Genetic advancement, global trade dynamics, persistent challenges and future prospects in ornamental fish culture

Abstract

Ornamental fish culture is a specialized branch of aquaculture. This domain has emerged as a dedicated endeavour involving the breeding, care and trade of visually captivating and often exotic fish species. This comprehensive review examines the dynamic landscape of ornamental fish culture within aquaculture, highlighting key advancements and challenges. The global industry, valued at billions, is propelled by selective breeding, resulting in diverse ornamental fish varieties. Singapore's pivotal role as an exporter, especially of culturally significant species like Betta fish, exemplifies the industry's global prominence. Artificial reproduction methods and genetic advancements, such as the identification of the MC1R gene, showcase innovations in breeding practices. Environmental management, crucial for ornamental fish health, is exemplified by cutting-edge practices in high-profile aquariums, emphasizing the influence of water parameters on fish well-being. Disease prevention strategies, including innovative diagnostic tools, are implemented by industry leaders like the Qian Hu Fish Farm. The global ornamental fish trade, influenced by cultural preferences, is supported by data revealing economic dimensions and market dynamics. India's potential in the industry, leveraging its biodiversity, is showcased with instances from the Eastern Ghats. Challenges, including diseases and habitat degradation, are addressed by initiatives like the Marine Aquarium Council (MAC), emphasizing responsible sourcing. Regulatory frameworks, exemplified by the European Union, underscore caution in genetic modification, emphasizing the need for responsible applications. In conclusion, the review provides a nuanced synthesis of data, facts, and instances, offering a comprehensive understanding of ornamental fish culture's present status, challenges, and promising future. The industry emerges as a leader in technological and ethical innovation within the broader realm of aquaculture.

Keywords: Ornamental, genetic trait, selective breeding, global trade, aquaria, sustainable

1. Introduction

Ornamental fish culture, a captivating and economically significant facet of aquaculture, has seen remarkable advancements that contribute to its global prominence [1]. Selective breeding has been a critical driver, emphasizing desirable traits like vibrant colours, distinct patterns, and unique morphologies, resulting in the evolution of an impressive array of ornamental fish varieties [2]. The ornamental fish trade has become a billion-dollar industry, with an estimated 1.5 billion ornamental fish traded globally each year [3]. Singapore, for example, stands as a global hub, exporting millions of ornamental fish annually. This includes popular species like the Betta fish, which holds cultural significance and has become a symbol of beauty and resilience [4]. Innovative artificial reproduction methods have played a crucial role in meeting the demands of this thriving industry. For instance, hormone-induced spawning has become a widely adopted technique, ensuring a controlled and efficient breeding process. Genetic advancements have further augmented the enhancement of ornamental traits, with studies revealing the specific genetic markers responsible for unique colourations and patterns in popular species [5]. For instance, identifying the MC1R gene's role in regulating melanin production has provided a deeper understanding of the genetic basis for colouration in popular species like koi fish [6]. Harnessing this knowledge allows targeted genetic manipulations to enhance and diversify ornamental traits. Environmental management is imperative for the health and vitality of ornamental fish populations. Water quality optimization, based on rigorous scientific parameters, ensures the well-being of these aquatic companions. Interestingly, studies have shown that maintaining specific water parameters, such as pH levels and temperature, significantly influences ornamental fish's colouration and overall health [7]. Habitat replication, an essential aspect of environmental management, not only enhances the visual appeal of aquariums but also contributes to the overall physiological well-being of the fish [8]. Instances of these innovative environmental management practices can be found in the meticulous care of high-profile aquariums worldwide. For example, the Georgia Aquarium in the United States, home to a diverse collection of marine life, employs cutting-edge filtration systems that mimic natural ocean processes. Their advanced life support systems utilize state-of-the-art technology to maintain optimal water quality, ensuring the health and vibrancy of their ornamental fish [9]. Similarly, the Oceanographic Museum of Monaco exemplifies the integration of aquascaping techniques inspired by natural ecosystems. Their displays showcase the aesthetic beauty of ornamental fish and replicate the intricate balance found in coral reefs. By incorporating live corals and carefully selected flora, the museum creates an immersive and ecologically harmonious environment for its ornamental fish inhabitants [10]. Disease prevention and control strategies, another critical dimension, involve continuous research and implementation of biosecurity measures. The Qian Hu Fish Farm, a prominent ornamental fish farm in Singapore, employs Loop-mediated Isothermal Amplification (LAMP) assays as part of its disease management protocol. This allows for rapid on-site testing, enabling the early detection of common pathogens like the koi herpes virus (KHV) [11]. The global ornamental fish trade, which transcends geographical boundaries, is supported by extensive data revealing this industry's economic dimensions and cultural dynamics. For instance, countries like Singapore and Thailand have emerged as significant exporters, contributing significantly to the global ornamental fish market. Moreover, regional nuances influence trade patterns, with certain species gaining popularity in specific regions due to cultural preferences [12]. Strategies for enhancing the ornamental fish industry in India, a country with a rich aquatic biodiversity, include leveraging its diverse native species for ornamental purposes. The Eastern Ghats of India, known for its rich biodiversity, serve as a hotspot for unique ornamental fish species such as Rasbora and Puntius [13]. India can become a crucial player in the global market, capitalizing on its unique ornamental fish resources. However, challenges such as inadequate infrastructure and limited awareness among stakeholders need to be addressed to unlock the industry's full potential [14].Despite its flourishing nature, ornamental fish culture faces challenges, including the spread of diseases, habitat degradation, and ethical concerns related to collecting wild-caught species. Addressing these challenges is crucial for the sustainable growth of the industry. Instances of initiatives addressing ethical concerns in ornamental fish culture are complemented by facts and data illustrating the positive impact of such programs. The Marine Aquarium Council (MAC) and their certification programs ensure stringent environmental and ethical standards, with data revealing a growing market preference for responsibly sourced ornamental fish [15]. Educational outreach, exemplified by the "Responsible Reefkeeping" program by the Reef Environmental Education Foundation (REEF), contributes to increased awareness among hobbyists about the importance of choosing sustainably sourced ornamental fish [16]. These instances demonstrate a global shift towards responsible and ethical practices in the ornamental fish industry, promoting conservation and sustainable management. The promising future of ornamental fish culture is grounded in data-backed instances of cutting-edge research and evolving practices. Ongoing studies are delving into revolutionary techniques, such as CRISPR gene editing, to achieve precision breeding of ornamental fish. The exploration of alternative, eco-friendly feed options is gaining traction. The rising demand for environmentally responsible aquaculture aligns with initiatives like the Aquafeed

