A Review of *Spirulina* as a Carotenoid and Vitamin Source for Cultured Shrimp

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The black tiger prawn (*Penaeus monodon*) is widely cultivated in South East Asia, and production has increased steadily to meet market demand. The majority of *P. monodon* is consumed in Japan, where the quality, and thus market price, is primarily based on visual appeal. In the shrimp farming industry many feed additives have been utilized, but *Spirulina* is the only microalgae additive which demonstrates benefits to growers that offset the initial cost and provide a significant cost/performance ratio. *Spirulina* was studied as a feed supplement for the giant freshwater prawn (*Macrobrachium rosenbergii*), and found to significantly improve growth, survival, and feed utilization. The supplementation range was 5-20% and results were similar at any of the ranges added to the feed (Nakagawa and Gomez-Diaz, 1975). A significant number of the larvae of both marine fish and crustaceans die in their first weeks of life due to infections by opportunistic pathogens. As evidenced by the decimation of shrimp populations in the USA, Thailand, Taiwan, and Latin America in the last several years, early development of immune systems may be the key to protecting larvae against pathogens.

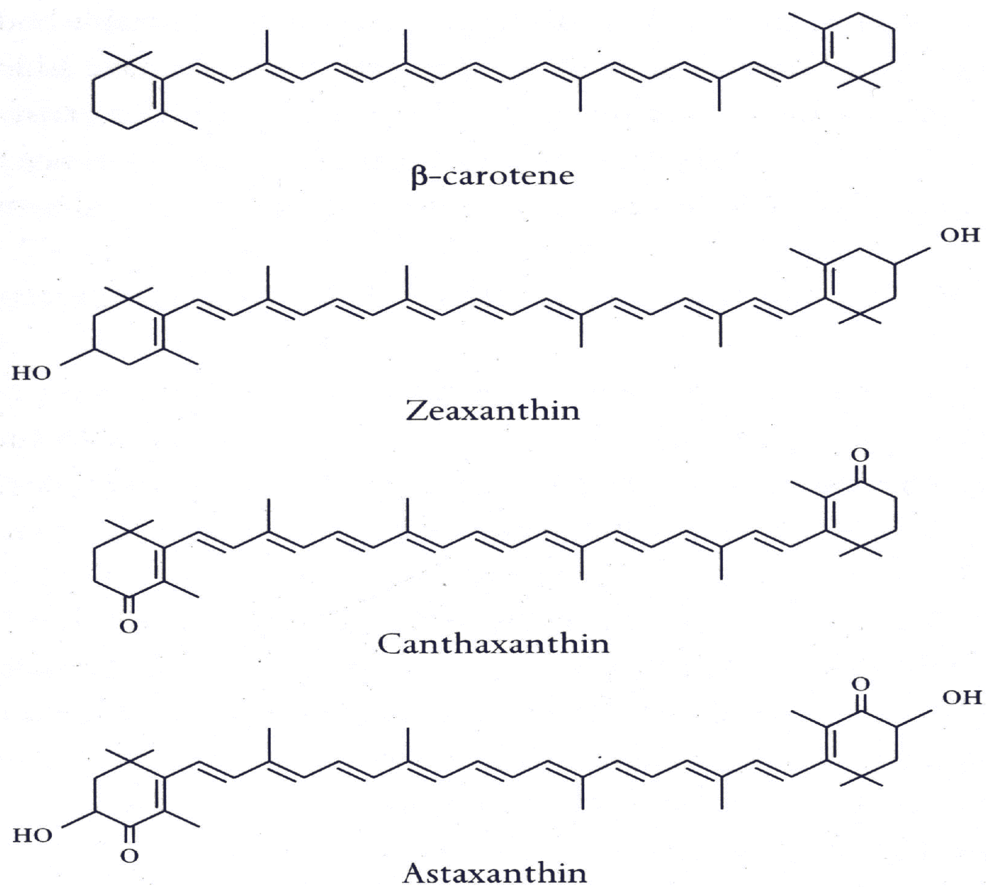
In addition to the nutritional benefits that *Spirulina* provides as a feed additive for cultured shrimp, the most profound effect is exceptional pigmentation. Color is one of the major factors that determines the price of several species of the fresh and saltwater shrimp in the world marketplace, just as pigmentation can cause the price of shrimp to vary $5-50 US per kilogram. Wild shrimp are more colorful than cultured shrimp due to their natural diet of carotenoid-containing food sources. Therefore, to acquire the highest market price, it is necessary to provide a pigment source in the diet to yield shrimp with coloration equivalent to those in nature. Well-pigmented raw shrimp commands higher prices, and result in a cooked product with desirable red coloration.

