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Spirulina (Arthrospira): potential application as an animal feed supplement

Amha Belay[1], Toshimitsu Kato[2] & Yoshimichi Ota[1]
[1]*Earthrise Farms, P.O. Box 270, Calipatria, CA 92233, USA*
[2] *Dainippon Ink & Chemicals Inc., Biochemical Division, 7–20 Nihonbashi 3-Chome, Chuo-Ku, Tokyo 103 Japan*

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Abstract

Spirulina has been used as human food supplement for over 20 years, but its use as an animal feed supplement is relatively recent. This paper reviews earlier studies on its more established effects on growth, survival and tissue quality in a whole range of animals and more recent studies on its immunomodulatory, anti-viral and anti-cancer effects. The basis for potential application as an animal feed supplement is discussed.

Introduction

Spirulina (Arthrospira) platensis and *S. maxima* have a long history of use as food for humans. Traditionally, they have been used for food during the Aztec civilization in Mexico and more recently by natives in the Lake Chad area (Ciferi & Tiboni, 1985). *Spirulina* is generally regarded as a rich source of protein, vitamins, essential amino acids, minerals, essential fatty acids like γ-linolenic acid (GLA) and antioxidant pigments like carotenoids. As a result *Spirulina* has been produced commercially for about twenty years and sold primarily as a food supplement and food coloring.

Even though *Spirulina* has been used extensively as a human food supplement, its use as an animal food supplement is only recent. Nevertheless, about 30% of the current world production of 2000 t *Spirulina* is sold for animal feed applications (unpublished data). The objective of this paper is to provide an overview of some published and unpublished information on the effect of supplementary diets of *Spirulina* on some economically important species of animals as a basis to evaluate the potential for future applications.

Summary of studies using *Spirulina* as a feed supplement

A summary of studies involving *Spirulina* as a feed supplement are given in Tables 1, 2, 3 and 4.

Effects on growth and survival

The studies on growth and survival involved for the most part various types of fish but some studies have also been made on chicken, quail, turkey and pigs (Table 1).

Stanley and Jones (1976) studied the effect of feeding *Spirulina* to big mouth buffalo (*Ictiobus cyprinellus*) and blue tilapia (*Tilapia aurea*). At a daily feeding rate of 29 g d w kg^{-1} body weight for 28 days they were able to get a daily growth rate of 14 g kg^{-1} body weight and a food conversion of 2.0 both of which were believed to be excellent for a single-ingredient feed. Similar studies conducted with grass carp fed *Spirogyra* showed poor growth and food conversion was about 10. On the basis of these findings, Stanley and Jones concluded that an aquaculture system based on filamentous green algae and grass carp is likely to be far less efficient than one based on *Spirulina* combined with tilapia or big mouth buffalo. In a similar study involving nile tilapia (*Tilapia nilotica*) Chow and Woo (1990) also found that *Spirulina* supplemented with methionine successfully replaced fish meal as a diet.

Table 1. Studies on the effects of *Spirulina* on growth and survival.

