Ornamental Fish Culture: Prospects, Challenges, AND Economic Significance

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Abstract
The ornamental fish industry is a rapidly growing sector with significant economic, ecological, and employment potential. India, with its rich biodiversity, harbors over 150 native ornamental fish species while also accommodating more than 280 exotic species. The successful captive breeding of over 100 species has contributed to the expansion of the trade, making it a vital contributor to the global market. This sector not only supports livelihoods, particularly in rural and coastal regions, but also fosters advancements in aquaculture technologies, sustainable breeding practices, and conservation efforts. However, challenges such as water quality management, disease control, and the ecological impact of invasive species pose concerns. This review explores the current status, emerging trends, and future prospects of ornamental fish culture, highlighting its role in the economy and sustainable aquaculture development.

Introduction
Ornamental fish keeping, introduced in 1805, is among the earliest and most cherished hobbies worldwide, second only to photography, while also supporting rural and coastal economies through exports. The first public aquarium was established in London in 1852. In recent years, what was once considered a luxury has evolved into a necessity, with aquarium fishkeeping gaining recognition as an effective stress-relieving activity. The global demand for ornamental fish is rising, with prices significantly higher than those of fish for consumption. Over the past 40 years, advancements in breeding technology have enhanced overall production of oviparous (egg-laying) and viviparous (live-bearing) fish. Intensified breeding operations now require a steady provision of a nutritious diets, economical feed, contributing to the steady growth of the ornamental fish industry. The ornamental fish sector is expanding at a remarkable pace, with the global trade valued at over US$1 billion, while the broader industry, encompassing fish diet (feed) and equipment's, is valued to be worth US$18–20 billion and is expanding at a yearly increase of 14%.

India holds a vital position in the ornamental fish sector, providing substantial employment opportunities and contributing significantly to the economy. The trade is primarily concentrated in metropolitan regions such as Kolkata, Mumbai, and Chennai. India boasts a rich biodiversity of ornamental fish, with over 150 native species, while more than 280 exotic species have been introduced into the country. Among them, more than100 exotic and native species are successfully breed in captivity condition. The Indian ornamental fish market is valued at approximately ₹25 crores for domestic trade, while exports, which rely heavily on wild collection, are estimated at ₹6 crores, accounting for just 0.3% of global trade. Kolkata leads the export market, handling 90% of shipments, followed by Mumbai (8%) and Chennai (2%). The industry has shown steady growth, with exports increasing from ₹5.65 crores in 2015–16 to ₹9.5 crores in 2016–17.
Ornamental fish are generally small, non-aggressive, and brightly colored, making them ideal for captive rearing. They are categorized into two groups: egg-layers (oviparous) and livebearers (ovo-viviparous). Among livebearers, the Poeciliidae family is the most commonly bred group (Alderton, 2012). This family includes species such as Guppy (*Poecilia reticulata*), Molly (*Poecilia sphenops*), Swordtail (*Xiphophorus helleri*), Platy (*Xiphophorus maculatus*), and Mosquito Fish (*Gambusia affinis*), all of which are easy to breed. These species are typically cultivated in cemented tanks, outdoor earthen ponds, or net enclosures. In controlled environments, livebearers prefer a diet consisting of live food organisms, fish meal, rice bran, skimmed milk powder, and wheat flour. However, such a diet may not fully meet the nutritional requirements of broodstock fish, as their dietary needs differ from juvenile fish due to variations in biological processes (Coad, 2017).

Ornamental fish have gained prominence due to their adaptability, vibrant color variations, and high reproductive efficiency. Given the increasing demand for ornamental fish farming, this article focuses on the breeding techniques and commercial viability of ornamental fish, highlighting their significance in the growing aquaculture industry. Additionally, it explores the economic potential, sustainability, and business opportunities associated with ornamental fish farming, making it an attractive venture for farmers, entrepreneurs, and aquarium enthusiasts.

