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Natural Pigments: The Secret to Brilliant Colour in Marine Ornamental Fish

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Abstract

Natural pigments play a vital role in enhancing the coloration, health and market value of marine ornamental fish. These bioactive compounds, primarily carotenoids, melanins and flavonoids are responsible for producing the brilliant hues that define ornamental species. As fish cannot synthesize most pigments endogenously, they rely on dietary sources such as algae, crustaceans and plant materials. The growing demand for sustainable aquaculture practices has encouraged the exploration of natural pigment sources as alternatives to synthetic additives, which may pose health and environmental risks. Research indicates that natural pigments not only intensify coloration but also improve immune response, stress resistance and reproductive performance. This article highlights the biological mechanisms, dietary influences and technological applications of natural pigments in ornamental fish culture. Advancing pigment research and eco-friendly feed formulations can promote sustainable aquaculture while preserving the aesthetic and ecological value of marine ornamental species.

Keywords: Natural pigments; carotenoids; marine ornamental fish; sustainable aquaculture; bio-pigments; eco-friendly feed additives

Introduction

The coral reef ecosystems are very important in the global industry of aquariums due to the beautiful colors of ornamental fish that compel viewing marine coral reefs so much. The intensity of colour, vibrancy and diversity in patterns play a big role in consumer preference and cost of products in a market (Das and Biswas, 2016). Nevertheless, these bright colors do not last long in captivity because of the variation in diet, stress and environmental conditions. With the development of the marine ornamental fish sector, aesthetic value has emerged as one of the primary economic forces, where the color of fish species such as *Pseudochromis fridmani*, *Amphiprion ocellaris*, and *Paracanthurus hepatus* exemplifies customers liking and appreciating color, and the fish industry sustaining coastal economies (Jiang et al., 2019).

These colors require natural pigments such as carotenoids, melanins and flavonoids to form and preserve such colors. Most marine animals are unable to produce carotenoids, meaning they must sustain themselves through the consumption of algae, shells of crustaceans and pigments generated by microorganisms (Monica and Swamy, 2022). Experiments have demonstrated that natural pigments do not only increase the coloration and growth, but also the immune responses and the ability to cope with the stress in fish (Tran et al., 2024). As more people are demanding environmentally-friendly aquaculture, natural pigment-based feeds continue to grow in size, eliminating the necessity of synthetic feed additives (Kaur and Shah, 2017). Marine ornamental fish industry is a multi-billion dollar (approximately 1020 billion) sector heavily dependent on nations such as Indonesia, Philippines and Sri Lanka that help the communities of the coastlines (Rhyne et al., 2017). The country can increase its market share by investing in sustainable practices by leveraging the fact that India is a biodiversity-rich land (CMFRI, 2023).

Distribution and Diversity of Marine Ornamental Fishes

The ornamental fishes found in the marine environment are incredibly diverse in the tropical and subtropical reefs with 2,682 species of 145 families being listed in the global aquarium trade (Linardich et al., 2023). Several of the biggest and most frequently traded groups including damselfishes, clownfishes, wrasses, butterflyfishes, gobies, cardinalfishes and blennies.Among others, over 100 species each that represents their relative abundance as well as their significance in ecosystems (Linardich et al., 2023). Famous instances of the combination of both widespread and very limited species in the trade are noted. Both the Banggai Cardinalfish (*Pterapogon kauderni*) of Indonesia has become significantly decreased as a result of overharvesting, whereas the Barber Goby of Brazil (*Elacatinus figaro*) is a Vulnerable species because of continuous harvesting (Linardich et al., 2023). Naoko's Fairy Wrasse, blue velvet angelfish and various damselfishes living on coral reefs like *Gobiodon axillaris, G. reticulatus, Oxymonacanthus longirostris* and *Amblyglyphidodon ternatensis* are other species of concern and are all threatened by habitat loss and trade (Linardich et al., 2023). Every year, 2,3002,500 species and up to 40 million specimens fall into the market, primarily in the United States, Europe and Japan. The imports conducted by 86 families into Europe reflect how extensive the industry went geographically (Biondo, 2019).

Natural Pigments

Marine ornamental fish depend on various natural pigments namely, carotenoids, melanins, flavins and pteridines, in order to generate their characteristic colors and their health, in general. The carotenoids that give the red, orange and yellow color are of

particular significance because marine fish themselves are unable to synthesize them but have to obtain them through natural products such as algae and crustaceans (Monica and Swamy, 2022). These color pigments have not only aesthetic benefits such as increasing color but also augmenting immune, reproductiveand antioxidant capacities (Das and Biswas, 2016). In their turn, melanins are created in nature and provide fish with a darker shade, which aids in simulation, defense against the sun and social communication (Cal et al., 2017). Less researched but involved into colour work, flavins and pteridines can be used to add yellow, in collaboration with carotenoids and resulting in more intense and brighter colors (Liu et al., 2024). The miscellany of functions of these pigments can be critical to regulating the coloration of marine ornamental fish to guarantee their visual characteristics together with their health (Jiang et al., 2019) (Table.1).

