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Survey-based insights into treatments of infectious diseases in freshwater ornamental fish in the UK

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Abstract

The ornamental fish trade transports over 1 billion fish annually to domestic, public, and private aquaria, with a current total value estimated at GBP 11 to 22.5 billion globally. One of the biggest threats to the industry is infectious diseases. Even though various chemical treatments have been used extensively and effectively in the past to combat disease, many such treatments have been banned, creating the need for alternatives. To improve health, the most efficacious current treatments need to be combined with optimal conditions to promote fish welfare. Here, a survey was undertaken to assess the most common treatment practices employed by hobbyists, retailers, and other professionals and the factors determining the selection and efficiency of the treatments. From 350 participants (mostly UK-based), hobbyists purchase more natural products compared to retailers, who rely on synthetic-based treatments. Retailers apply prophylactic and curative treatments and take more precautionary steps to avoid economic losses. Furthermore, whereas both hobbyists and retailers closely monitor water quality, only retailers treat fish at a specific time of day. When dealing with infectious diseases, the treatment of choice and associated factors, such as chronotherapy, need to be considered in order to reduce disease susceptibility and infection.

Keywords: *ornamental trade, infectious diseases, fish health, treatment*

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1. Introduction

Aquatic infectious diseases pose a significant threat to the ornamental fish trade. The retail trade in aquarium fish has grown rapidly in recent decades (14% annual growth since the 1970s) and has now reached over 1.5 billion fish being moved between countries each year [1, 2], accounting for approximately 4% of fish utilised globally [2]. Most are freshwater species, with more than 5300 freshwater and 1450 marine fish species traded as pets [3–6]. The current total retail value of the fish pet trade is estimated at GBP 11–22.5 billion annually [1, 7, 8].

The ornamental fish trade involves fishermen and breeders, fish exporters/suppliers, wholesalers, and specialised retailers who supply from aquarium hobbyists to general pet owners [9, 10]. Given the complexity and dynamics of ornamental fish trading, two million people are involved in the trade [11]. Based on European Union (EU) and World Organisation for Animal Health (WOAH) legislation, fish undergo health and welfare checks at designated border inspections before being collected by wholesalers and consolidators (transhippers) [12]. Pre-border and at-border prevention measures include controls on the trade and movement of live animals, health certification, border inspection protocols, and documentation of stock movements [12]. The specific measures implemented often depend on the origin of ornamental fish imports and typically require importers to submit a biosecurity plan. Imported fish may also be subject to inspection and disease testing. Furthermore, authorization requirements vary based on whether the species are susceptible to notifiable diseases and whether the importer is a commercial entity, hobbyist, or public aquarium [13]. Fish are then transported to retailers before eventually reaching their final destination in domestic (hobbyists), public (zoos), or private aquaria (pet shops, research labs, etc.) [12]. Across this supply chain, there are challenges of inadequate holding conditions, poor water quality, and suboptimal handling and transportation conditions, all confounded by infectious diseases [6, 14, 15]. Fish mortality rates, estimated at 2–73%, pose major welfare and economic concerns [6], yet they are often based on estimates rather than empirical data [16, 17].

Infectious diseases are a major threat to the ornamental fish trade, second only to water quality issues [18], as fish frequently develop bacterial, viral, fungal, and parasitic infections. These are influenced by host susceptibility, pathogen virulence, and environmental conditions [19–21]. Key bacterial pathogens for the ornamental trade include *Flavobacterium columnare*, *Edwardsiella* spp., *Aeromonas* spp., *Pseudomonas* spp., and *Vibrio* spp., with symptoms detailed by [20]). Additionally, over 125 RNA and DNA viruses have been identified in lower vertebrates [22], many of which are linked to disease outbreaks in ornamental fish, leading to high morbidity and mortality due to limited treatment options [22, 23]. Fungal infections are also widespread, with *Aspergillus*, *Rhizopus*, and *Mucor* spp. associated with significant fish mortality [24], with fungal-like oomycetes, such as *Saprolegnia*, *Achyla*, and *Dictyuchus* spp., also prevalent in freshwater species due to their broad host range [25, 26]. Additionally, protists, monogeneans, and crustaceans pose serious risks, spreading rapidly and impacting host populations [27]. Common parasites in the trade include *Piscinoodinium* spp. (velvet disease), *Ichthyophthirius multifiliis* (white spot), *Gyrodactylus* and *Dactylogyrus* gill

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and skin worms, as well as *Camallanus* spp. nematodes [28]. Parasitic diseases facilitate secondary infections, and co-infections are the norm, making it even harder to treat fish effectively [20]. Furthermore, exposure to stressors over prolonged periods of time can compromise the host immune system, making them even more susceptible to infection [29]. Regardless of the type of infection, clinical signs tend to be visible (i.e., altered skin and fin condition or different swimming and feeding behaviour), and if caught early, the infection can be reversible [20].