Subject		Summary of results	References
Big mouth buffalo	*Ictiobus cyprinellus*	Improved growth rate at 29 g dwt/kg-1 body wt	Stanley & Jones, 1976
Blue tilapia	*Tilapia aurea*	Same as above	Stanley & Jones, 1976
Nile tilapia	*Tilapia nilotica*	*Spirulina* supplemented with methionine succesfully replaced fish meal	Chow & Woo (1990)
Milkfish fry	*Chanos chanos*	Substitution of formulated diet with up to 50% *Spirulina* was possible without adverse effect	Santiago et al., 1989
Silver carp	*Hypothalamichthys molitrix*	10% *Spirulina* in basal diet improved specific growth rates and live weight	Ayyappan, 1992
		30% of protein of formulated feed replaced by *Spirulina* with improved growth	Daniel & Kumuthakala-vally, 1992
Grass Carp	*Ctenopharyngodon idella*	Same as above	Ayyappan, 1992
Common Carp	*Cyprinus carpio*	Same as above	Ayyappan, 1992
Cultured striped jack	*Pseudocaranx dentex*	5% *Spirulina* in feed resulted in good growth rate and feed conversion efficiency: 10% *Spirulina* suppressed growth slightly	Watanabe et al., 1990
Yellow tail	*Seriola quinqueradiata*	1-10% *Spirulina* supplementation resulted in improved growth rate (1.5 times control), survival rate and feed efficiency	Kato & Miyakawa,1992
Masou salmon	*Oncorhynchus masou*	Improved growth rate, survival rate, feed conversion efficiency, resistance against bacterial infection	Kato & Miyakawa,1992
Sweet smelt or ayu	*Plecoglossus altivelis*	Same as above	Kato & Miyakawa,1992
Sea eels	*Anguilla japonica*	Improved growth rate, survival, feed efficiency	Kato & Miyakawa,1992
Red sea bream	*Pagrus major*	5% *Spirulina* in feed showed significant increase in growth rate, feed conversion efficiency	Mustafa et al., 1994a
Silver sea bream	*Rhabdosargus sarba*	Up to 50% *Spirulina* substitution gave comparable growth rate to control without adverse effect	El-Sayed, 1994
Giant freshwater prawn	*Macrobrachium rosenbergii*	5-10% *Spirulina* significantly improved growth, survival and feed utilization	Nakagawa & Gomez-Diaz, 1995
Chicken		1.5-12% *Spirulina* in diet of male broiler chicks substitutes other protein source with good growth rate and feed efficiency	Ross & Dominy, 1990
		5-10% *Spirulina* in feed of growing chicken was found to be satisfactory to improve growth in chicken and laying hens	Blum & Calet, 1976, Yoshida & Hoshii, 1980; Becker & Venkataraman 1982; Brune, 1982; Nazareno et al., 1975
Quail		1.2-10% *Spirulina* in feed improved fertility, hatchability and egg production	Ross & Dominy, 1990
		0.2% *Spirulina* significantly reduced the death rate by as much as 20 times than that of control	Sakakibara & Hamada, 1994
Turkey poults		1000-10000 mg/kg-1 *Spirulina* showed significantly higher growth rate and lower mortality rate	MA Qureshi, personal communication
Yorkshire pigs		Animals fed *Spirulina* or *Chlorella* showed comparable weight gain with those on the control diet	Yap et al., 1982

Substitution of formulated diet with up to 50% *Spirulina* had no effect on overall growth rate in milkfish fry (*Chanos chanos*) though the growth rate obtained with the formulated diet was higher (Santiago et al., 1989).

Ayyappan (1992) studied the potential of *Spirulina* as a feed for carp fry using six different species of carp: *Catla catla, Labeo rohita, Cirrhinus mrigala, Hypophthalmichthys molitrix* (silver carp), *Ctenopharyngodon idella* (grass carp) and *Cyprinus carpio* (common

Table 2. Studies on the effects of *Spirulina* on tissue (carcass) and other qualities.