Sustainability Certification Program. This program, supported by organizations like the Global Aquaculture Alliance, emphasizes sustainable and responsibly sourced ingredients in aquafeeds [17]. The potential ecological impacts of introducing genetically modified organisms into ecosystems remain a focal point of scrutiny. Specific cautionary approaches can be seen in regulatory frameworks adopted by countries like the European Union, which imposes stringent regulations on releasing genetically modified organisms into the environment [18].

2. Diversity of Ornamental Fish

Ornamental fish comprising diverse species which are systematically classified based on genetic and morphological characteristics that provide a structured framework for understanding their evolutionary relationships [19]. The Siamese Fighting Fish (*Betta splendens*) belongs to the family Osphronemidae show systematic organization that aids both scientific research and the management of the ornamental fish trade [20]. Recent strides in molecular taxonomy including DNA barcoding and phylogenetic analysis have revolutionized understanding of ornamental fish diversity. These techniques are useful in identifying hidden relationships and cryptic species, ensuring genetic diversity is preserved and supporting the long-term sustainability of the trade [21]. The Angelfish (*Pterophyllumscalare*) belonging to the Cichlidae family showcases various cultivated varieties resulting from selective breeding. From the iconic *B. splendens*, renowned for its vibrant colors and territorial behavior to the elegant *Pterophyllumscalare* characterized by triangular bodies and elongated fins, each species brings its distinct attributes to the aquarium landscape [22]. The Neon Tetra, with its iridescent blue and red stripes and the Clownfish are famous for their symbiotic relationship with sea anemones [23]. Understanding the taxonomy and diversity of ornamental fish sets the stage for a comprehensive exploration of breeding techniques, environmental management and the broader economic and social impacts of this fascinating and continually evolving field [24].