Commercially Important Ornamental Fish Species

The ornamental fish industry has experienced significant growth over the years, with more than 2,000 species identified globally. India, with its rich biodiversity, plays an important role in this trade, particularly in the northeastern region where a diverse range of freshwater ornamental fish species is found. The aquarium fish trade is a thriving industry contributing to global commerce, with ornamental fish being exported worldwide. India has reported over 217 species of ornamental fish in its northeastern region alone, with around 150 species considered to have commercial value. Despite its vast natural resources, India's participation in the global ornamental fish trade is still developing. Among the key ornamental fish species, egg layers such as goldfish, koi carp, tiger barb, neon tetra, and gouramis, along with livebearers like guppies, mollies, platies, and swordtails, dominate the market. Egg-laying ornamental fish comprise some of the most widely traded species. Goldfish (*Carassius auratus*), one of the most popular species, is known for its adaptability and diverse color variations. Other significant species include koi carp (*Cyprinus rubrofuscus*), tiger barb (*Puntigrus tetrazona*), silver shark (*Balantiocheilos melanopterus*), zebra fish (*Danio rerio*), and various species of tetras and gouramis. These species require specific breeding conditions such as well-oxygenated water, stable temperature, and appropriate diet to ensure optimal growth and reproduction.

Livebearers, characterized by their ability to give birth to free-swimming juveniles, are widely favored due to their ease of breeding and adaptability. The most popular livebearing ornamental fish include guppies (*Poecilia reticulata*), platies (*Xiphophorus maculatus*), mollies (*Poecilia sphenops*), and swordtails (*Xiphophorus helleri*). These species exhibit vibrant colors and are easy to care for, making them highly desirable in the aquarium trade. Guppies are particularly notable for their wide variety of fin shapes and colors, making them a staple in the ornamental fish market. They can thrive in various environmental conditions and are relatively easy to breed. Platies are another widely kept species, known for their peaceful nature and genetic diversity, which has resulted in numerous color morphs. Mollies, on the other hand, require slightly brackish water and a diet rich in plant matter. Swordtails, closely related to platies, are distinguished by the elongated lower lobe of the male's caudal fin, resembling a sword. The breeding of ornamental fish, particularly livebearers, is relatively straightforward, requiring optimal water parameters and adequate nutrition. Most livebearers prefer a water temperature of 22-28°C, a pH range of 7.0-8.0, and moderate aeration. Selective breeding programs have been implemented to enhance desirable traits such as coloration, fin shape, and disease resistance. For successful breeding, livebearers require well-structured environments with hiding spaces for fry, as adult fish may prey on their offspring. Plants, breeding traps, and separate nursery tanks are commonly used to protect young fish. Proper feeding, including a mix of high-quality dry food, live feeds, and vegetable-based diets, is essential for maintaining healthy breeding stock. The ornamental fish trade is valued at over $10 billion annually, with an increasing demand for both freshwater and marine species. More than 60% of the species traded are freshwater fish, with livebearers and egg layers forming a significant portion of the market. Countries like Singapore, the USA, and various European nations dominate the global ornamental fish trade.

India, despite its rich aquatic biodiversity, has yet to fully capitalize on its potential in this sector. Developing sustainable aquaculture practices and improving breeding techniques could significantly enhance India's position in the global market. Despite its growth, the ornamental fish trade faces several challenges, including overexploitation of wild populations, habitat degradation, and disease outbreaks. Sustainable breeding programs, improved aquaculture techniques, and enhanced biosecurity measures are crucial to ensuring the long-term viability of this industry. Research into genetic improvements, disease resistance, and water quality management will further contribute to the success of ornamental fish farming. Commercially important ornamental fish species, particularly livebearers and egg layers, play a significant role in the aquarium trade. Advances in breeding techniques, habitat management, and trade policies can contribute to sustainable development in this industry. With appropriate investment and research, India can expand its participation in the global ornamental fish market while ensuring the conservation of its native species.

Types of Ornamental Livebearers

Livebearers are ornamental fish species that give birth to live young rather than laying eggs. These fish are highly popular in the aquarium trade due to their vibrant colors, adaptability, and ease of breeding. The most commonly kept livebearers include guppies, mollies, swordtails, and platies, each of which has distinct characteristics that make them suitable for different aquarium environments.

Guppies, also known as million fish (*Poecilia reticulata*), originate from Central America and have a lifespan of approximately two years. They are small fish with a variety of caudal fin shapes and colors, an upturned mouth, and large eyes. Male guppies are more colorful than females and possess a gonopodium for reproduction. They thrive in temperatures ranging from 22-24°C and a pH of 7.0-8.0. Guppies consume various types of food, including live feed such as bloodworms and daphnia. Since they are cannibalistic towards their fry, breeding traps are often used to protect the young. Guppies reproduce frequently, with a single female giving birth to up to 250 fry every 4-6 weeks. Common guppy varieties include black guppy, double sword guppy, red snakeskin guppy, and tuxedo guppy.