Table.1. Common Natural Pigments extracted from natural sources

Pigment	Natural Source	Colour Produced	Key Benefits
Astaxanthin	Microalgae, shrimp shells	Deep red-orange	Strong red tones, antioxidant
Lutein	Marigold petals	Yellow-gold	Brightens yellow hues
β-Carotene	Carrots, seaweeds	Orange	Enhances orange tones
Phycocyanin	Spirulina (blue-green algae)	Blue-green	Boosts blue coloration
Carminic acid	Cochineal insects	Crimson-red	Eco-friendly red pigment

Table.2 Natural pigments for tentative colour enhancer for Common Marine Ornamental fishes

Common Marine Ornamental Fishes	Colour Enhanced	Tentative Effective Pigment
Clownfish (*Amphiprionocellaris*)	Orange and red	Astaxanthin, marigold

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Mandarinfish (*Synchiropussplendidus*)	Blue-green	Spirulina, phycocyanin
Royal Gramma (*Gramma loreto*)	Violet	Mixed microalgae pigments
Dottybacks (*Pseudochromis*spp.)	Purple-red	Cochineal, shrimp meal
Wrasses (*Halichoeres*spp.)	Multi-coloured	Algae blends, astaxanthin

Mechanisms of Colour Development

Marine ornamental fish develop color development as a result of a set of cellular, molecular and environmental inputs. Color is produced by specialized pigment cells known as chromatophores and all of them are of the same type, melanophores (produce dark colour), xanthophores and erythrophores (produce yellow or red colour), and iridophores and leucophores (produce iridescent effects) (Cal et al., 2017). These are the cells that change color rapidly because of hormones and neurotransmitters that enable them to expand and contract enabling the fish to have camouflage, communication and response to stress (Sugimoto, 2002). At the molecular level pigment production is under enzymatic control as well as under the control of genetic pathways. As an example, the enzymes such as tyrosinase convert melanin to melanophores (Cal et al., 2017), and carrier proteins such as SCARB1 and BCO2 decompose carotenoids (Toews et al., 2017). Light or background color is also among environmental factors influencing chromatophores activity (Leclercq et al., 2010).

Nutritional Sources of Natural Pigments

Natural pigment nutrients are important in determining the color and quality of the ornamental fish in the marine environments. Most of the fish species are unable to produce carotenoids and other pigments, and they depend on their food, such as microalgae, crustaceans and plant extracts (Chien and Shiau, 2005). *Hematococcus pluvialis*, *Dunaliella salina* and *Spirulina platensis* are source algae that are abundant in carotenoids such as astaxanthin, 2-carotene and zeaxanthin, which increase pigmentation (Monica and Swamy, 2022). Carotenoid is well playing the role of enhancing red and yellow tons of fish, marigoldsand it may contain in natural things such as red pepper and sweet potato crustacean by-products (Diler et al., 2017). The pigments do not only enhance coloration but also antioxidant ability, immune and reproductive (Das and Biswas, 2016).

The digestive grafts such as fish lipid levels and activity of digestive enzymes influence the uptake of these pigments and their usage (Katsuyama et al., 1987). Carotenoids are consumed in the intestines and moved into the skin and eyes among the other tissues. Astaxanthin accumulation is effectively accumulated in species such as *Amphiprion ocellaris* and *Pseudochromis fridmani* (Jiang et al., 2019). Esterified carotenoids are more stable than the free ones and the carotenoids are present in algae and crustaceans (Higuera-Ciapara et al., 2006). Proper pigment types and quality feed are likely to help in improvement of coloration and sustainable aquaculture (Olivotto et al., 2011).

Influence of Environmental and Genetic Factors

Environmental factors as well as genetics determine the pigmentation of the marine ornamental fish. Unfavorable water parameters including elevated ammonia or insufficient oxygen might effect pigment development and the activity of chromatophore (Bhat et al., 2019), and the extent of light, particularly, blue and red, light also affect carotenoid deposition and intense colour (Leclercq et al., 2010; Ghosh et al., 2016). Stressors due to the environment such as the treatment or temperature changes may cause hormonal changes, which inhibit pigmentation (Sugimoto, 2002). Vibrant coloration must be maintained by keeping water quality, light andlow-stress conditions to optimality. Genetically, melanin synthesis is regulated by such genes as MITF, TYR, DCT and carotenoid intake is controlled by SCARB1 and BCO2 (Yuan et al., 2023). Different color morphs are caused by genetic variations, and adaptive color changes can also be caused by epigenetic mechanisms (Guo et al., 2022), proving that genes and environment interact intricately to create pigmentation.