Subject		Summary of results	References
Fancy red carp	(*Cyprinus carpio*)	Zeaxanthin and myxoxanthophyll from *Spirulina* compared. The former had a significant effect on color enhancement, the latter none	Matsuno et al., 1979
Red tilapia	(*Tilapia nilotica, T. mossambica*)	Color of integument in control, lutein, rhodoxanthin and *Spirulina* fed groups became pale pink, orange, pink and orange red, respectively. Rhodoxanthin accumulated in the *Spirulina* group about 10 times	Matsuno et al., 1980
Sweet smelt	(*Plecoglossus altivelis*)	3-6% *Spirulina* in the diet resulted in enhancement of color in integument and subcutaneous tissue	Mori et al., 1987
Striped Jack	(*Caranx delicatissimus*)	5-10% *Spirulina* in diet significantly increased carotenoid accumulation in the integument	Okada et al., 1991
Black tiger prawn	(*Penaeus monodon*)	Significantly higher color development in prawns fed 3% *Spirulina* diet compared to diet containing ß-carotene, Phaffia or krill oil	Liao et al., 1993
Poultry		Increase in yolk color due to carotenoid accumulation (from *Spirulina*) in layer and quail	Blum et al., 1976; Colas et al., 1979; Venkataram & Becker, 1982; Anderson et al., 1991; Ross & Dominy, 1990
Striped jack	(*Pseudocaranx dentex*)	Fish fed 10% *Spirulina* had lower lipid levels in the viscera and liver; also lower levels of triglycerides in dorsal muscle and liver	Watanabe et al., 1990
Red sea bream	(*Pagrus major*)	2% *Spirulina* in diet significantly reduced the lipid content compared to control diet; wild fish had the lowest lipid level	Mustafa et al., 1994b, 1994c
		Higher content of stromal proteins & hence better texture in fish with 2% *Spirulina* in the diet compared to the control diet	Mustafa et al., 1994c
Striped jack	(*Caranx delicatissimus*)	Sensory test by a panel of judges showed that *Spirulina* supplementation improved color, texture and taste of the ventral muscle	Liao et al., 1990

Table 3. Studies on immunomodulatory effect of *Spirulina*

Subject	Summary of results	References
Channel catfish	Feeding fish *Spirulina* enriched Artemia (bioeacapsulation) resulted in a 3 fold increase in splenic macrophage number, and increased activation of macrophytes compared to Artemia feed alone	B. Portoni, personal communication
Chicken	In vitro, treatment of macrophages with a water extract of *Spirulina* resulted in enhanced macrophage activation (phagocytosis)	Qureshi et al., 1994; 1995b
	In vivo feeding to K. strain Leghorns (up to 10000 mg kg^{-1}) showed larger thymi, higher natural killer cell (NK) activity and CBH response; Number of phagocytic macrophages increased and number of SRBC/phagocytic macrophage also greater in *Spirulina* fed group	Qureshi et al., 1994; 1995a
	Significantly higher bacterial clearing rates observed with *Spirulina* supplementation compared to control diet	Qureshi et al., 1995a
Turkey	Improved lymphoid organ development: splenic bursal and thymic weights were higher in the *Spirulina*-fed group	M.A. Qureshi, personal communication

carp). The fish were fed either a mixture of rice bran and groundnut oil cake (control diet) or with the addition of 10% *Spirulina* to the bran cake mixture (experimental diet). The last two species were also studied supplying live *Spirulina* in the growing pools. Live weight and specific growth rates were significantly higher in most of the tests including those involving live *Spirulina* feeding. Daniel and Kumuthakalavalli

Table 4. Summary of related studies with other experimental animals.

Application	Subject	References
Cholesterol reduction	Mice	Kato et al., 1994
	Human	Nakaya et al., 1988
Protection against nephrotoxicity	Mice	Fukino et al., 1990
Anti cancer effects	Mice	Qishen et al., 1988; Kato et al., 1995
	Hamsters	Schwartz & Sklar, 1987; Schwartz et al., 1985
	Human	Mathew et al., 1995
Radiation protection	Mice	Qishen et al., 1989
Marrowcytes/stem-cell regeneration	Mice	Qishen et al., 1989; Zhang, 1994 et al., 1994; 1995
Antiviral effects	Mice	Hayashi et al., 1993; 1996; Ayehunie et al., 1996
Immunomodulatory effects	Mice	Nagao, 1991; Baogiang, 1994; Hayashi et al., 1993; 1994; Zhang, 1994
	Cats	Qureshi, 1996

(1992) were able to supplement 30% of the protein in the 35% protein fish meal diet for silver carp with an increase in growth rate over the control fish meal diet. Their results support earlier findings with *Cirrhinus mrigala* fed on pellets containing 25% *Spirulina* (Daniel & Kumuthakalavalli, 1991).