Swordtails (*Xiphophorus helleri*), another widely kept livebearer, are recognized for the elongated lower lobe of the male's caudal fin, resembling a sword. These fish originate from Central America and can live up to five years. Males are smaller than females, reaching about 10 cm in length, while females grow up to 12 cm. They thrive in temperatures of 22-25°C and a pH of 7.0-7.5. Swordtails are omnivorous and accept a variety of foods, including bloodworms and tubifex worms. They breed easily, with females giving birth to 50-60 fry every 4-6 weeks. Notable varieties of swordtails include marigold wag swordtail, pineapple swordtail, and hi-fin lyretail swordtail.

Platies (*Xiphophorus maculatus*), another livebearer species, are known for their deep-bodied shape and peaceful nature. They exhibit an impressive range of colors due to selective breeding. Males are smaller, measuring around 3.5 cm, while females can grow up to 6 cm. Platies prefer water temperatures of 22-27°C and a pH of 7.0-7.5. They are omnivorous, feeding on both live and artificial food. A single female can produce 30-100 fry within 20-25 days of mating. The species' vibrant color variations make them highly desirable in home aquariums.

Mollies (*Poecilia sphenops*) are another significant group of livebearers, requiring slightly brackish water for optimal health. They can live for 3-5 years and thrive at temperatures between 20-25°C with a pH of 7.0-7.5. Male mollies are distinguished by their elongated dorsal fins and gonopodium, whereas females have a fan-shaped caudal fin. Mollies exhibit diverse colors, including black, white, and marbled patterns. A female molly can give birth to 30-100 fry after a gestation period of 20-25 days. Common types include sailfin molly (*Poecilia latipinna*), short-fin molly (*Poecilia mexicana*), and marble molly.

Livebearers are highly adaptable and accept a variety of foods, including commercial pellets and flakes. However, live foods such as bloodworms, daphnia, glass worms, and tubifex worms enhance their health and coloration. Fry require finely crushed live and artificial feed initially, with vegetable-based foods introduced after two weeks. The recommended sex ratio for breeding is generally 2 females per male to reduce stress and increase reproductive success.

Water quality is crucial for the well-being of livebearers. Fry thrive at temperatures between 22-24°C, while adults prefer slightly warmer conditions ranging from 24-27°C. A stable pH level of 7.0-7.5 is ideal for maintaining healthy fish.

Other notable livebearer species include *Poecilia formosa* (Amazon molly), *Poecilia latipinna* (sailfin molly), *Poecilia mexicana* (short-fin molly), and *Poecilia latipinna* (marble molly). These species contribute to the diversity of ornamental fish available in the aquarium trade, offering a range of colors, patterns, and sizes to suit different aquarists' preferences. These livebearers are easy to breed and maintain, making them ideal for both novice and experienced aquarists. Their vibrant coloration, peaceful temperament, and adaptability to various environmental conditions make them some of the most commercially important ornamental fish in the global aquarium trade.

Culture and Breeding of Livebearers Livebearers are widely cultured due to their ability to give birth to free-swimming juveniles, eliminating the need for egg incubation. Their breeding process is relatively simple, with females capable of storing sperm and producing multiple broods from a single mating event. The ideal breeding conditions include a temperature range of 22-28°C, a pH of 7.0-8.0, and well-aerated water. A sex ratio of 1 male to 3-5 females is recommended to optimize reproduction and minimize stress on females.

Selective breeding programs have been implemented to enhance desirable traits such as color intensity, fin shape, and disease resistance. Moreover, breeding traps and separate nursery tanks are used to protect fry from predation by adult fish. Advancements in recirculatory aquaculture systems (RAS) and raceway ponds have improved the mass production of livebearers, ensuring a steady supply to the ornamental fish market.

Importance of nutrition in Broodstock

Broodstock nutrition remains one of the least explored and least understood aspects of aquaculture . Due to the high costs and complexity of broodstock nutrition research, it is often considered a high-risk area of study. The composition of the broodstock diet, particularly its protein, lipid, and fatty acid content, is a key determinant of reproductive success and the survival of offspring. Several studies have highlighted a strong correlation between maternal nutrition and reproductive efficiency, emphasizing its significance in aquaculture.

