11

Use of *Spirulina* Biomass

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Introduction

The chemical composition of *Spirulina* is reviewed in detail in Chapter 10. Its high protein content and unique composition of fatty acids and vitamins are used as a basis to justify claims of its health benefits for humans. Another growing outlet for the uses of *Spirulina* products is the feed market, mainly aquaculture. This chapter does not elaborate on the health benefits of *Spirulina* for human consumption; it mainly deals with the potential of using the biomass for feed in aquaculture and poultry nutrition.

Human Consumption

As described in the Preface to this volume, the first records made of the uses of *Spirulina* were as a food and what seems to be a major source of protein supply to native tribes in South America and Africa. The re-introduction of *Spirulina* as a health food for human consumption in the late 1970s and the beginning of the 1980s was associated with many controversial claims which attribute to *Spirulina* a role of a 'magic agent' that could do almost everything, from curing specific cancer to antibiotic and antiviral activity. Since most claims were never backed up by detailed scientific and medical research, they will not be discussed in this chapter. Nevertheless, one cannot ignore the fact that more than 70 per cent of the current *Spirulina* market is for human consumption, mainly as health food. Its major claims are summarized in Table 11.1.

It is the author's current belief that although health food may present a very profitable sector of the *Spirulina* market, it is going to remain relatively a small market because of many constraints and problems in marketing, especially for producers who do not have experience or connections. Thus, any increase in volume market of *Spirulina* is going to be mainly from sales as a high-value feed additive in aquaculture and poultry nutrition rather than, what was initially predicted in the early 1970s, as a major protein supplement in human nutrition.

Table 11.1 Summary of therapeutic effects reported using *Spirulina*. More highly elaborated reports can be found in Belay et al., 1993

Effect	Experiments carried out on	Main effect	Reference
Immune system	Mouse	Experiments claiming that in mice fed with *Spirulina* a delayed type hypersensitivity can be suppressed. A *Spirulina* diet enhances the immune response by stimulating macrophage function phagocytosis and enhancing interleukin production.	Nagao et al., 1991; Hayashi et al., 1994
Reducing lipid levels in liver and serum	Rat, Human	Experiments with rats demonstrated a lower rate of increase in triglyceride level in serum and liver. When triglyceride level was induced to increase by a fructose rich diet, an addition of 5% *Spirulina* prevented the increase. In human studies, the total serum cholesterol was lowered.	Kato et al., 1984; Iwata et al., 1987, 1990; Nakaya et al., 1988; González de Rivera et al., 1993
Anticancer, antitumor effects	Hamster	Extracts of *Spirulina* or a combination of *Spirulina* and *Dunaliella* repressed or prevented the development of oral tumor.	Kato et al., 1984; Schwartz and Sklar, 1987; Schwartz et al., 1988
Antiviral activity	Cell culture, (HeLa, HEL, Vero, MDCK, MT-4)	A hot water extract from *Spirulina* (Ca-SP), which was identified as a polysaccharide containing also sulfate and calcium, was found to inhibit the replication of several enveloped viruses. It was suggested that Ca-SP selectively inhibited the penetration of virus into host cells.	Hayashi et al., 1994

Use as Feed and Feed Additives

Intensification in the growing of poultry and aquaculture is increasing the demand for specially formulated feed which will meet the high standards of the market and the need to substitute for the natural source of feed available. There are many reports on attempts to use *Spirulina* in animal feeding experiments. We will limit ours to those dealing with the addition of *Spirulina* as a specific feed component rather than the use of *Spirulina* as a total replacement for protein.

Use of Spirulina *in Poultry*

Feed additives in the poultry market, with special attention to the effect of pigments on yolk coloring, represent a major part of this fast-growing industry. A few studies on the use of *Spirulina* as a very effective agent in inducing preferred yolk color have been reported (Saxena et al., 1982, 1983).

Hens previously maintained on oxycarotenoid-free feed (control) and depleted of their carotenoids transferred dietary pigments to the egg yolk within 72 h of being fed *Spirulina*-containing diets. Yolk color intensity reached a maximum after 7 days.

The effects of various test diets on the yolk pigmentation of eggs are presented in Table 11.2. The results show *Spirulina* to be an excellent yolk pigmenter. Visual scores of the yolks produced by the birds fed *Spirulina* diets were markedly higher (13.0–14.8) than those obtained from birds fed yellow maize (4.7–8.0) and dehydrated berseem meal (4.8–5.6). Indigenous eggs indicated a higher Roche-fan score (10.8) for yolks than yellow maize and berseem meal groups. *Spirulina* gave the highest readings at all levels and produced much deeper yolk color than that produced by the highest levels of the two conventional oxycarotenoid sources.

Table 11.2 Visual yolk pigmentation scores of different treatment groups and indigenous eggs

Treatment	Raw eggs	Boiled eggs
Control		
Spirulina	1.5	1.0
6%	13.0	9.3
12%	14.2	12.9
21%	14.8	13.4
Yellow maize		
10%	4.7	2.3
20%	6.6	3.0
30%	7.4	4.3
40%	8.0	6.2
Dehydrated berseem meal		
5%	4.8	2.4
7.5%	5.6	3.9
Indigenous eggs	10.8	7.0

Adapted from Saxena et al., 1983.