Table 1: Some common ornamental fish species with their peculiar features

Species	Family	Notable Features
***Betta splendens* (Siamese Fighting Fish)**	Osphronemidae	Vibrant colors, flowing fins, and territorial behaviour
***Pterophyllumscalare* (Angelfish)**	Cichlidae	Triangular body, elongated dorsal and anal fins

***Paracheirodoninnesi* (Neon Tetra)**	Characidae	Iridescent blue and red stripes, schooling behaviour
***Amphiprionocellaris* (Clownfish)**	Pomacanthidae	Wide color variations, symbiotic relationship with anemones
***Danio rerio* (Zebrafish)**	Cyprinidae	Striking horizontal stripes, small size, active behaviour
***Poecilia reticulata* (Guppy)**	Poeciliidae	Colorful and diverse patterns, live-bearing reproduction
***Carassius auratus* (Goldfish)**	Cyprinidae	Various color varieties, distinctive body shapes
***Symphysodon spp.* (Discus)**	Cichlidae	Disc-shaped body, vibrant colors, intricate social behaviour
***Gasteropelecus spp.* (Freshwater Hatchetfish)**	Gasteropelecidae	Distinctive hatchet-shaped body, surface-dwelling behaviour
***Pseudotropheusdemasoni* (Demasoni Cichlid)**	Cichlidae	Blue and black coloration, social and territorial nature

3. Advances in Ornamental Fish Breeding

3.1. Selective Breeding for Desirable Traits

Selective breeding in ornamental fish culture has advanced significantly through understanding of genetic principles and the heritability of traits. For instance, the *B. splendens* where selective breeding has resulted in a diverse range of color patterns and fin shapes. Studies in Betta genetics have identified specific genes responsible for the expression of colors such as red, blue and iridescence [25]. The "Marble" trait characterized by a dynamic interplay of colors on the fish's body which has been traced back to genetic variations in pigment cells [26]. The Guppy (*Poecilia reticulata*) is another species that exemplifies the outcomes of selective breeding. Guppy breeders have focused on enhancing coloration, fin size and patterns through generations of careful selection. Scientific studies on guppy genetics have revealed the heritability of ornamental traits and the role of various genes in determining the expression of colors which ranges from vibrant hues to intricate patterns. Selective breeding has not only influenced aesthetics but also the behaviors [27]. In Cichlids, particularly the Discus (*Symphysodon spp*.), selective breeding has been employed to enhance the social behavior and compatibility of individuals within a group [28]. Studies have shown that certain genetic factors contribute to the development of harmonious social structures that reduce aggression and stress in captive environments [29]. Advancements in molecular genetics have provided a more precise understanding of the genetic basis of ornamental traits.Identification of specific color genes in ornamental fish has facilitated more targeted breeding programs. The knowledge gained from mapping the genomes of ornamental fish species contributes to the precision of selective breeding efforts ultimately minimizing unintended genetic consequences and promoting the stability of desired traits across generations.

3.2Artificial Reproduction Methods

Artificial reproduction methods have become pivotal in the domain of ornamental fish breeding that represent convergence of scientific innovation and conservation objectives [30]. Hormone induced spawning, a well-established technique that deals with the precise administration of hormones to synchronize the reproductive cycles of fish [31]. Scientific studies, particularly in popular species such as the Angelfish (*Pterophyllumscalare*) have optimized hormone dosages and administration methods, exemplifying the meticulous refinement of protocols to enhance spawning success rates [32].In vitro fertilization (IVF) has emerged as another fundamental technique that involves retrieving eggs from fish ovaries and manually combining them with sperm in a lab for fertilization. [33]. Genetic and endocrinological studies play a crucial role in the success of these artificial reproduction methods that provide insights into the hormonal regulation of reproductive processes and the genetic factors influencing gamete production. The Clownfish (*Amphiprionocellaris*) stands as an example where such studies have elucidated the hormonal control of sex change, a vital aspect for maintaining balanced populations in captivity [34]. Beyond economic considerations, the conservation implications of these methods are profound, offering a scientific avenue for the propagation of endangered species and contributing to genetic diversity within captive populations.Artificial reproduction methods underscore the dynamic play between scientific research and the practical applications that sustain the ornamental fish trade while concurrently supporting broader conservation initiatives.