Fish meal is a nutrient-dense, high-protein ingredient commonly used in broodstock diets due to its superior nutritional profile and ability to meet the dietary requirements of broodstock fish . High-quality fish meal typically contains 60–72% protein, making it an excellent protein source. The optimal dietary protein requirement for ornamental fish varies based on species, age, diet composition, feeding levels, and protein-energy balance. Research on livebearing fish has demonstrated that dietary protein levels between 25–40% result in significant improvements in growth parameters, including body weight, ovary weight, gonado-somatic index (GSI), and yolky oocyte production. These findings confirm the crucial role of broodstock nutrition in egg production, larval survival, and overall reproductive performance.

Since livebearers reproduce easily in captivity, breeders often overlook the importance of providing them with nutritionally balanced feed. However, inadequate diets can result in reduced brood sizes, poor-quality fry, and lower survival rates. The level of dietary protein directly affects body weight and growth efficiency in various fish species. Studies have shown that higher protein levels in the diet lead to improved feed conversion efficiency, which in turn supports greater growth and reproductive success in guppies and mollies. However, dietary protein supplementation has shown inconsistent results concerning protein efficiency ratios, likely due to the limited growth potential of poecilid fish. Reports indicate that the protein content in broodstock diets for ornamental livebearers generally falls within the range of 25–40%. Specifically, Pandey et al. (2016) found that a dietary protein level of 28.8% is adequate for optimal growth and reproductive performance in *Poecilia sphenops* (molly fish). Additionally, the inclusion of fish meal in ornamental fish diets has been shown to enhance reproductive outcomes. Research on *Xiphophorus helleri* (swordtail fish) suggests that

incorporating up to 20% fish meal in broodstock diets significantly improves both growth and reproductive performance. Furthermore, broodstock fed higher levels of dietary protein exhibited increased ovary weight, fry production, and GSI compared to those receiving lower protein diets, indicating enhanced ovarian maturation and oocyte development in black mollies.

Diets containing 25–40% protein have been identified as the most effective for supporting reproductive health, yielding the highest ovary weights and the greatest number of yolky oocytes in poecilid fish species. Optimal broodstock nutrition is closely linked to enhanced growth rates and reproductive performance, as it contributes to accelerated oocyte maturation, improved vitellogenesis, and superior spawning efficiency. Oocyte maturation is particularly dependent on the adequate transportation and accumulation of proteins and lipids within the oocytes. Thus, ensuring an optimal dietary composition in broodstock nutrition is essential for achieving successful reproduction and sustaining healthy fish populations in aquaculture.

Food and feeding habits

Food, particularly the initial diet of larvae, is crucial for ensuring high survival rates. Small-scale farmers often cannot afford commercial pellet feed or brine shrimp larvae. Instead, they successfully utilize low-cost alternative live feeds. Common options include green water, water fleas, *Tubifex* (sludge worms), mosquito larvae, and chopped earthworms. Additionally, various homemade feeds such as whole-wheat bread, vegetable peelings, and rice are used.

However, most farms primarily rely on *Daphnia*, tubificid worms, and mosquito larvae. Farmers collect *Daphnia* from nearby ponds by sieving them through fine mesh screens early in the morning, while *Tubifex* worms and mosquito larvae are typically gathered from sewage water channels. In fact, some individuals make a living by collecting and selling these live feeds to farmers.

Feeding is generally done once daily, preferably in the morning, with the quantity depending on the species, size, and season. Overfeeding poses a greater risk than underfeeding, as excess feed deteriorates water quality.

Research on the dietary nutritional needs of ornamental fish, particularly the development of specialized diets for broodstock, has significantly lagged behind studies focused on food fish (James & Sampath, 2004a, 2004b). Despite the importance of this studies, information on the nutritional requirements ornamental fish remains limited (Blom & Dabrowski, 2000; Sales & Janssens, 2003; Vijayagopal et al., 2008).

In many cases, ornamental fish are fed diets originally formulated for food fish rather than those specifically designed for their needs (Tamaru et al., 2001). While some commercial diets claim to be formulated for ornamental fish, they are often sold in small, expensive packages aimed at the hobbyist market, making them impractical for large-scale aquaculture (Chong et al., 2003; Mosig, 2007). Furthermore, the credibility of these claims is often questionable.

For successful marine ornamental fish culture, greater attention must be given to the dietary needs of broodstock. Factors such as diet composition, feed ingredients, feeding frequency, and nutritional content play a crucial role in maintaining overall health, reproductive performance, and the quality of gametes and larvae (Donelson et al., 2008).