Carotenoids and carotenoproteins are responsible for the various colors of crustaceans (Britton et al., 1981). Recently, astaxanthin was shown to be the predominant carotenoid associated with the red body color of the black tiger prawn *P. monodon* (Howell and Matthews, 1991). Although animals do not have the biosynthetic pathways to synthesize carotenoids, certain crustacean and koi species are unique in that they have the ability to convert dietary β-carotene and zeaxanthin directly into astaxanthin. *Spirulina platensis* strain pacifica contains the highest levels of β-carotene and zeaxanthin of any natural source, both of which are converted to astaxanthin, the red pigment desired by consumers. The distribution and metabolic pathways of carotenoids in crustacea have been reviewed by Goodwin 1984, Davis 1985, and Matsuno and Hirao, 1989. Tanaka et al. investigated the metabolism of dietary carotenoids in the prawn *P. japonicus* and suggested the presence of two oxidative pathways which convert carotenoids into the xanthophyll, astaxanthin (Figure 1):

1. β-carotene ~> isocryptoxanthin ~> echinenone ~> canthaxanthin ~> phoenicoxanthin~>
astaxanthin.

2. zeaxanthin ~> 4-ketozeaxanthin ~> astaxanthin.

Figure 1



A recent study verified the efficacy of various carotenoid sources, determined optimum levels in feeds, and established a practical strategy of pigmentation for cultured *P. monodon* (Liao et al., 1993). Four different carotenoid sources were tested, β-carotene, *Spirulina*, *Phaffia*, and krill oil. *Phaffia rhodozyma* contained 84 mg/100 grams carotenoids (82% astaxanthin), and krill oil consisted of 93 mg/100 grams of astaxanthin

diesters(Yamaguchi et al., 1983). The *Spirulina* used was a spray-dried product. The content and composition of carotenoids were analyzed by the method of Miki et al.. The carotenoid fraction of *Spirulina* was 346 mg/100 grams and consisted of 52% β-carotene, 21% zeaxanthin, 10% echinenone, 6% beta-cryptoxanthin, 5% 3'-hydroxyechinenone, and 7% unidentified carotenoids.

In the first feeding trial, the efficacy of four pigmentation sources were examined by measuring the deposition in the carapace after 1 month. Carotenoids in each diet were equalized to 10 mg/100 grams. Feeding of *Phaffia* and krill oil proved less effective than *Spirulina*. *Spirulina* lead to a 24% higher deposition of carotenoids in the carapace than β-carotene, 29% higher than *Phaffia*, and 30% higher than krill oil. The feed efficiency after 28 days was also the highest in the *Spirulina*-supplemented group.

Since *Spirulina* was found to provide superior pigmentation, a second trial was conducted to determine the optimal dose of *Spirulina* required for desirable pigmentation. Supplementation of 1%, 3% and 5% were tested in the feeds and it was found that the 3% *Spirulina* resulted in 46% higher carotenoid deposition into the carapace than 1% *Spirulina*-supplemented feed. The higher level of 5% *Spirulina* brought about no increase in effect, thus it was concluded that 3% was the optimal and saturating concentration. The percent gain and feed efficiency in the group fed 3% *Spirulina* also surpassed the control group which received no supplementation.

The composition of the carotenoids deposited in the carapace of prawns fed with the 3% *Spirulina*-supplemented diet were analyzed to follow the bioconversion of dietary carotenoids. Astaxanthin accounted for 69% of the carotenoid fraction, and β-carotene 12%.

***Spirulina* contains β-carotene, β-cryptoxanthin and zeaxanthin as major carotenoids. Each of these are transformed into astaxanthin through an oxidative process. The effectiveness of *Spirulina* as a pigment for *P. monodon* is especially attributable to zeaxanthin, which can be converted into astaxanthin via 4-ketozeaxanthin. Analysis of carapace carotenoids of prawns that received the Spirulina-supplemented diet revealed the absence of zeaxanthin, and only a small amount of 4-ketozeaxanthin was found. This finding suggests that dietary zeaxanthin is rapidly metabolized to astaxanthin in *P. monodon*. That may be the principal reason why *Spirulina* is such an efficient pigmentation source.**

Summary

***Spirulina* significantly enhances the pigmentation of *P. monodon* and increases the economic value. *Spirulina* is the single most effective natural pigmentation source for cultured *P. monodon.* The most practical strategy is a supplemented diet of 3% S*pirulina* for one month prior to harvest of *P. Monodon.* However, it is also becoming clear that *Spirulina* as a feed supplement has other benefits such as increased feed efficiency and health benefits that provide larger and healthier stock.**

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