3.3 Genetic Advancements in Enhancing Ornamental Traits

Ornamental fish breeding has recently made significant progress in understanding the genetic mechanisms that govern the diverse traits seen in different species like *B. splendens*, Guppy (*Poecilia reticulata*) and Discus (*Symphysodon spp.*). In case of *B. splendens* genetic research has pointed specific alleles and loci responsible for the striking color variations [35]. The MC1R gene plays a crucial role in determining red pigmentation while other genes contribute to the synthesis of iridescent hues. High-resolution molecular techniques such as genome-wide association studies (GWAS) have enabled the identification of genomic regions associated with specific color traits. These studies provide breeders with a molecular roadmap for precise selection based on the genetic markers associated with desired phenotypes [36].Male guppies exhibit a mosaic of complex and diverse coloration patterns, including blacks, oranges, and iridescent blues, which vary in number, shape, size, and position of spots. Female guppies show a strong mate choice preference for male color patterns, particularly for large spots and/or intensity of orange color. The genetic basis of color patterns in guppies involves various color loci, such as blue and golden, which play a decisive role in the formation of their color patterns. The observation of many diverse color patterns within the species represents a classic example of the genetic basis of color diversity. The genetic architecture of color patterns in guppies has a major effect on how these patterns evolve and diverge, and it involves a multivariate trait approach. The genetic basis of sex determination in guppies is also highly variable. Despite the wealth of knowledge about the ecological importance of coloration in guppies, the specific genes and developmental pathways underlying their pigment pattern formation are still not fully understood [37].In Discus (*Symphysodon spp.*) breeding, genetic studies have identified genes related to melanin production and distribution. *TYR* and *SILV* genes are responsible for synthesis of melanin and pigment regulation respectively. The application of quantitative trait locus (QTL) mapping techniques has facilitated the identification of genomic regions associated with color pattern heritability that provide a molecular foundation for the selection of breeding pairs. The advent of high-throughput sequencing technologies has enabled the analysis of entire ornamental fish genomes [38]. The availability of complete genomic data allows researchers to explore not only specific genes associated with ornamental traits but also the broader genomic landscape governing these characteristics.

4. Environmental Management in Ornamental Fish Culture

4.1 Water Quality Optimization

Rigorous monitoring of aquatic parameters such as pH, temperature and nitrogenous compounds are imperative for maintaining the health of ornamental fish. Environmental management in ornamental fish culture, particularly water quality optimization is a crucial aspect of sustainable aquaculture. The water quality parameters such as temperature, pH, nitrate, phosphate and dissolved oxygen concentration play a significant role in the health and well-being of ornamental fish [39]. Maintaining good water quality is essential for the success of ornamental fish farming, as it directly impacts their growth, reproduction, and overall health. Several studies emphasize the importance of water quality in sustaining the ornamental fish business, highlighting the need for measures such as Good Aquaculture Practices (GAP) to ensure water quality and environmental sustainability [40]. Advancements in microbial feed additives and sensor technologies have been proposed to improve water quality and ensure the sustainable aquaculture of ornamental fish[41]. Therefore, effective environmental management, particularly in optimizing water quality, is fundamental to the long-term sustainability of ornamental fish culture.

4.2 Habitat Replication

Replication of natural habitats within aquariums is not merely an aesthetic pursuit but a scientifically guided practice rooted in a wealth of research findings. Scientific studies demonstrated that the inclusion of structured microenvironments such as live plants and hiding places significantly reduces stress levels in ornamental fish. These enriched environments offer opportunities for natural behavioral activities, thereby contributing to the mental and physical well-being of the fish [42]. Lighting conditions play a critical role, it influences reproductive behavior of species like freshwater angelfish. Specific lighting conditions are demonstrated to stimulate courtship displays and improve reproductive outcomes. Scientifically guided adjustments of lighting for habitat are very essential for better results [43]. The dynamics of water flow greatly contribute to the creation of environments that mirror natural habitats, particularly for species adapted to flowing water [44]. Understanding temperature gradients enhances the thermoregulatory behaviors of ornamental fish, allowing them to move between warmer and cooler areas for optimal comfort and health [45]. In essence, the integration of these habitat replication practices isevidence to the thorough application of scientific knowledge, ensuring that aquariums not only showcase vibrant displays but also provide environments that closely align with the ecological and behavioral needs of these captivating aquatic species.