Applications in Aquaculture and Feed Technology

The use of natural pigment supplements to feed in modern ornamental fish aquaculture is currently considered a major approach to improving fish color and subsequent health. Research has indicated that carotenoids obtained on the basis of plants, algae extracts and crustacean-waste pigments enhance coloration and marketability (Monica and Swamy, 2022). Carotenoids cannot be produced by ornamental fish and therefore those provide pigment-fortified feed to keep the fish colorful, which has a direct effect on the commercial value of the fish (Kaur and Shah, 2017). On top of this, there are natural pigments such as carotenoids, that are antioxidants and immune enhancers, which improve fish health and diminish mortality (Yuli et al., 2024). The best results can be achieved by using effective feed formulation taking into account the source of pigments and their maintenance (Das and Biswas, 2016).

Comparison between Natural and Synthetic Pigments

Recent studies in aquaculture test the comparisons of natural and artificial pigment supplements mainly astaxanthin which discover the trade off of efficacy, cost, safety and sustainability. Synthetic astaxanthin tends to result in increased pigment composition and colour contents in comparison to its natural sources such as the algae, which have undergone the process of esterification (Zhao et al., 2023). As an illustration, synthetic astaxanthin increased the levels of redness and pigment retention in trout (Zhao et al., 2023). Nonetheless, natural astaxanthin has superior antioxidant capacity, bioavailability and more desirable stereoisomer profile (Ambati et al., 2020). Compared to synthetic pigments, natural pigments help in the health and sustainability of fish; but they are priced high (Sun and Chen, 2021).

Sustainability and Environmental Implications

The application of natural pigments in aquaculture is a major advancement in the way that is more sustainable and friendly. Alternatives such as natural sources such as microalgae, yeasts, crustacean by-products and plant extracts provide a renewable alternative to synthetic colorants, resulting in waste valorization and modeling of the bioeconomy in a circle. Such marine yeast as *Rhodotorulapa ludigena* VA 242 can offer a more sustainable source of pigments to improve the color and help to recover resources in a marine biomass(Rekha et al., 2024). If the pigments are enhanced using algal and floral extracts, including *H. pluvialis* and marigold, the process does not pollute the chemical (Monica and Swamy, 2022). These natural dyes are not toxic to aquatic life and unlike the synthetic dyes, which may impart toxins, these natural dyes are biodegradable and pose no harm to aquatic life (Castro-Castellón et al., 2025). Also, natural sources of carotenoids increase antioxidant power and immunity and decrease the necessity to use antibiotics in ornamental aquaculture (Tran et al., 2024). The sustainability of these pigments however is relying on effective production systems. There are new advancements such as integrated multi-trophic aquaculture that is taking into consideration the issues of land, nutrients, and energy inputs (Castro-Castellón et al., 2025). Natural pigments are also in line with the preferences of consumers towards products labeled as eco-friendly products by boosting the marketability of sustainably farmed fish (Monica and Swamy, 2022).

Future Directions and Research Priorities

With new technologies available due to the development of marine ornamental aquaculture, there are new possibilities in enhancing pigments and optimization of colors. Genetic technology, including genome editing and the selection of pigment-cell genes are taken up with optimism in order to force desirable color phenotypes (Liu et al., 2024).

Such microbial systems as yeast and fungi become sustainable alternatives to pigment production, which produces high-yield carotenoids with a smaller environmental impact (Zantioti et al., 2025). Moreover, other innovations micro-encapsulation and smart nutrient delivery can improve the ability of pigment in decorative fish (Andrian et al., 2024). Future studies will be based on the optimization of the pigment biosynthesis, methods of feeding the pigs and combining the pigment production with the culture of the species. Such issues as pigment quality, safety, and environmental sustainability are of key concern (Zantioti et al., 2025). With the interdisciplinary work, it is possible to turn the industry into a resource-efficient, climate-resilient sector, as the rich color would create a sign of ecological and economic sustainability.

Conclusion

In order to promote the beauty, health and sustainability of marine ornamental fish, natural pigments are required. They enhance color to add aesthetic and commercial value and promote environmentally friendly initiatives through the drawback of synthetic chemical application. Improved profitable aquaculture increasingly relies on pigment-enriched feeds derived by algae, yeasts, plants and crustaceans producing feeds with high levels of pigments that are environmentally responsible. Natural color enhancement process is made efficient by innovations in biotechnology and formulation of feeds contributing to a sustainable blue economy.

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