Formulated diets with known nutritional compositions are essential for consistent broodstock performance in aquaculture. However, even in the food fish industry, few diets fully meet the nutritional and palatability needs of broodstock, leading to supplementation with raw or live natural foods like squid, fish, mussels, and Artemia (Izquierdo et al., 2001). Marine ornamental broodstock similarly rely on raw or live foods due to their natural feeding preferences, particularly in wild-caught species such as seahorses and pipefish (Job et al., 1997; Wittenrich et al., 2007).

This dependence on live feeds raises concerns about disease transmission and inconsistent nutritional quality. Over time, domestication may reduce this reliance, necessitating research on dietary adaptation. Additionally, processed feeds mimicking the sensory properties of live food, including chemical attractants and visual cues, could improve acceptance (Davis et al., 2006). Optimizing feeding ration and frequency is also crucial, as underfeeding can delay maturation and reduce larval survival, while overfeeding leads to waste and poor water quality, ultimately affecting reproductive performance.

Broodstock nutrition significantly influences fecundity, gamete quality, and larval viability, yet research on this topic remains limited, particularly for marine ornamentals. Studies on food fish indicate that protein, lipids, and essential fatty acids (e.g., DHA, EPA, ARA) play key roles in reproduction. Despite this, marine ornamental broodstock diets are often extrapolated from food fish formulations, making them costly and impractical for large-scale production (Sales & Janssens, 2003).

Currently, there is a lack of high-quality formulated diets for ornamental fish, leading to the widespread use of live and raw feeds (Chong et al., 2003; James & Sampath, 2004b). Given their shorter reproductive cycles and ease of maintenance, marine ornamental fish could serve as ideal models for advancing broodstock nutrition research, potentially benefiting both ornamental and food fish aquaculture.

Broodstock Management

Effective broodstock management is crucial for ensuring the production of high-quality fertilized eggs in aquaculture. This process requires a deep understanding of gonad maturation, spawning induction, and fertilization techniques. Ornamental fishes exhibit diverse and complex reproductive strategies, making it challenging to accommodate their breeding needs for sustainable production.

Reproduction in broodstock fish follows three key stages: gonad and gamete development, final oocyte maturation, and gamete release. However, this process is highly complex and influenced by various environmental factors, including behavioral, physical, and chemical conditions . Proper conditioning of broodstock is essential to maximize gamete output

and quality, yet this remains a major challenge in both foodfish and marine ornamental fish aquaculture. Critical factors such as careful broodstock selection, appropriate husbandry, optimized tank design, and spawning induction techniques play a vital role in ensuring reproductive success.

Selecting the right broodfish is fundamental to obtaining high-quality gametes. While basic selection criteria include size, age, and external traits, more advanced considerations such as social interactions, genetic background, and disease risk must also be taken into account. In foodfish species, age and spawning history significantly impact gamete quality, with very young and old individuals producing lower-quality eggs and sperm compared to middle-aged broodfish . However, research on these factors in marine ornamental fish is limited, as their broodstock supply primarily relies on wild-caught specimens. The lack of data on age and spawning history in wild broodfish complicates selection, underscoring the need to establish a database documenting gamete quality variation over time. Such information would enable aquaculturists to make informed decisions about broodstock selection and determine the optimal reproductive lifespan of individuals.

Broodfish size is another critical factor influencing reproductive success. Larger individuals generally produce more and larger eggs, a trend widely observed in foodfish species. This relationship is also evident in certain marine ornamental fish, such as the Banggai cardinalfish (*Pterapogon kauderni*) and blueband goby (*Valenciennea strigata*), where larger females have been reported to produce higher-quality eggs in greater numbers . By refining broodstock selection criteria based on these factors, aquaculturists can enhance breeding efficiency and sustainability in both foodfish and ornamental fish aquaculture.

Ornamental fish trade in India

India's rich ichthyofauna biodiversity supports a booming ornamental fish trade, which is driven by aquarium keeping, the second-largest hobby in the country. The industry is valued at approximately US$7 billion, with around 2,000 species traded annually. However, India’s ornamental fish exports were relatively modest in 2010-2011, totaling only US$1.24 million, highlighting a significant untapped market.

The domestic ornamental fish trade in India is growing, with the market valued at Rs. 500 crores and exports reaching Rs. 8.40 crores in 2017-18, reflecting an annual growth rate of 11.6%. The majority of exports come from wild species collected in the northeastern and southern states, with the northeast contributing 85% of the market share.