4.3 Disease Prevention and Control Strategies

In ornamental fish culture, disease prevention and control strategies are crucial for maintaining the health of the fish. Several methods and factors play a significant role in this aspect. A study by A.P. Lipton from the Central Marine Fisheries Research Institute in India emphasized the importance of preventing the entry of infectious agents to ornamental fish farm conditions. The study also highlighted that several diseases of economic importance are recorded in ornamental fishes, and it summarized the common diseases, symptoms, and methods of inspection together with treatment protocols [46]. Furthermore, the Agriculture, Fisheries and Conservation Department of Hong Kong pointed out that fish diseases affect the survival and growth rates of fish under culture, leading to lower harvest and higher costs [47]. The document "Prevention and Treatment of Fish Diseases" emphasizes the importance of regular monitoring of fish health as an effective way to identify disease causes and take appropriate measures. Additionally, research on sustainable ornamental fish aquaculture has shown that the implication of microbial feed additives can contribute to disease prevention and control[48]. Various diseases affect ornamental fish and each require specific treatment strategy. *Ichthyophthiriusmultifiliis* (Ich) is a protozoan parasite which causes white cysts on the skin, gills and fins of Guppies, Tetras, Bettas, Angelfish and Goldfish. This can be treated by increasing water temperature and using anti-parasitic medications like formalin or copper. Columnaris Disease caused by *Flavobacterium columnare* leads to lesions in Tetras, Guppies, Goldfish and Bettas. Treatment involves isolation and antibiotics like florfenicol or sulfonamides. Dropsy is a symptom of an underlying disease that can be caused by poor water quality, stress, or other diseases. It is characterized by abdominal swelling and can affect Goldfish, Guppies, Betta, Tetras, and Angelfish. Treatment involves addressing the underlying causes through antibiotics or water condition improvements. Velvet Disease (Oodinium) is a parasitic infection that causes colored dust on Tetras, Guppies, Angelfish, Discus, and Goldfish. It is treated by quarantine and copper-based medications. Hexamita, a protozoan parasite causing gastrointestinal issues, affects Cichlids, Discus, Angelfish, Guppies, and Tetras, and is treated with anti-protozoal medications. Lymphocystis, a viral infection causing wart-like growths, affects Goldfish, Guppies, Angelfish, Tetras and Discus, with no specific treatment but recovery aided by good water quality and stress reduction. Spring Viremia of Carp (SVC), a viral disease in Koi, Goldfish, Rosy Barb and Tetras, has no specific treatment, prevention involves strict biosecurity measures and the destruction of infected fish [49]. Some of the common ornamental fish diseases are given in table 2.

Table 2: Common Ornamental Fish Diseases: Causative Agents, Symptoms, Affected Species, and Treatment Strategies

Disease	Agent	Symptoms	Ornamental fish affected	Treatment strategies	Reference
White spot disease	*Ichthyophthiriu smultifiliis*	white cysts on the skin, gills and fins.	Guppies, Tetras, Bettas, Angelfish and Goldfish	Use anti-parasitic drugs, like formalin or copper.	[50]
Fin Rot	*Pseudomonas fluorescens*	deterioration of fins.	Guppies, Tetras, Betta, Goldfish	Administer antibiotic containing tetracycline.	[51]
Columnaris Disease	*Flavobacteriu m columnare*	Lesions all over the body	Tetras, Guppies, Goldfish, Bettas	Administer antibiotic treatments like florfenicol or sulphonamides	[52]
Dropsy	*Aeromonas hydrophila*	Abdominal swelling	Goldfish, Guppies, Betta, Tetras, Angelfish	Broad spectrum antibiotic specifically formulated for gram-negative bacteria	[53]
Velvet Disease	*Oödiniumpilul aris*	Lethargy, Loss of appetite and weight, discoloration	Tetras, Danios, Angelfish, Discus, Goldfish	Add aquarium salt and treat with Mardel Coppersafe for ten days	[54]
Gill Flukes	*Dactylogyrus*	Rapid Gill Movement, Color Change	Koi and goldfish	Praziquantel liquid, Formalin and Malachite Green	[55]
Hexamita	*Octomitus,Spir onucleus*	large quantities of white, yellow mucous	Discus fish, Cichlids, Oscars, Silver dollar	Metronidazole andEpsom salt	[56]
Lymphocystis	*Iridovirus*	small size irregular, nodular, wart-	Gobies, snook butterflyfish, clownfish and	potassium permanganate (100 mg/L or higher), formalin (2000 mg/L or	[57]

		like growths on fins and skin	gouramies	higher)	

5. Globalornamental fish trade

In 2021, ornamental fish emerged as the world's significant traded product, with a total trade value of $392 million, accounting for 0.0019% of the global trade. The exports of ornamental fish grew by 18.6% between 2020 and 2021, increasing from $330 million to $392 million. The top exporters of ornamental fish in 2021 were Japan ($44.9 million), Singapore ($41.7 million), Indonesia ($40.7 million), the Netherlands ($31.5 million), and Sri Lanka ($23.1 million). The top importers were the United States ($74.8 million), Germany ($31.1 million), France ($25.5 million), the United Kingdom ($24.4 million), and China ($19.1 million). In 2018, the average tariff for ornamental fish was 11.3%, making it the 1888th lowest tariff using the HS6 product classification [58]. Ornamental fish ranks3954th in the Product Complexity Index (PCI) [59]. Figure 1 and 2 represent the top importer and exporter countries in ornamental fish culture.India's share of the global ornamental fish export is around 0.4%, and the domestic ornamental fish trade is estimated to be about Rs. 500 crore, with an export trade of Rs. 8.40 crore in 2017-18, growing at an average annual rate of 11-12%. The industry is supported by the Pradhan Mantri Matsya Sampada Yojana (PMMSY), which has an allocation of Rs. 576 crores to catalyze its growth [60]. Despite this potential, India still remains a marginal player in the global ornamental fish trade. India has great potentials in Ornamental fish production due to the rich biodiversity of species, favourable climatic conditions and availability of cheap labour. Kerala, Tamil Nadu and West Bengal are mainly involved in practicing ornamental fish farming in India [61].