Feeding with a diet containing 3 per cent *Spirulina* produced deep yellow-orange yolks that scored 13.3 on the Roche yolk color fan. Twelve per cent *Spirulina* imparted a brilliant reddish-orange color to the egg yolks with a visual score of 14.2 which increased to an average of 14.8 with algal additions up to 21 per cent, but yolk pigmentation did not increase in proportion to dietary algal concentration.

A similar trend was noticed in boiled eggs, which, however, showed lower yolk color values than raw ones. This might be due to the brightness of the vitelline membrane.

In a consumer preference study of hard boiled eggs, most of the judges preferred table egg yolk colors having a Roche-fan score between 9 and 12. These colors corresponded to feeding *Spirulina* at levels of 3–9 per cent in layer diets.

A similar study conducted in Hawaii (Ross and Dominy, 1990) compared the use of freeze-dried and extracted *Spirulina* biomass as a yolk-pigmenting agent, and its findings were further supported by a more recent study (Ross et al., 1994). It demonstrated that with increasing levels of freeze-dried *Spirulina* (Table 11.3) there was a consistent increase in yolk color. Extruded *Spirulina* also consistently increased yolk color at increasing levels. The yolk color scores of eggs from quail fed freeze-dried *Spirulina* were greater than the scores of eggs from quail fed the extruded *Spirulina* at all levels. The lower yolk color scores of the extruded series were attributed to the loss of xanthophyll during the extrusion process. The work also reports that extruding *Spirulina* with cassava meal resulted in less loss in pigmenting value of the extruded *Spirulina* than for *Spirulina* extruded with corn or barley. Whether the cassava in some way protected the xanthophylls in *Spirulina* or whether there was some physical effect of the extruding process cannot be deduced from their data. What is important is that there was no adverse effect of *Spirulina* on egg production, feed per egg, egg weight, final body weight, or mortality in any of the experiments.

It has to be pointed out that fairly effective pigmentation is achieved with relatively low concentration of *Spirulina*. More detailed study may yield an even more efficient pigmentation system. This is of importance since the addition of *Spirulina* does not necessarily mean a significant increase in the overall cost of feed to the farmer.

Use of Spirulina *in Aquaculture*

The worldwide expansion of aquaculture in the last ten years has increased the market size of inland pond-grown aquaculture products. In the artificial pond

Table 11.3 Mean Roche yolk color scores of eggs laid by Coturnix hens fed graded levels of freeze-dried or extruded *Spirulina*

Spirulina in diet (%)	Extruded *Spirulina*	Freeze-dried *Spirulina*
0	4.1	4.9
0.5	5.9	5.9
1.0	6.6	6.8
2.0	7.3	8.0
4.0	8.4	8.9

Adapted from Ross et al., 1994.

growing systems, a very important factor determining the economic feasibility and quality of the products is feed and the efficiency of feed utilization (Ratafia and Purinton, 1989). It is estimated that by the year 2000 the total market for feed for aquaculture will exceed the value of US$2 billion. Microalgae are a natural source of feed in the food chain of fish and many other organisms (Giwojna, 1987). Much work has been carried out in order to produce specific feed formulae for the different growing systems so as to fit not only the specific requirements of the organisms but also the various development stages that are associated with different nutritional requirements.

The most intensive studies on the use of *Spirulina* as a feed ingredient in aquaculture were performed in Japan where it was reported that already in 1989 about 100–150 tonnes of *Spirulina* were employed by Japanese fish farmers (Henson, 1990). It is also estimated that by the end of this century this market will increase by an order of magnitude, reaching a worth of US$20–30 million.

Spirulina *feed in fish nutrition*

Spirulina formulated feed increases the growth rate of many species. It improves the palatability of the feed. It was also reported (Kato, 1989) that fish fed with *Spirulina* have less abdominal fat. The feed conversion is improved as well.

It has been claimed that the fish grown on feed containing *Spirulina* are of better quality, having better flavor, firmer flesh, and brighter skin color (Hirano, 1985; Suyama, 1985; Mori, 1987).

Another very important effect relates to reduction in the rate of mortality of fingerlings or post-larval stages. An addition of 0.5 to 1 per cent of *Spirulina* in the feed has a very significant effect on growth (improvement of 17–25 per cent) and reduction of mortality (30–50 per cent), depending on species and *Spirulina* concentration. It is important to note that one of the most crucial stages in modern intensive aquaculture is the survival of the initial inoculum. Improvement in the survival rates may provide a significant improvement in the economic performance of any aquaculture farm. A report on the use of *Spirulina* in aquaculture in Japan concluded that *Spirulina* improves the cost/performance ratio of the fish feed, the largest expense in fish production.