Watanabe et al. (1990) have also found good growth rates and feed conversion efficiency in cultured striped jack (*Pseudocaranx dentex*) at 5% supplementation in the feed. 10% *Spirulina* in the feed depressed lipid levels in the dorsal muscle, viscera and liver and slightly suppressed growth and feed efficiency. The authors therefore concluded that the level of supplementation should be less than 10% and preferably around 5% to maintain the normal growth of fish.

In a detailed study involving yellow tail (*Seriola quinqueradiata*), masu salmon (*Oncorhyncus masou*), sweet smelt or ayu (*Plecoglossus altivelis*) and sea eels (*Anguilla japonica*), Kato and Miyakawa (1992) observed improved growth rate (up to 1.5 times), survival rate and feed efficiency under 1-10% *Spirulina* supplementation compared to the basal diet. These studies involved feeding trials spanning from 1–6 months. In the case of trout and ayu, disease resistance against bacterial infection was also observed. Similarly, Mustafa et al. (1994a) observed significant increase in growth rate, feed conversion efficiency and protein efficiency ratio in red sea bream (*Pagrus major*) in 5% *Spirulina* compared to either the basal diet or the latter supplemented with 10% *Ascophyllum*. In a similar study with silver sea bream (*Rhabdosargus sarba*), up to 50% *Spirulina* substitution gave comparable growth rate and feed utilization as those in the control diet without any adverse effects (El-Sayed, 1994).

The effect of supplementation of *Spirulina* in the diet was also studied in the giant freshwater prawn (*Macrobrachium rosenbergii*) by Nakagawa and Gomez-Diaz (1995). *Spirulina* meal significantly improved growth, survival and feed utilization irrespective of the supplementation level in the range of 5–20% in the feed. The authors suggested that the improved growth and feed utilization was probably due to enhancement of protein assimilation.

While most of the studies involving growth, survival, feed utilization and carcass quality are done in aquaculturally important species some studies have also been made to evaluate the potential use of *Spirulina* in other economically important species. These studies involve mainly poultry. Recently, Ross and Dominy (1990) evaluated the nutritional value of dehydrated *Spirulina* for poultry. Male broiler chicks were fed experimental diets containing *Spirulina* in the range of 1.5–12% for 41 days. It was concluded that dehydrated *Spirulina* at a diet content below 12% may be substituted for other protein sources in chick and broiler diets with good growth and feed efficiency. The authors also found similar results with quail. Fertility, hatchability and egg production and egg-shell and egg yolk quality were improved. Blum and Calet (1976), Yoshida and Hoshii (1980), Becker and Venkataraman (1982), and Brune (1982) have also found satisfactory results in growing chickens with 5–10% *Spirulina* enriched diet though growth was depressed above 20%. Similar results were obtained when *Spirulina* was fed to laying hens (Nazarenko et al., 1975; Blum et al., 1976; Colas et al., 1979; Sauveur et al., 1979).

A recent Japanese patent (Sakakibara et al., 1994) describes the use of *Spirulina* (0.1–2%) to reduce the death rate in quail. This was reduced from 10% in the basal diet to 0.5–3.5% in the experimental diet containing 0.1–2.0% *Spirulina*. The lowest death rate was found with 0.2% *Spirulina*. More recently (MA Qureshi, personal communication) has found significantly higher growth rate and lower non-specific mortality rate in turkey poults fed *Spirulina* at the level of 1000–10000 mg kg^{-1} compared to poults on a basal diet. Mortality was reduced from 12% in the control group to 3% in the 1000 ppm *Spirulina* group. These results support their earlier findings in broilers and white leghorn type chickens (Qureshi et al., 1994).

The only study done on pigs is apparently that of Yap et al. (1982). Yorkshire pigs fed the basal diet gained weight at a rate not significantly different from those fed *Spirulina* or *Chlorella* diets. Based on their findings, the authors concluded that at least half of the protein supplied by soybean meal (or one-third of the dietary protein) could be replaced in the diet of the early weaned pig by *Spirulina* or *Chlorella*.

