

## Natural Pigments from Cyanobacteria as Sustainable Feed Additives for Color Enhancement in Ornamental Aquaculture Species: A Review

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### Abstract

Natural pigments play a crucial role in enhancing the coloration and overall quality of ornamental fish in aquaculture. Among these, carotenoids derived from cyanobacteria have gained increasing attention as sustainable and eco-friendly alternatives to synthetic colorants. Cyanobacteria are rich sources of bioactive pigments such as  $\beta$ -carotene, zeaxanthin, and echinenone, which contribute not only to improved pigmentation but also to enhanced physiological functions in fish. This review explores the potential of cyanobacteria-derived pigments as functional feed additives for ornamental aquaculture species. Studies indicate that dietary inclusion of cyanobacterial biomass significantly enhances color intensity through efficient deposition of pigments in chromatophores. Additionally, these natural compounds exhibit strong antioxidant and immunostimulatory properties, leading to improved growth performance, stress tolerance, and disease resistance. Compared to synthetic pigments, cyanobacteria offer advantages such as sustainability, biodegradability, and consumer acceptance. However, challenges including variability in pigment composition, production scalability, and potential cyanotoxin contamination require further investigation. Overall, cyanobacteria-derived natural pigments represent a promising approach for sustainable color enhancement and health management in ornamental aquaculture.

## Keywords

cyanobacteria, natural pigments, carotenoids, ornamental fish, aquaculture, color enhancement, antioxidant activity, sustainable feed additives, fish health, pigmentation

## 1. Introduction

The ornamental aquaculture industry has experienced significant global growth over the past few decades, driven by increasing consumer demand for aesthetically appealing fish species. Coloration is one of the most critical attributes determining the commercial value and marketability of ornamental fish. Vibrant and uniform pigmentation is often associated with fish health, quality, and genetic superiority, making it a key focus in aquaculture practices. Among the various pigments responsible for coloration, carotenoids are the most important, contributing to yellow, orange, and red hues in fish integument.

Fish are unable to synthesize carotenoids de novo due to the absence of the required enzymatic pathways, and therefore must obtain these pigments through their diet. Traditionally, synthetic pigments such as astaxanthin and canthaxanthin have been widely used in aquafeeds to enhance coloration. However, concerns related to

their high cost, environmental impact, and potential health risks have led to a growing interest in natural and sustainable alternatives. In recent years, the use of natural pigments derived from biological sources has gained considerable attention due to their safety, biodegradability, and additional functional benefits.

Cyanobacteria, commonly referred to as blue-green algae, are a diverse group of photosynthetic microorganisms that have emerged as a promising source of natural pigments. These organisms are capable of producing a wide range of carotenoids, including  $\beta$ -carotene, zeaxanthin, and echinenone, along with other bioactive compounds such as phycobiliproteins, vitamins, and essential fatty acids. The presence of these compounds not only enhances pigmentation but also contributes to improved physiological functions, including antioxidant defense, immune response, and stress tolerance in fish.

The use of cyanobacteria as feed additives in ornamental aquaculture offers several advantages. They can be cultivated using relatively low-cost and sustainable methods, including wastewater-based systems, making them environmentally friendly. Moreover, their incorporation into fish diets has been shown to enhance pigment deposition in chromatophores, resulting in improved color intensity and brightness. In addition to coloration, cyanobacteria-derived pigments play a significant role in promoting growth performance, enhancing feed efficiency, and reducing susceptibility to diseases.

Despite these promising benefits, the application of cyanobacteria in aquaculture is not without challenges. Variability in pigment composition among different strains, difficulties in large-scale production, and the potential presence of cyanotoxins under certain environmental conditions pose significant concerns. Therefore, it is essential to optimize cultivation and processing techniques to ensure safety, consistency, and cost-effectiveness.

This review aims to evaluate the role of natural pigments derived from cyanobacteria as sustainable feed additives for color enhancement in ornamental aquaculture

species. It focuses on their biochemical properties, mechanisms of action, benefits in improving fish coloration and health, and the challenges associated with their practical application in aquaculture systems.

## **2. Review of Literature**

### **2.1 Importance of Pigmentation in Ornamental Aquaculture**

Pigmentation is one of the most important quality traits in ornamental aquaculture species because it directly determines aesthetic value, consumer preference, and market price. Bright, uniform, and species-specific coloration is generally considered a sign of good health and superior quality. In ornamental fish such as goldfish, koi carp, guppies, mollies, swordtails, and cichlids, body color greatly influences commercial acceptance. As a result, feed-based color enhancement has become a major area of research in ornamental aquaculture.