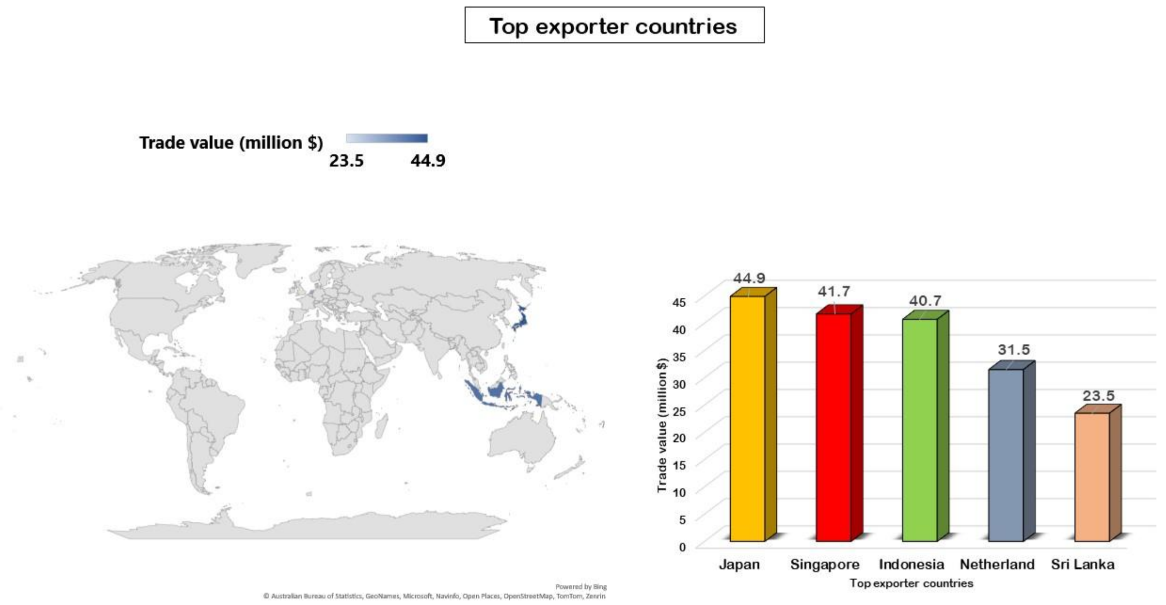

Figure 1: Graph represents top exporter of ornamental fish worldwide. Japan is leading exporter of ornamental fish in global trade