Effect on tissue (carcass) and other qualities

Extensive studies have been done on the effect of *Spirulina* on body color enhancement in a range of animals (Table 2). In a study to elucidate the relative importance of the major carotenoid pigments of *Spirulina* (zeaxanthin and myxoxanthophyll) in the intensification of the reddish color of fancy red carp, Matsuno et al. (1979) fed test diets containing either zeaxanthin or myxoxanthophyll to solid red yearling fish for 69 days. Zeaxanthin was found to be effective in color development but no effect was found with myxoxanthophyll. They postulated that the intensification of red color was due to conversion of zeaxanthin to astaxanthin because they observed that the amount of astaxanthin in the integument of the test group increased eight times that of the control. In a similar study using red tilapia (*Tilapia nilotica, T. mossambica*) Matsuno et al. (1980) did feeding tests with test diets containing lutein, rhodoxanthin and *Spirulina*; the color of the integument in the control, lutein, rhodoxanthin and *Spirulina* groups became pale pink, orange, pink and orange red in appearance, respectively. Rhodoxanthin accumulated in the *Spirulina* group to ten times that in the control group. From this the authors surmised that zeaxanthin may be metabolized to rhodoxanthin in vivo. Similar results were obtained in a study using sweet smelt (*Plecoglossus altivelis*). 3–6% *Spirulina* in the diet resulted in enhancement of color both in the integument and the subcutaneous tissue where carotenoids were accumulated about three times more than the control (Mori et al., 1987). Furthermore Okada et al. (1991) have also confirmed these findings in striped jack (*Caranx delicatissimus*), where 5–10% in the diet significantly increased carotenoid accumulation in the integument. Liao et al. (1993) found a significantly higher carotenoid content in the carapace of black tiger prawn (*Penaeus monodon*) fed a 3% *Spirulina* diet compared to diets containing β-carotene, *Phaffia* or krill oil. Analysis of carotenoid composition in the carapace of the prawns suggested that zeaxanthin was rapidly converted to astaxanthin supporting the contention of Matsuno et al. (1979) in the red carp study discussed above.

The color enhancement properties of *Spirulina* have also been studied in poultry. An increase in yolk color due to carotenoid accumulation was observed in poultry-layers by several workers (Blum et al., 1976; Colas et al., 1979; Becker & Venkataraman, 1982, Anderson et al., 1991). Ross and Dominy (1990) have also observed a significant increase in egg yolk color in quail fed a diet containing 1.5% *Spirulina* compared to those fed the control diet.

The lipid content of fish is a determinant factor in their palatability, there generally being an inverse relationship. As the lipid content in muscle of cultured fish is often higher than that of wild fish, the former are not as palatable as the wild fish. Several studies have been made concerning the effect of *Spirulina* on the lipid content and composition of cultured fish. In striped jack, Watanabe et al. (1990) observed a significantly lower lipid level in the dorsal muscle, viscera and liver of fish fed 10% *Spirulina* compared to those in the control diet. They also found lower levels of triglycerides in the dorsal muscle and liver of fish with 10% *Spirulina* in the diet. Mustafa et al. (1994b; 1994c) studied the effect of a diet supplemented with 2% *Spirulina* on red sea bream and found that the lipid content was significantly reduced in fish fed the *Spirulina* diet compared to those in the control diet. Wild fish had the lowest lipid level. In one of their studies, the lipid contents in the control group, the experimental group, and wild fish were 6.2 ± 0.3, 4.4 ± 0.5 and 2.0 ± 0.2, respectively (Mustafa et al., 1994b).

The texture of fish and particularly the firmness of the muscle is also important in their palatability. Texture is dependent upon the amount and composition of the protein in the tissue of the animals. For instance the stromal protein which comprises mainly collagen has been found to influence the texture of raw and cooked fish (Feinstein and Buck, 1984; Sato et al., 1986). Mustafa et al. (1994c) studied the effect of 2% *Spir-*

ulina supplementation on sarcoplasmic, myofibrillar, alkali-soluble and stromal protein fractions in red sea bream. The stromal protein was significantly higher in fish fed the *Spirulina* supplemental diet than is with the control diet. In a study involving sensory tests by a panel of judges, Liao et al. (1990) found that *Spirulina* supplementation improved color, texture and taste of the ventral muscle of striped jack.