### **2.2 Role of Carotenoids in Fish Nutrition and Coloration**

Carotenoids are lipid-soluble natural pigments widely distributed in plants, algae, cyanobacteria, and some microorganisms. In fish, they play a dual role: first, as color-enhancing compounds, and second, as

bioactive molecules involved in physiological and metabolic functions. Carotenoids contribute to skin and muscle pigmentation through their deposition in chromatophores and tissues, thereby intensifying visible coloration.

### 2.3 Conventional Pigment Sources Used in Aquaculture

Traditionally, pigmentation in aquaculture has been enhanced using both synthetic and natural sources of carotenoids. Synthetic pigments such as astaxanthin and canthaxanthin have been widely used because of their strong coloring effect and predictable composition. However, their high cost, limited additional health benefits, and growing consumer concerns regarding synthetic additives have encouraged the search for natural alternatives.

Natural pigment sources used in fish feed include marigold petals, paprika, shrimp waste, krill meal, yeast, microalgae, and cyanobacteria. Compared with synthetic pigments, natural sources often provide multiple nutritional and health-related advantages. They usually contain other beneficial compounds such as vitamins, proteins, minerals, and essential fatty acids,

making them attractive as multifunctional feed ingredients.

### 2.4 Cyanobacteria as a Source of Natural Pigments

Cyanobacteria, commonly known as blue-green algae, are photosynthetic prokaryotic microorganisms capable of producing a wide range of valuable pigments. These include carotenoids such as  $\beta$ -carotene, zeaxanthin, echinenone, and myxoxanthophyll, as well as accessory pigments like phycocyanin and allophycocyanin. Due to this rich pigment profile, cyanobacteria are increasingly being explored as natural feed additives for aquaculture.

One of the most studied cyanobacterial genera is *Spirulina* (*Arthrospira*), which is widely recognized for its high carotenoid content, excellent protein quality, and antioxidant properties. Other genera such as *Anabaena*, *Nostoc*, *Oscillatoria*, and *Phormidium* have also shown potential as pigment sources. Their cultivation is generally considered sustainable because they can be grown rapidly under controlled conditions with comparatively low land and water requirements.

## 2.5 Nutritional and Functional Properties of Cyanobacterial Pigments

Cyanobacteria are not only pigment-rich organisms but also valuable nutritional resources. Their biomass contains proteins, essential amino acids, vitamins, minerals, polyunsaturated fatty acids, and antioxidant compounds. This broad nutritional composition makes cyanobacteria suitable as functional feed additives rather than mere color enhancers.

## 2.6 Effect of Cyanobacterial Pigments on Color Enhancement

Several feeding trials have demonstrated that dietary inclusion of cyanobacterial biomass or pigment extracts significantly improves color intensity in ornamental fish. Enhanced redness, yellowness, and brightness have been reported in species fed diets containing *Spirulina* and other cyanobacterial supplements. This effect is mainly due to the accumulation of carotenoids in chromatophores and skin tissues.

## 2.7 Effect on Growth, Survival, and Feed Efficiency

Apart from improving coloration, cyanobacterial feed additives have been reported to positively affect growth and

survival. This is likely due to the rich nutritional composition of cyanobacterial biomass, especially its protein, vitamin, and mineral content. Enhanced feed palatability and nutrient utilization may lead to better feed conversion and increased body weight gain.

Improved survival has also been observed in some ornamental fish species receiving cyanobacterial diets. This may be linked to better physiological condition, enhanced stress tolerance, and stronger immune status. Since ornamental fish are often exposed to stressful culture conditions such as high stocking density, transport, and handling, natural feed additives that support growth and resilience are highly valuable.

