (1974)**  
As reported on the Intergovernmental Institution for the Use of Microalgae Spirulina Against Malnutrition (Permanent Observer to the United Nations Economic and Social Council) [www.iimsam.org](http://www.iimsam.org)
- 2 **United Nations Food and Agriculture Organisation (FAO) Report (2008)**  
As reported on the Intergovernmental Institution for the Use of Microalgae Spirulina Against Malnutrition (Permanent Observer to the United Nations Economic and Social Council) [www.iimsam.org](http://www.iimsam.org)

- 3 **Henrikson R (1989)**  
Earth Food Spirulina Ronore Enterprises, Inc ISBN #0-9623111-0-3
- 4 **Moorhead K, Capelli B, Cysewski G (2005)**  
Nature's Superfood: Spirulina ISBN #0-9637511-3-1
- 5 **Gemma C, Mesches MH, Sepesi B, Choo K, Holmes DB, Bickford PC (2002)**  
Diets enriched in foods with high antioxidant activity reverse age-induced decreases in cerebellar b-andrenergic function and increases in pro-inflammatory cytokines  
*J Neurosci* **22**(14) 6114-6120
- 6 **Stromberg I, Gemma C, Vila J, Bickford PC (2005)**  
Blueberry and Spirulina-enriched diets enhance striatal dopamine recovery and induce a rapid, transient microglia activation after injury of the rat nigrostriatal dopamine system  
*J Exp Neurol* **196**(2) 298-307
- 7 **Wang Y, Chang CF, Chou J, Chen HL, Deng X, Harvey BK, Cadet JL, Bickford PC (2005)**  
Dietary supplementation with blueberries, spinach or Spirulina reduces ischemic brain damage.  
*J Exp Neurol* **193**(1) 75-84
- 8 **Blinkova LP, Gorobets OB, Baturo AP (2001)**  
Biological activity of Spirulina  
*Mikrobal Epidemiol Immunobiol* **2** 114-118
- 9 **Hirahashi T, Matsumoto M, Hazeki K, Saeki Y, Ui M, Seya T (2002)**  
Activation of the human innate immune system by Spirulina: augmentation of interferon production and NK cytotoxicity by oral administration of hot water extract of Spirulina platensis  
*Internat Immunopharmacol* **2**(4) 423-434
- 10 **Pugh N, Ross SA, ElSohly HN, ElSohly MA, Pasco DS (2001)**  
Isolation of three high molecular weight polysaccharide preparations with potent immunostimulatory activity from Spirulina platensis, aphanizomenon flos-aquae and Chlorella pyrenoidosa  
*Planta Medica* **67**(8) 737-742
- 11 **Grzanna R, Polotsky A, Phan PV, Pugh N, Pasco D, Frondoza CG (2006)**  
Immulina, a high-molecular-weight polysaccharide fraction of Spirulina, enhances chemokine expression in human monocytic THP-1 cells  
*J Alternate Compliment Med* **12**(5) 429-435
- 12 **Balachandran P, Pugh ND, Ma G, Pasco DS (2006)**  
Toll-like receptor 2-dependent activation of monocytes by Spirulina polysaccharide and its immune enhancing action in mice  
*Internat Immunopharmacol* **6**(12) 1808-1814
- 13 **Lobner M, Walsted A, Larsen R, Bendtzen K, Nielsen CH (2008)**  
Enhancement of human adaptive immune responses by administration of a high-molecular-weight polysaccharide extract from the cyanobacterium Arthrospira platensis  
*J Med Food* **11**(2) 313-322
- 14 **Nemoto-Kawamura C, Hirahashi T, Nagai T, Yamada H, Katoh T, Hayashi O (2004)**  
Phycocyanin enhances secretory IgA antibody response and suppresses IgE antibody response in mice immunized with antigen-entrapped biodegradable microparticles  
*J Nutri Sci Vitaminol* **50**(2) 129-136
- 15 **Mao TK, Van de Water J, and Gershwin ME (2005)**  
Effects of a Spirulina-based dietary supplement on cytokine production from allergic rhinitis patients  
*J Med Food* **8**(1) 27-30
- 16 **Mao TK, Van de Water J, Gershwin ME (2000)**  
Effect of Spirulina on the secretion of cytokines from peripheral blood mononuclear cells  
*J Med Food* **3**(3) 135-140
- 17 **Hayashi T, Hayashi K, Maeda M, Kojima I (1996)**  
Calcium Spirulan, an inhibitor of enveloped virus replication, from a blue-green alga Spirulina platensis  
*J Nat Prod* **59**(1) 83-87
- 18 **Hayashi K, Hayashi T, Kojima I (1996)**  
A natural sulfated polysaccharide, Calcium Spirulan, isolated from Spirulina platensis: *In vitro* and *ex vivo* evaluation of anti-herpes simplex virus and anti-human immunodeficiency virus activities  
*Aids Res Human Retroviruses* **12**(15) 1463-1471
- 19 **Teas J, Hebert JR, Fitton JH, Zimba PV (2004)**  
Algae - a poor man's HAART?  