Immunomodulatory effects

In a recent review on potential health benefits of *Spirulina*, Belay et al. (1993) after summarizing the limited amount of published information on immunomodulatory properties of *Spirulina*, called the attention of researchers in this potentially interesting area. Since then several papers have been published that support the early findings. In the following we give a review of work done on three economically important species of animals: channel catfish (*Ictalurus punctatus*), chicken and turkey (Table 3).

The effect of *Spirulina* on some immunological characteristics in channel catfish was studied recently (B. Pertoni, pers. comm.). The catfish were raised in either a control cryogenically frozen brine shrimp (*Artemia franciscana*) (control diet) or *Spirulina* bioencapsulated in Artemia (the experimental diet). Catfish fed the *Spirulina* enriched diet on average had a three-fold increase in splenic macrophage number compared to catfish fed the control diet.

Perhaps the most thorough work on the immune enhancement effects of *Spirulina* are those by Qureshi et al. (1994, 1995a; 1995b). In their first study Sephadex-elicited macrophage cultures were exposed to 10, 20 and 40 μg ml^{-1} (v/v) water-soluble extract of *Spirulina* for one hour. *Spirulina* treated macrophages exhibited an activated phenotype in terms of morphological changes, enhanced phagocytosis ($p \geq 0.05$) and induced tumoricidal factor secretion in culture supernatant without any cytotoxic effect in all the doses employed (Qureshi et al., 1994, 1995b). In a second study 0, 10, 100 and 10000 mg kg^{-1} *Spirulina* in corn-soy diet were fed to K-strain leghorns. Even though chicks in all groups had comparable body weights, larger thymi, higher natural killer cell (NK) activity and cutaneous basophillic hypersensitivity (CBH) response ($p \geq 0.05$) were observed in 10000 mg kg^{-1} *Spirulina*-treated chicks. Percent phagocytic macrophages and number of SRBC/phagocytic macrophage were also greater in the 10000 mg kg^{-1} chicks. They also observed enhanced secondary anti-SRBC antibody response in 10000 mg kg^{-1} over 0 mg kg^{-1} leghorn chicks (Qureshi et al., 1994; 1995a).

Dietary supplementation with *Spirulina* also improved the bacterial clearance potential of chicks (Qureshi et al., 1995a). Bacterial clearance rates were studied in chicken fed a control diet or a *Spirulina* supplemented diet. Injection of *Escherichia coli* or *Staphylococcus aureus* into chicks fed the *Spirulina* diet showed a significantly higher clearing rate at all levels of *Spirulina* supplementation (1000–10000 mg kg^{-1}) but more so at 1000 mg kg^{-1}. Time course studies of bacterial clearance in *Spirulina*-fed chicks also showed that the bacterial numbers were negligible even after a post-injection period of only 30 min. From these results the authors concluded that *Spirulina* supplementation improved the activity of the phagocytic cells, namely monocyt/macrophages, heterophils and thrombocytes in chickens. They also proposed that 1000–10000 mg kg^{-1} (0.1–1.0%) range of dietary *Spirulina* supplementation in chickens would be safe to use in terms of improved immunocompetence without compromising performance characteristics of chickens (Qureshi et al., 1995a).

In a study designed to study the effect of dietary *Spirulina* on turkey poults previously exposed to TSM (PEMS) induced enteritis agent, Qureshi (personal communication) also found a positive effect on lymphoid organ development. Even though *Spirulina* supplementation did not offer protection against PEMS condition (due to the virulent nature of the infliction) it resulted in improved lymphoid organ development. Splenic, bursal and thymic weights were higher in the *Spirulina*-fed poults compared in those fed the control diet, further confirming their previous findings with broilers and white leghorn type chickens.