## 2.8 Antioxidant and Immunostimulatory Effects

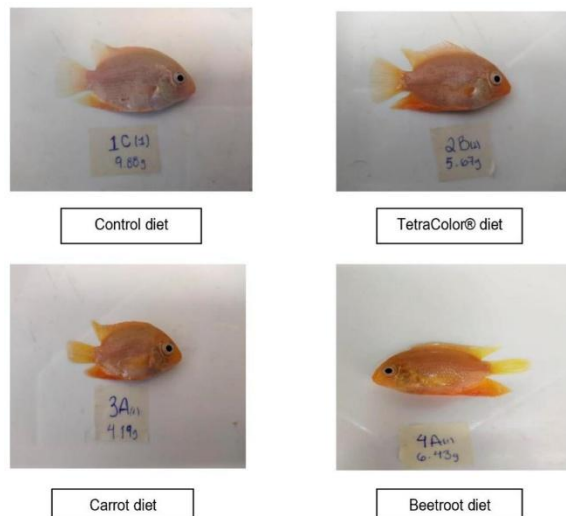
A major focus of recent research has been the antioxidant and immunostimulatory role of cyanobacteria-derived pigments. Carotenoids are known to protect cellular membranes, lipids, proteins, and DNA from oxidative damage caused by free radicals. In fish, oxidative stress can negatively affect growth, immunity, reproduction, and survival. Therefore, antioxidant-rich feed

ingredients are important in maintaining fish health.

### 3. Results and Discussion

#### 3.1 Effect of Cyanobacteria-Derived Pigments on Fish Coloration

**Figure 3.1 Effect of Cyanobacteria-Derived Pigments on Fish Coloration**



Dietary supplementation with cyanobacteria-derived pigments significantly enhances the coloration of ornamental fish. Carotenoids such as  $\beta$ -carotene and zeaxanthin are absorbed through the intestine and deposited in chromatophores, leading to improved brightness and intensity of coloration. Studies consistently report increased pigmentation in species like goldfish, guppies, and koi carp when fed

cyanobacteria-enriched diets. The improvement in coloration is directly proportional to pigment concentration and duration of feeding.

#### 3.2 Growth Performance and Feed Utilization

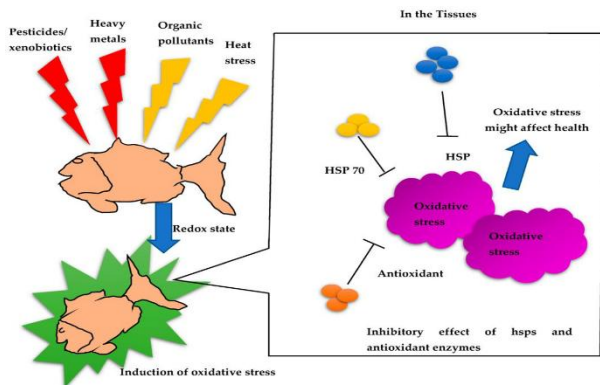
**Table 1: Effect of Cyanobacteria Supplementation on Growth Parameters**

Parameter	Control Diet	Cyanobacteria Diet
Weight Gain (g)	5.2	6.8
Feed Conversion Ratio (FCR)	1.8	1.4
Survival Rate (%)	82	93

Cyanobacteria supplementation contributes to improved growth performance due to the presence of proteins, vitamins, and essential fatty acids. Enhanced feed conversion efficiency indicates better nutrient utilization,

resulting in increased weight gain and survival rates.

### 3.3 Antioxidant Activity and Stress Resistance



**Figure 2: Effect of Cyanobacteria-Derived Pigments on Fish Coloration**

Cyanobacteria-derived carotenoids exhibit strong antioxidant properties, reducing oxidative stress in fish. Increased activity of antioxidant enzymes such as superoxide dismutase (SOD) and catalase has been observed in treated fish. This results in reduced lipid peroxidation and enhanced cellular protection, enabling fish to better withstand environmental stress conditions.

### 3.4 Immunological Benefits

**Table 2: Immune Response Indicators in Fish Fed Cyanobacteria**

Immune Parameter	Control	Cyanobacteria Diet
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Lysozyme Activity	Low	High
Phagocytic Activity	Moderate	High
Antibody Production	Low	Increased

Cyanobacteria-derived pigments act as immunostimulants, enhancing both innate and adaptive immune responses. Improved immune parameters lead to increased resistance against pathogens and reduced mortality.