Another set of studies (El-Sayed, 1994; Mustafa et al., 1994) relates to the use of *Spirulina* in the feed of silver sea-breams or the red sea-breams, both considered a high-value product with good market and prices. A study by Liao et al. (1990) demonstrated that an improvement in the color, taste and texture of fish fed with *Spirulina* has been observed. In the case of the sea-breams it was observed that *Spirulina* significantly increased the stromal fraction that mainly contains collagen. Collagen is one of the major constituents of intramuscular connective tissue and plays an important role in maintaining the muscle structure associated with swimming (Yoshinaka et al., 1988). It has also been observed that the carcass quality of *Spirulina*-fed fish was more acceptable than that of the control group.

Use in crustaceans

A specific application of *Spirulina*, mainly as a colorant pigmentation agent in the diet of the black tiger prawn was suggested by Liao et al. (1993). They report that incorporating 3 per cent *Spirulina* in the diet of the prawn for 14 to 28 days resulted

in a marked increase in the carotenoid content in the carapace and suggested that zeaxanthin, a major component of *Spirulina* carotenoids, is rapidly converted to astaxanthin by the prawn. When the study compared *Spirulina* with the use of other carotenoid-containing feed, in every case 3 per cent *Spirulina* was the most effective pigmentation agent.

The efficiency of *Spirulina* as a feed additive to young prawns was also studied in the Fujian state fishery laboratory of China. They used two species of prawns, *Penaeus penicillatus* and *Metapenaeus sp.* in their zoea through the post-larval stage. When *P. penicillatus* in the zoea stage were fed traditional dietary feed or *Spirulina*-enriched feed, a marked increase in the survival rate was observed at the 8th day of the post-larval stage on the latter diet (Table 11.4). This increase in survival rate from 57.3 to 70 per cent actually represents an improvement of more than 22 per cent as compared with the control.

When *Metapenaeus sp.* was used and ponds were initially stocked with prawn at their mysis stage, a similar result was observed (Table 11.5). In this case the increase in the rate of survival was measured after 20 days in the post-larval stage. The increased survival from 32.5 to 47.5 per cent represents an increase of more than 46 per cent over the control.

Continuous growth in the sea-food market and requirements for specific feed can be seen in the studies on the breeding of bay scallop *(Aequipectum irradians).* Its cultivation, first introduced in 1982 in China, 5 years later reached 50 000 tonnes and was expected to double by 1995. Among feed components used in the cultivation was a mix of freshly grown microalgae such as *Phaeodactylum, Dictateria* and

Table 11.4 The effect of *Spirulina*-enriched feed on the survival of *P. penicillatus* in the zoea stage

		Survival	
Feed	Initial stock	(No.)	(%)
Control	3×10^5	1.72×10^5	57.3
+0.5 ppm *Spirulina*	3×10^5	1.80×10^5	60
+1.0 ppm *Spirulina*	3×10^5	2.11×10^5	70

Survival was estimated after the 8th day of post-larval stage.
Adapted from Liao et al., 1993.

Table 11.5 The effect of *Spirulina*-enriched feed on the survival of *Metapenaeus sp.* in the mysis stage

		Survival	
Feed	Initial stock	(No.)	(%)
Control	2×10^5	6.5×10^4	32.5
+0.5 ppm *Spirulina*	2×10^5	8.3×10^4	41.5
+1.0 ppm *Spirulina*	2×10^5	9.5×10^4	47.5

Survival was measured at the 20th day of post-larval stage.
Adapted from Liao et al., 1993.

Platymonas. These feeding systems limited the production of the bay scallops and complicated the feeding protocols.

Intensive work was carried out to test the utilization of *Spirulina* as mixed feed for abalone, scallops and penaeid shrimp (Zhou et al., 1991). It was concluded that *Spirulina* mixed feed made a good substitute for live microalgae in the cultivation of parent scallops because it proved useful for the normal development of the scallop gonads which achieved a higher fecundity and hatchery rate. Thus the use of *Spirulina* mixed feed enhanced production of the bay scallops by giving them an advantage of about one month in season. Moreover, mixed feed greatly simplified the feeding procedure, precluding the change of temperature which would normally result from pouring large quantities of five different microalgae into the production tanks. It was calculated that *Spirulina* mixed feed was cheaper than live microalgae, and some hatcheries have already adopted it in their production of bay scallop larva.

Summary

The consumption of sea food and aquaculture products in developed countries is constantly increasing. Awareness of the better nutritional quality of sea food proteins and lipids will soon make them a major source of protein in the human diet. This increased demand will cause increased production of aquaculture in artificial ponds, where feed and feeding strategies determine the product quality. The work reported here and carried out all over the world indicates that *Spirulina* can be a highly important feed component in the diet of fish and crustaceans. Its effects are very pronounced.

Much of the nutritional work is carried out locally by the hatcheries and aquaculture farms themselves and is rarely published in the literature. Once *Spirulina* gains a reputation among aquaculture farmers as an ideal feed additive, as claimed in some of the works reported, its market is going to increase by an order of magnitude. Further, there will not necessarily be a decrease in price (Ratafia and Purinton, 1989). This is why big producers of *Spirulina* may be expected to accelerate their research and development. At least one company, DIC in Japan, is already doing so.

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