Freshwater ornamental fish farming is concentrated in states such as West Bengal, Tamil Nadu, Kerala, Maharashtra, and Karnataka. West Bengal is the leading producer, with ornamental fish farms located in districts like North and South 24 Parganas, Nadia, Hooghly, and Howrah in Kolkata. Tamil Nadu ranks second in production, while Maharashtra, once a prominent producer, is now focused on high-value species like discus. Kerala’s ornamental fish culture is expanding rapidly, particularly in districts like Thiruvananthapuram, Ernakulam, and Thrissur, where many villages have set up backyard production units.

West Bengal’s favorable climate, abundant species diversity, cheap labor, and efficient distribution networks make it an ideal hub for ornamental fish culture. Kolkata serves as the main distribution and export center, with 90% of exports originating from the city, followed by Mumbai (8%) and Chennai (2%). Over 2,000 individuals are engaged in the trade in West Bengal, including breeders, growers, traders, and exporters, with around 150 families relying on ornamental fish farming for their livelihoods. Additionally, more than 500 families use it as a supplementary income source.

India's northeastern states and Western Ghats host over 100 indigenous species, making the country a rich source of ornamental fish. Most tropical species are small, around 3-4 cm, which makes them ideal for moderate-sized aquariums. When selecting fish, factors such as vibrant coloration, peaceful temperament, compatibility, and adaptability to confined spaces are key. Ornamental fish are categorized into egg layers and livebearers. Popular egg layers include goldfish, barbs, danios, and tetras, while livebearers like guppies, mollies, swordtails, and platies are also widely traded. The ornamental fish industry in India, with its abundant species and growing domestic and international demand, holds considerable potential for further expansion.

Ornamental fish are broadly categorized into egg layers and livebearers. Among egg layers, popular species include goldfish (*Carassius auratus*), known for their adaptability and diverse colors, along with barbs, such as rosy barb (*Puntius conchonius*) and striped barb (*P. fasciatus*), as well as danios like the zebra fish (*Danio rerio*), which is easy to breed. Tetras, originating from South America, include species like neon tetra (*Hyphessobrycon innesi*) and cardinal tetra (*Cheirodon axelrodi*). Siamese fighting fish (*Betta splendens*) are prized for their striking colors and hardy nature, though males are aggressive toward each other. Angelfish and gouramis, including three-spot gourami (*Trichogaster trichopterus*) and dwarf gourami (*Colisa lalia*), are also popular choices, with bettas and gouramis being notable for their nest-building behavior and respiratory adaptations. Livebearers, which give birth to free-swimming young, include guppies (*Poecilia reticulata*), black mollies (*Poecilia sphenops*), swordtails (*Xiphophorus helleri*), and platies (*X. maculatus*). The ornamental fish trade in India holds significant potential for growth, given its vast biodiversity and increasing demand in the aquarium industry.

Global scenario of ornamental fish culture

The global ornamental fish trade has experienced steady growth since the 1980s, with an estimated market value of US$18–20 billion. Despite having extensive natural resources, India has yet to fully capitalize on this industry, lagging behind nations such as Sri Lanka, Singapore, Indonesia, and Malaysia. India's diverse freshwater and marine species, particularly those found in the Lakshadweep and Andaman and Nicobar Islands, the Kerala coast, and the Gulf of Mannar, have significant commercial potential. However, limited expertise in aquaculture and the live fish trade remains a major challenge.

Worldwide, the ornamental fish industry involves over 2,500 species, with freshwater fish making up more than 60% of the market. While many freshwater species are bred in captivity, a substantial portion of wild-caught fish and invertebrates also contribute to the trade. Popular species such as guppies, neon tetras, angelfish, goldfish, and discus dominate the market, with guppies and neon tetras alone accounting for over 25% of total trade volume. In contrast, marine species represent over 15% of the market by value, with around 98% sourced from the wild.

Singapore plays a key role as a global export hub, importing and re-exporting ornamental fish and related accessories. The European Union is the largest collective market, while the United States remains the top individual importer, accounting for 19.5% of global ornamental fish imports in 2017. The popularity of marine aquariums is rising, particularly in the USA and Europe, as advancements in technology have made complete reef systems more accessible. Ornamental fishkeeping is a widely enjoyed hobby, with approximately 7.2 million households in the United States and 3.24 million in the European Union owning aquariums. To meet increasing demand, fish farming has expanded across 125 countries. Developing nations such as the Czech Republic, Malaysia, Thailand, and India have also shown significant growth in production. At the retail level, the ornamental fish trade exceeds US$10 billion, with an annual growth rate of over 10%. When including accessories, plants, feeds, and pharmaceuticals, the overall industry value surpasses US$18 billion, demonstrating its economic significance and ongoing expansion.