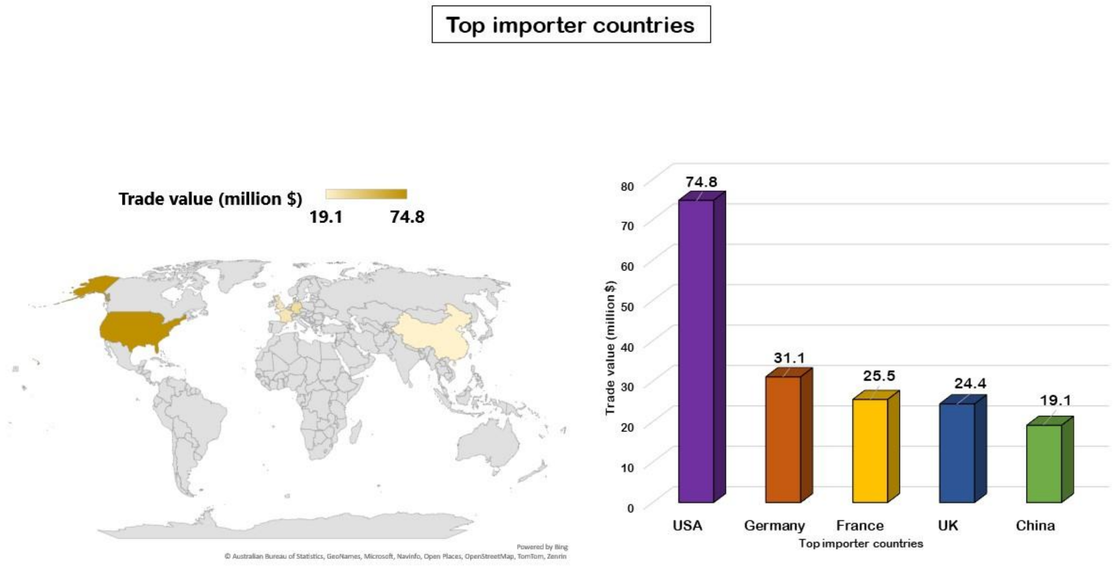

Figure 2: Graphrepresents top importer of ornamental fish worldwide. Data shows USA is leading importer of ornamental fish in globally

6. Strategies for enhancing ornamental fish industry in India

The ornamental fish industry in India holds great promise for expansion, with the country currently contributing approximately 1% of the global ornamental fish trade, exporting around 54 tons of ornamental fish. To further develop and grow this industry, it is essential to assess the potential of ornamental fishes for rational utilization and export, as well as to improve the production practices, which currently rely on low-input and low-output concepts [62]. This improvement can be achieved through intensive training programs, support for fish breeders and the promotion of modern breeding techniques. Additionally, the government can increase its growth to several folds by providing financial assistance, infrastructure, instrumentations and marketing support to the ornamental fish industry. By implementing these strategies, India can enhance its position in the global market of ornamental fish trade and further boost the economic importance of this sector. India's share in the global ornamental fish trade is 0.4%, and it is ranked 31^{st} in exporting countries, indicating significant potential for growth and improvement in this industry [63].

7. Challenges in Ornamental Fish Culture

The ornamental fish culture industry faces several challenges that need to be addressed for sustainable growth. One of the primary challenges is the overexploitation of wild fish, which make up the majority of the trade, with less than 10% coming from hatchery production[64]. This overexploitation raises concerns about the impact on native species and the need for gender equality in the supply chain. Developing nations, particularly in Asia, are significant players in the sector, and there is a need to ensure that the industry does not negatively impact the environment and local communities. The market for ornamental fish is dominated by hobbyists, and there are implications for sustainable aquaculture, such as the use of microbial feed additives [65]. Research is being conducted to address some of these challenges, including ornamental fish behavior analysis using IoT and ML approaches [66]. Additionally, there is a need for sustainable ornamental fishing practices, breeding practices for aquarium fish, and the development of entrepreneurship in the rural sector for indigenous ornamental fish production. The global ornamental fish market was valued at USD 9509.4 million in 2019, with an expected CAGR of 6.2% during 2021-2026, and is poised for significant growth between 2023 and 2029. However, overexploitation by the aquarium fish trade, habitat degradation and destruction, alien species introductions, pernicious tourism, and pollution are principal threats to marine biodiversity[67]. To address these challenges, research is needed to identify susceptible species and develop sustainable practices for the industry.

8. Future perspectives and research gaps

As we look ahead, the integration of genomic tools into selective breeding programs holds great promise for the ornamental fish industry. Recent study on *B. splendens*, have successfully identified specific genes associated with vibrant color variations, laying the foundation for more precise and efficient selective breeding [68]. Fine-tuning artificial reproduction techniques remains a priority, and data from controlled breeding programs, like those involving freshwater angelfish, emphasize the need for species-specific optimization. Additionally, exploring the molecular mechanisms behind ornamental traits is a burgeoning field. Studies on zebrafish, for instance, have uncovered the pivotal role of genes like agouti signaling protein (ASIP) in regulating melanin distribution, providing valuable insights into coloration patterns [69]. Further research should extend these investigations to species like discus fish, examining genes such as MC1R and DCT to deepen our understanding of genetic pathways influencing color variations [70]. Environmental management practices are paramount for sustainable ornamental fish culture. Data from environmentally conscious aquaculture systems, such as integrated aquaponics, showcase the potential for optimizing nutrient recycling and water quality. Efforts should focus on quantifying the environmental benefits of such systems and exploring their scalability. In the realm of the global ornamental fish trade, collaborative initiatives, like the Coral Triangle Initiative, underscore the importance of responsible trade practices for ecosystem conservation [71]. Research should analyze the effectiveness of such initiatives and advocate for collaborative efforts globally to ensure the sustainability of the ornamental fish trade. Tailoring strategies for the ornamental fish industry in India requires a nuanced approach. Data from regional studies on indigenous species, such as the Miss Kerala Barb (*Puntius denisonii*), highlight the potential for sustainable aquaculture [72]. Research should further quantify the economic and ecological benefits of promoting local species and explore market dynamics to tailor strategies for the Indian ornamental fish industry. Addressing emerging challenges in ornamental fish culture, particularly the rise of novel diseases like the iridovirus affecting koi carp, necessitates proactive measures [73]. Future research should focus on monitoring disease trends, identifying potential pathogens, and developing effective prevention strategies. Lastly, bridging knowledge gaps through interdisciplinary approaches, as exemplified by projects like the Mekong Ornamental Fish Research Center [74] is crucial. Encouraging more interdisciplinary research can foster better understanding of ornamental fish culture and promote sustainable practices in the industry.