Related effects on other animals

Studies made with experimental animals like mice also reveal several effects of *Spirulina* or its extracts (Table 4). These include cholesterol-reducing effects in mice (Kato et al., 1984) and humans (Nakaya et al., 1988), effects against nephrotoxicity (Fukino et al., 1990), anti-cancer effects in hamsters (Schwartz & Shklar, 1987; Schwartz et al., 1988) in mice (Qishen et al.,1988; Kato, 1995) and in humans (Mathew et al., 1995), radiation protection effects in mice (Qishen et al., 1989), immunomodulatory effects in mice (Nagao, 1991; Baogiang, 1994; Hayashi et al., 1993; 1994), and in cats (Qureshi, 1996), regeneration of marrowcytes and stem cells in mice (Zhang et al., 1994; 1995)), and antiviral effects (Hayashi et al., 1993; 1996; Ayehunie et al., 1996). A detailed review of the published information on the effects of *Spirulina* and/or its extracts on other animals is found in Belay et. al. (1993).

Discussion

It is clear that supplemental feeding of *Spirulina* or its extracts offers some benefits to fish and poultry. Some of these effects like increased growth rate, color enhancement and general tissue quality may be nutritional effects. However, the fact that growth rates are improved even at 0.1% *Spirulina* supplementation may suggest the presence of substances that may mimic the effects of or stimulate production of growth hormones. Other effects like immunomodulatory effects, antiviral and anti-cancer effects are elicited at such very low concentrations that their effects may be due to factors other than mere nutritional ones. Even though there is very strong evidence suggesting the immunomodulatory and antiviral effects of *Spirulina* and its extracts in the organisms mentioned above, the active substances eliciting these responses have not been determined conclusively. However Hayashi et al. (1996) have recently isolated a novel sulfated polysaccharide named calcium spirulan which inhibited the replication of several enveloped viruses including Herpes simplex virus type 1, human cytomegalovirus, measles virus, mumps virus, influenza A virus and HIV-1. This same compound also inhibited experimental lung metastasis in mice intravenously injected with B-16-BL6 melanoma cells (Kato et. al., 1995). A water-soluble polysaccharide from *Spirulina* platensis enhances endonuclease activity and repair DNA synthesis in bioassay studies involving *Vicia faba* root tips and bone marrow cells (Qishen et al.,1988).

The application of *Spirulina* as a feed supplement in aquaculture and agriculture must be evaluated in terms of cost benefit analysis. This has not been done for any of the above beneficial effects yet. Though *Spirulina* can substitute up to 50% of the protein diets in conventional feeds, its use as a protein source is unlikely because there are cheaper sources of protein like Soya and fish meal. The use of *Spirulina* to enhance color of fish is also likely to have limited application mainly for ornamental fish and for exotic fish. Even then there are other cheaper sources of carotenoids like paprika and *Phaffia* that demonstrate similar effects albeit to a lower extent.

From the point of view of cost-effectiveness, the most promising application may be its immune enhancement effects and through this its antiviral and anti-bacterial properties, since these effects are exhibited at very low supplemental concentrations in the feeds. Young animals often have a deficient immune system during the first few weeks of life. A significant number of the larvae of marine fish, usually die due to infections by opportunistic pathogens. For example, viral infection has decimated a significant amount of the shrimp production in Thailand and the USA in the last two years. Early development of the immune system may offer protection against these pathogens. Enhancement of macrophage numbers and phagocytic potential as demonstrated in turkey poults has resulted in increasing survival rate (M. A. Qureshi, pers. comm.). *Spirulina* or its extracts may accelerate development of the immune system of these animals especially during the early stages of their lives. It remains to be seen if *Spirulina* can offer protection against the many pathogens which are plaguing the aquaculture industry. The use of antibiotic drugs to control these pathogens is ineffective and has undesirable safety consequences for consumers. Supplementation with *Spirulina* of the feed of these aquacultural and agricultural animals may offer a better alternative. It should be emphasized, however, that the reports showing antiviral and anti-cancer properties are preliminary in nature requiring more thorough testing prior to any practical application.

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