Aquarium Keeping and Intensive Rearing of Livebearers

Aquarium keeping is a popular recreational activity, and livebearers are widely kept due to their aesthetic appeal and ease of care. Aquariums can be made from various materials, with rectangular tanks being the most preferred. Essential equipment includes tanks, lighting, filters, heaters, and air pumps. Aqua scaping enhances both aesthetics and functionality by incorporating biological filters, gravel, rocks, and aquatic plants like Vallisneria and Java fern to mimic natural habitats. Livebearers adapt well to varied tank conditions; guppies, mollies, platies, and swordtails require specific water volumes, with swordtails needing the most space due to their active swimming. They coexist peacefully with species like barbs, danios, rasboras, and tetras. With millions of ornamental fish sold annually, advanced aquaculture systems such as LDPE-lined ponds, raceway ponds, and recirculatory aquaculture systems (RAS) are used for intensive rearing. LDPE-lined ponds prevent water loss, raceway ponds enhance water movement, and RAS ensures water purification and high stocking density. These systems minimize water use, reduce disease outbreaks, and optimize fish growth. RAS also supports sustainable breeding with improved survival rates. Overall, modern rearing techniques ensure efficient and sustainable livebearer cultivation for both hobbyists and commercial breeders.

Water Quality Management in Ornamental Fish Farming

Water quality is vital for ornamental fish, directly affecting their growth, reproduction, and overall health. Key parameters such as temperature, pH, hardness, dissolved oxygen, carbon dioxide, and chlorine must be carefully monitored to maintain a stable environment. Tropical fish thrive within a temperature range of 21°C-30°C, with livebearers showing optimal growth at 22°C-25°C and breeding best at 27°C. Since temperature fluctuations impact metabolism and oxygen levels, the use of heaters and aeration devices helps stabilize conditions and prevent stress-related issues.

Maintaining the correct pH balance is essential, as livebearers prefer a range of 6.5-8.5. While guppies thrive in soft water, mollies and platies require harder water with a hardness level of 100-300 ppm. Dissolved oxygen, crucial for respiration, should be maintained above 3.5 ppm. Since photosynthesis increases oxygen levels during the day and respiration depletes it at night, proper aeration and circulation are necessary to prevent oxygen depletion and excessive CO2 buildup. Elevated carbon dioxide levels above 15 ppm can severely impact fish health, making regular monitoring crucial.

Another critical factor is chlorine, which, even in low concentrations of 0.1 ppm, can damage fish gills and impair respiration. Dechlorination, aeration, or aging water overnight effectively remove chlorine from water sources. Ammonia (NH_3), a byproduct of metabolic waste, is highly toxic and must remain below 0.02 mg/L. Proper biological filtration, water changes, and optimized stocking densities help control ammonia levels. Similarly, nitrite should not exceed 0.2 mg/L, while nitrate levels must be kept below 50 mg/L through efficient filtration and plant absorption.

Phytoplankton plays a crucial role in water quality management by oxygenating the water, reducing harmful compounds like CO_2, NH_3, NO_2, and H_2S, and preventing filamentous algae growth. Additionally, phytoplankton helps maintain turbidity, stabilizes temperature, reduces fish stress and aggression, and binds heavy metals while absorbing excess ammonia, further enhancing water conditions.

Dissolved metabolic organics, if left unchecked, deteriorate water quality by increasing ammonia levels and promoting microbial growth, leading to high fish mortality. Regular water exchanges, activated carbon filtration, and supplemental aeration facilitate nitrification, effectively breaking down toxic compounds and ensuring a clean and healthy aquatic environment. By implementing comprehensive water management practices, stress levels can be minimized, disease outbreaks prevented, and sustainable ornamental fish farming achieved.