*Med Hypothesis* **64**(4) 507-510
- 20 **Ayehunie S, Belay A, Baba TW, Ruprecht RM (1998)**  
Inhibition of HIV-1 replication by an aqueous extract of Spirulina platensis (Arthrospira platensis)  
*J Acq Immune Def Syndromes Human Retrovirol* **18**(1) 7-12
- 21 **Hernandez-Corona A, Nieves I, Meckes M et al (2002)**  
Antiviral activity of Spirulina maxima against herpes simplex virus type 2  
*Antiviral Res* **56**(3) 279-285
- 22 **Gorobets OB, Blinkova LP, Baturo AP (2002)**  
Action of Spirulina platensis on bacterial viruses  
*Mikrobal Epidemiol Immunobiol* **(6)** 18-21
- 23 **Schwartz J, and Shklar G (1987)**  
Regression of experimental hamster cancer by beta carotene and algae extracts  
*J Oral Maxillofacial Surg* **45**(6) 510-515
- 24 **Schwartz J, Shklar G, Reid S, Trickler D (1988)**  
Prevention of experimental oral cancer by extracts of Spirulina-Dunaliella algae  
*Nutr Cancer* **11**(2) 127-134
- 25 **Mathew B, Sankaranarayanan R, Nair PP, Varghese C, Somnathan T, Amma BP, Amma NS, Nair MK (1995)**  
Evaluation of chemoprevention of oral cancer with Spirulina fusiformis  
*Nutr Cancer* **24**(2) 197-202
- 26 **Mishima T, Marata J, Toyoshima M, Fujii H et al (1998)**  
Inhibition of tumor invasion and metastasis by calcium spirulan (Ca-SP), a novel sulfated polysaccharide derived from a blue-green alga, Spirulina platensis  
*Clin Exp Metas* **16**(6) 541-550
- 27 **Zhang HQ, Lin AP, Sun Y, Deng YM (2001)**  
Chemo- and radio-protective effects of polysaccharide of Spirulina platensis on hemopoietic system of mice and dogs  
*Acta Pharmacol Sinica* **22**(12) 1121-1124
- 28 **Liu XM, and Zhang HQ (2002)**  
Effect of polysaccharide from Spirulina platensis on hematopoietic cells proliferation, apoptosis and Bcl-2 expression in mice bearing tumor treated with chemotherapy  
*Acta Pharmacol Sinica* **37**(8) 616-620
- 29 **Grawish ME (2008)**  
Effects of Spirulina platensis extract on Syrian hamster cheek pouch mucosa painted with 7,12-dimethylbenz(a)anthracene  
*Oral Oncol* **44**(10) 956-962

- 30 Grawish ME, Zaber AR, Gaafar AI, Nasif WA (2010)**  
Long-term effect of Spirulina platensis extract on DMBA-induced hamster buccal pouch carcinogenesis (immunohistochemical study)  
*Med Oncol* 27(1) 20-28
- 31 Akao Y, Ebihara T, Masuda H, Saeki Y, Akazawa T et al (2009)**  
Enhancement of antitumor natural killer cell activation by orally administered Spirulina extract in mice  
*Cancer Sci* 100(8) 1494-1501
- 32 Subbashini J, Mahipal SV, Reddy MC, Mallikarjuna Reddy M, Rachamalla A, Reddanna P (2004)**  
Molecular mechanisms in C-Phycocyanin induced apoptosis in human chronic myeloid leukemia cell line K-562  
*Biochem Pharmacol* 68(3) 453-462
- 33 Roy KR, Arunasree KM, Reddy NP, Dheeraj B et al (2007)**  
Alteration of mitochondrial membrane potential by Spirulina platensis C-phycocyanin induces apoptosis in the doxorubicinresistant human hepatocellular-carcinoma cell line HepG2  
*Biotechnol Appl Biochem* 47(Pt 3) 159-167
- 34 Li B, Gao MH, Zhang XC, Chu XM (2006)**  
Molecular immune mechanism of C-phycocyanin from Spirulina platensis induces apoptosis in HeLa cells *in vitro*  
*Biotechnol Appl Biochem* 43(Pt 3) 155-164
- 35 Li B, Zhang X, Gao M, Chu X (2005)**  
Effects of CD59 on antitumoral activities of phycocyanin from Spirulina platensis  
*Biochem Pharmacol* 59(10) 551-560
- 36 Chen T, Wong YS (2008)**  
*In vitro* antioxidant and antiproliferative activities of selenium-containing phycocyanin from selenium-enriched Spirulina platensis  