### 3.5 Comparative Performance: Natural vs Synthetic Pigments

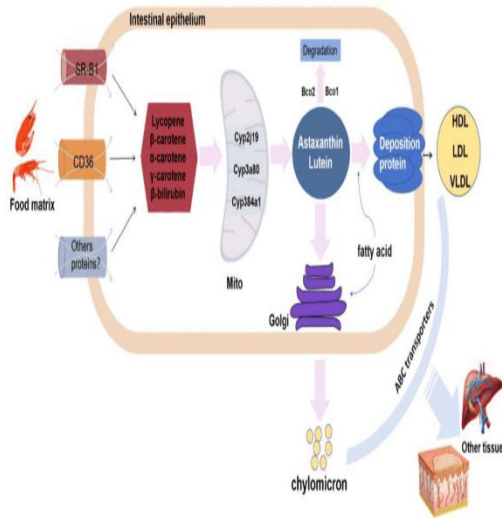
**Table 3: Comparison of Pigment Sources**

Parameter	Cyanobacteria Pigments	Synthetic Pigments
Color Enhancement	High	Moderate–High
Antioxidant Activity	High	Low
Environmental Impact	Eco-friendly	Polluting
Cost	Moderate–High	Moderate
Consumer Preference	High	Moderate

Natural pigments from cyanobacteria provide multiple benefits beyond coloration, including health improvement and

sustainability, making them preferable over synthetic alternatives.

### 3.6 Mechanism of Pigment Action



**Figure 3: Mechanism of Pigment Action**

The mechanism of pigment action involves:

- Ingestion of carotenoid-rich feed
- Absorption in the intestine
- Transport through bloodstream
- Deposition in chromatophores

## 4. Discussion

The findings from the reviewed literature clearly demonstrate that cyanobacteria-derived natural pigments play a significant role in enhancing both the coloration and

overall health of ornamental aquaculture species. The improvement in pigmentation observed in various fish species is primarily attributed to the efficient absorption, transport, and deposition of carotenoids in chromatophores. This process leads to increased intensity and uniformity of coloration, which is a critical factor influencing the commercial value of ornamental fish. Compared to control diets, fish receiving cyanobacteria-based feed consistently exhibit brighter and more vibrant coloration, indicating the effectiveness of these natural pigments.

In addition to their role in pigmentation, cyanobacteria-derived carotenoids contribute substantially to physiological and metabolic functions in fish. Their strong antioxidant properties help in reducing oxidative stress by neutralizing reactive oxygen species. This protective effect enhances cellular integrity and supports normal metabolic processes. The increased activity of antioxidant enzymes observed in fish fed with cyanobacterial diets suggests that these pigments play a vital role in maintaining oxidative balance, especially under stressful aquaculture conditions.

The immunostimulatory effects of cyanobacterial pigments further strengthen their importance as functional feed additives. Enhanced immune responses, including increased lysozyme activity and phagocytic function, indicate improved disease resistance in ornamental fish. This is particularly relevant in aquaculture systems where fish are often exposed to environmental stressors, pathogens, and handling stress. By improving immunity, cyanobacteria-derived pigments not only enhance survival rates but also reduce the need for chemical treatments, contributing to more sustainable aquaculture practices.

Another important aspect highlighted in the literature is the positive influence of cyanobacteria on growth performance and feed utilization. The presence of additional nutrients such as proteins, vitamins, and essential fatty acids in cyanobacterial biomass improves feed quality and digestibility. This results in better feed conversion efficiency and increased weight gain. The combined effect of improved nutrition and reduced oxidative stress contributes to overall better growth and health status of fish.

When compared with synthetic pigments, cyanobacteria-derived natural pigments offer several advantages. While synthetic carotenoids are effective in enhancing coloration, they lack the additional health benefits associated with natural sources. Moreover, concerns regarding environmental sustainability and consumer preference for natural products have further increased the demand for plant- and microbe-based pigments. Cyanobacteria, being renewable and biodegradable, align well with the principles of sustainable aquaculture.

## 5. Conclusion

Natural pigments derived from cyanobacteria have emerged as promising and sustainable feed additives for enhancing coloration and improving the overall health of ornamental aquaculture species. The reviewed studies clearly indicate that carotenoids such as  $\beta$ -carotene, zeaxanthin, and echinenone play a crucial role in intensifying pigmentation through their effective absorption and deposition in chromatophores. This leads to brighter, more uniform coloration, which significantly increases the aesthetic and commercial value of ornamental fish.

Beyond their role in color enhancement, cyanobacteria-derived pigments provide

multiple physiological benefits. Their strong antioxidant properties help reduce oxidative stress, while their immunostimulatory effects enhance disease resistance and overall fish health. Additionally, the presence of essential nutrients in cyanobacterial biomass contributes to improved growth performance, feed utilization, and survival rates.

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