Disease and Health Management in Ornamental Livebearers

Effective disease and health management in ornamental fish farming relies on the interaction between the host, pathogens, and environmental conditions. A disease outbreak occurs when a susceptible host is exposed to a pathogen under unfavorable environmental conditions that either enhance the pathogen's virulence or weaken the host's immunity. Diseases in aquarium fish are broadly classified into non-infectious and infectious categories, both of which require proper

management to ensure fish health and longevity. Non-infectious diseases arise due to environmental imbalances, stress, or nutritional deficiencies rather than pathogens. A major concern is dissolved oxygen (DO) depletion, which occurs when fish, organic waste, and microbes consume oxygen, especially in overcrowded conditions, leading to gasping and sluggish movement, which can be remedied by aeration, waste removal, and filtration. Excess oxygen, on the other hand, causes gas bubble disease, resulting in discomfort and mortality, which can be controlled by reducing plant density and light exposure. Water pH fluctuations also impact fish health, as values outside the preferred range of 6.5-8.5 cause skin discoloration, fin damage, and gill irritation, which can be managed by adjusting CO2 levels and regulating plant density. Temperature variations significantly affect fish metabolism, immunity, and susceptibility to infections, as livebearers thrive best in temperatures between 20-28°C, with stability reducing stress. Nitrogen waste accumulation from organic matter and fish excreta leads to ammonia and nitrite toxicity, resulting in gill and skin damage, which can be managed through bio-filters and aquatic plants. Chlorine from tap water also poses a risk, causing respiratory distress and gill damage, which can be mitigated by dechlorination or activated charcoal filtration. Contaminants like heavy metals from pipes, equipment, and water supply should be monitored to prevent toxicity. Nutritional imbalances, including overfeeding and poor-quality diets, lead to obesity, intestinal inflammation, and reproductive issues, which can be avoided with a balanced diet of natural and artificial feeds. Infectious diseases in ornamental fish are primarily caused by parasites, bacteria, fungi, and viruses, often appearing externally on the body, fins, or gills. Protozoan diseases such as Ich result in white spots and mucus buildup, treated with acriflavine or methylene blue, while velvet disease caused by Costia species leads to skin irritation and folded fins, managed with acriflavine. Parasitic infestations from Gyrodactylus, Argulus (fish lice), Ergasilus, and Lernaea cause gill damage and scratching behavior, which can be controlled with salt baths, potassium permanganate dips, and physical removal. Bacterial infections like dropsy (*Aeromonas hydrophila* and *Pseudomonas*), fin rot, and red pest cause bloating, scale protrusion, and hemorrhagic lesions, which require antibiotic treatments such as chloramphenicol, tetracycline, and sulfadiazine. Fungal infections like Saprolegnia manifest as cotton-like growths, affecting skin and eggs, and can be treated with malachite green. Preventing diseases is crucial for sustainable ornamental fish farming, requiring optimal water quality, stable environmental conditions, balanced nutrition, and effective waste management. Regular tank maintenance, controlled stocking densities, and proper quarantine of new fish minimize pathogen introduction, while aeration, filtration, and chemical parameter monitoring further support fish health. Implementing good husbandry practices and early disease detection ensures disease-free and thriving livebearer cultivation.

Challenges and Future Prospects

While ornamental fish culture presents significant opportunities, several challenges must be addressed. One of the primary concerns is disease management, as high-density farming conditions can lead to outbreaks that threaten entire populations. The use of probiotics, immunostimulants, and vaccination techniques is being explored to enhance disease resistance and reduce antibiotic dependency. Additionally, the overharvesting of wild populations for the ornamental trade poses environmental risks. Sustainable aquaculture practices, including captive breeding programs and habitat conservation efforts, are essential to protect wild stocks. Research on improving genetic diversity and breeding efficiency can also contribute to the development of hardier, more resilient strains of ornamental livebearers.

Technological advancements in water recirculation and automated feeding systems have the potential to increase production efficiency while reducing environmental impact. Further, integrating artificial intelligence and data analytics into aquaculture management can optimize breeding programs and health monitoring, ensuring higher survival rates and better-quality fish.

Conclusion

Ornamental fish culture continues to be a cornerstone of the aquarium fish industry due to their ease of breeding, aesthetic appeal, and adaptability. Advancements in aquaculture technology, selective breeding, and sustainable trade practices have significantly improved their production and marketability. Future research should focus on genetic improvement, disease resistance, and eco-friendly rearing techniques to enhance the sustainability of ornamental fish culture. With appropriate investment and policy support, countries like India can capitalize on their rich aquatic biodiversity to strengthen their position in the global ornamental fish trade. Expanding education and training programs for aquaculture professionals and hobbyists will further drive innovation and sustainability in the ornamental fish sector.

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