9. Discussion

Ornamental fish culture is a rapidly growing industry worldwide, generating billions of dollars annually. This review article discusses various aspects of ornamental fish culture, including taxonomy and diversity, breeding, artificial reproduction methods, genetic advancements, environmental management, water quality optimization, habitat replication, disease prevention and control strategies, global trade, strategies for enhancing the industry in India, challenges, and future perspectives. Advances in breeding techniques have led to new strains and varieties of ornamental fish. Breeding programs have successfully produced fish with desirable colour, shape and size traits. Artificial reproduction methods such as hormone-induced spawning and stripping have been developed for many ornamental fish species. Water quality optimization, habitat replication and disease prevention and control strategies are critical components of environmental management. Water quality optimization is essential for the health and growth of ornamental fish. Proper filtration, aeration, and maintenance of water parameters such as temperature, pH, and dissolved oxygen are critical for optimal water quality. Replicating the natural habitat of the fish can help reduce stress and improve their health and growth. Proper quarantine, hygiene, and disease monitoring can help prevent the spread of diseases in fish farms. The global trade in ornamental fish is a rapidly growing industry, generating billions of dollars annually. The industry involves most tropical and subtropical regions, with Asia being the largest producer and exporter of ornamental fish. The trade is regulated by international and national laws to prevent the spread of diseases and protect endangered species. India has a rich diversity of ornamental fish, with over 195 species in inland and marine waters. However, most of these species are collected from the wild due to a lack of species-specific culture or breeding. Strategies for enhancing the ornamental fish industry in India include developing breeding programs, promoting sustainable aquaculture practices, and establishing a regulatory framework for the trade of ornamental fish. Ornamental fish culture faces several challenges, including disease outbreaks, environmental degradation, and the illegal trade of endangered species. The lack of proper infrastructure, technical knowledge, and funding also poses a significant challenge to the development of the industry. The future of ornamental fish culture lies in developing sustainable aquaculture practices, using genetic engineering techniques to produce fish with desirable traits, and establishing a regulatory framework for the trade of ornamental fish. CRISPR gene editing holds promise for precision breeding, though ethical and ecological considerations require careful examination. The ecological ramifications of genetic modifications remain a complex area, necessitating rigorous studies to quantify and understand potential long-term impacts on natural ecosystems. More specific data on the interactions between genetically modified ornamental fish and their environments needs to be more specific. This gap hinders the formulation of informed policies and guidelines. Additionally, developing sustainable and nutritionally balanced feeds for ornamental fish, while a growing focus, needs more detailed technical specifications and comprehensive data on the environmental footprint of alternative feed sources. Disease prevention strategies, exemplified by rapid diagnostic tools, underscore proactive industry measures, yet ongoing research into emerging pathogens is crucial. The global ornamental fish trade, influenced by cultural preferences, highlights the significance of certification programs like the Marine Aquarium Council (MAC) in fostering sustainability. The industry's future relies on collaborative efforts to navigate these complexities and ensure a balanced and thriving ornamental fish culture globally.

10. Conclusion

The review highlights significant advancements in breeding practices, environmental management, global trade dynamics, and challenges faced by the industry in India. Selective breeding and artificial reproduction methods have led to the development of visually stunning and genetically unique ornamental fish varieties. Genetic advancements further contribute to enhancing desirable traits. Environmental management, including water quality optimization, habitat replication, and disease prevention, is crucial for the well-being of ornamental fish populations. The global ornamental fish trade showcases the widespread appeal of these aquatic specimens, while strategies for industry enhancement in India emphasize the potential for economic growth. Despite the industry's promise, challenges like ecological concerns, disease outbreaks, and market fluctuations persist. Addressing these challenges requires collaborative efforts to establish sustainable practices. Looking to the future, continued research into breeding technologies, genetic advancements, and sustainable management practices is essential for the ornamental fish industry's long-term success and biodiversity preservation.

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