*J Agricul Food Chem* 56(12) 4352-4358
- 37 Chen F, and Zhang Q (1995)**  
Inhibitive effects of Spirulina on aberrant crypts in colon induced by dimethylhydrazine  
*Chinese J Prevent Med* 29(1) 13-17
- 38 Dasgupta T, Banejee S, Yadav PK, Rao AR (2001)**  
Chemomodulation of carcinogen metabolizing enzymes, antioxidant profiles and skin and forestomach papillomagenesis by Spirulina platensis  
*Mol Cell Biochem* 226(1-2) 27-38
- 39 Chamorro-Cevalls G, Garduno-Siciliano L, Barron BL, Madrigal-Bujaidar E, Cruz-Vega DE, Pages N (2008)**  
Chemoprotective effect of Spirulina (Arthrospira) against cyclophosphamide-induced mutagenicity in rats  
*Food Chem Toxicol* 46(2) 567-574
- 40 Juarez-Oropeza MA, Mascher D, Torres-Duran PV, Farias JM, Paredes-Carbajal MC (2009)**  
Effects of Spirulina on vascular reactivity  
*J Med Food* 12(1) 15-20
- 41 Torres-Duran PV, Ferreira-Hermosillo A et al (2007)**  
Antihyperlipidemic and antihypertensive effects of Spirulina maxima in an open sample of Mexican population: a preliminary report  
*Lipids Health Dis* 26 6-33
- 42 Park HJ, Lee YJ, Ryu HK, Kim MH, Chung HW, Kim WY (2008)**  
A randomized double-blind, placebo-controlled study to establish the effects of Spirulina in elderly Koreans  
*Annals Nutr Metab* 52(4) 322-328
- 43 Samuels R, Mani UV, Iyer UM, Nayak US (2002)**  
Hypocholesterolemic effect of Spirulina in patients with hyperlipidemic nephrotic syndrome  
*J Med Food* 5(2) 91-96.
- 44 Nagaoka S, Shimizu K, Kaneko H, Shibayama F, Morikawa K, et al (2005)**  
A novel protein C-phycocyanin plays a crucial role in the hypocholesterolemic action of Spirulina platensis concentrate in rats  
*J Nutr* 135(10) 2425-2430
- 45 Khan M, Shobha JC, Mohan IK, Naidu MU, Sundaram C, Singh S, Kuppusamy P, Kutala VK (2005)**  
Protective effect of Spirulina against doxorubicin-induced cardiotoxicity  
*Phytother Res* 19(12) 1030-1037
- 46 Khan M, Varadharaj S, Shobha JC, Naidu MU, Parinandi NL, Kutala VK, Kuppusamy P (2006)**  
C-Phycocyanin ameliorates doxorubicin-induced oxidative stress and apoptosis in adult rat cardiomyocytes  
*J Cardiovasc Pharmacol* 47(1) 9-20.
- 47 Khan M, Varadharaj S, Ganesan LP, Shobha JC, Naidu MU et al (2005)**  
C-phycocyanin protects against ischemia-reperfusion injury of heart through involvement of p38 MAPK and ERK signaling  
*Am J Physiol-Heart Circulatory Physiol* 290(5) H2136-2145
- 48 Han LK, Li DX, Xiang L, Gong XJ, Kondo Y, Suzuki I, Okuda H (2006)**  
Isolation of pancreatic lipase activity-inhibitory component of Spirulina platensis and it reduces postprandial triacylglycerolemia  
Yakugaku Zasshi  
*J Pharmaceut Soc Japan* 126(1) 43-49
- 49 Kaji T, Fujiwara Y, Hamada C, Yamamoto C, Shimada S, Lee JB, Hayashi T (2002)**  
Inhibition of cultured bovine aortic endothelial cell proliferation by sodium spirulan, a new sulfated polysaccharide isolated from Spirulina platensis  
*Planta Medica* 68(6) 505-509
- 50 Kaji T, Okabe M, Shimada S, Yamamoto C, Fujiwara Y, Lee JB, Hayashi T (2004)**  
Sodium Spirulan as a potent inhibitor of arterial smooth muscle cell proliferation *in vitro*  
*Life Sci* 74(19) 2431-2439
- 51 Riss J, Decorde K, Sutra T, Delage M, Baccou JC, Jouy N, Brune JP, Oreal H, Cristol JP, Rouanet JM (2007)**  
Phycobiliprotein C-phycocyanin from Spirulina platensis is powerfully responsible for reducing oxidative stress and NADPH oxidase expression induced by an atherogenic diet in hamsters  
*J Agricul Food Chem* 55(19) 7962-7967