Chemical treatments are widely used to treat aquatic infectious diseases. Traditionally, formalin, a fixative, embalming agent and potent biocide was used against parasites; hydrogen peroxide was readily used against fungal and protozoan infections in fish [30]; and malachite green and methylene blue, industrial dyes that were extensively used against a wide range of fungal pathogens [31]. Other treatments included metronidazole, nitrofurans, potassium permanganate, and praziquantel [32]. The efficacy of these chemical treatments varied and was often dose-dependent, but they were generally effective. These treatments, however, have been associated with rapidly developing resistance and toxicity for both fish and the environment [31, 33, 34]. As a result, the use of malachite green has been banned by the US Environmental Protection Agency for use on any aquatic species and in the European Union (EU) for use in aquaculture and food-producing fish [35, 36]. Because malachite green persists in the aquatic environment and could pass via the food chain to untreated fish intended for human consumption, utmost care must be taken when used for ornamental fish [35].

Antibiotics, another prophylactic measure taken to prevent disease outbreak, are frequently used during transportation. Antibiotics pose serious risks in the ornamental fish trade, affecting both fish and humans. People handling live fish, residues, or transport water—especially traders and, to a lesser extent, hobbyists—may be directly exposed to antibiotic-resistant bacteria that can spread resistance genes to human pathogens, making infections harder or impossible to treat [37, 38]. This pattern of antimicrobial resistance (AMR) and the prevalence of multi-resistance (MDR) has already been found in the ornamental fish trade, in cases such as *Escherichia coli* isolates in Polgahawela, Sri Lanka [39]. Therefore, more natural products, including herbal remedies, are marketed nowadays over old synthetic chemical treatments [40].

Control strategies can be prophylactic, often applied before introducing fish into aquaria, and curative, applied after fish exhibit signs of infection [32]. Prophylactic methods can include the quarantine of new fish to avoid the spread of an existing infection and monitoring of water quality, as changes in the physical environment may precede an infection outbreak or follow it when fish are treated, thus destroying the biological filter by causing spikes in ammonia, nitrate, nitrite, and pH levels and affecting water composition [32]. Additionally, factors such as transportation, stocking density, water quality, and poor handling and netting can further facilitate disease spread, as stressed fish are often immunocompromised, thus making them more susceptible to infection [32, 41, 42]. Regarding the curative aspect, although treatments used against infectious diseases often cause stress and discomfort to fish, the benefits usually outweigh any side effects by reducing disease burden [43].

In the current study, a survey was conducted to identify the most common treatment practices employed by professionals and hobbyists in freshwater ornamental fish to tackle infectious diseases, with the reasons determining treatment of choice and any additional factors influencing treatment efficacy.

2. Materials and methods

2.1. Questionnaire design and distribution

A Jisc Online Survey was designed in collaboration with a British pet suppliers' retailer, Pets at Home [44]. The first page outlined the aims of the survey and stated the estimated time (10 min) required to complete the 17 questions on the treatments used against aquatic infectious diseases of freshwater ornamental fish. Responses were either selected from predefined options (e.g., yes/no or before/after/both) or provided as answers to open-ended questions. Within the 17 questions, information was gathered on the participants' nationality, their involvement in the ornamental trade, their use and acquirement of treatments, and personal opinions on the effectiveness of these treatments. The survey also assessed whether the participants considered other factors such as transport, water quality, and time of day when applying treatments. The survey was answered anonymously, and participation was voluntary. Consent was assumed by the voluntary choice of participating, and this procedure was approved by Cardiff University's Ethics Committee. The survey, open from January 2018 to June 2020, was circulated by Pets at Home to their VIP group via email and Guppy Keepers Society (UK) (178 members) via social media and advertised on the authors' social media feeds (LinkedIn, X—formerly known as Twitter—and Facebook).

In total, 350 completed questionnaires were submitted, with most respondents being UK-based (n = 330) and the sample sizes from other countries too small to analyse independently. The three participant groups analysed included hobbyists (those who kept ornamental freshwater fish as a hobby, n = 186), retailers (those who work in fish stores and pet shops, n = 129), and researchers/experts (academics, aquaria and zoo specialists, and vets, n = 15). As the latter group only included 15 responses, this category could not be statistically analysed. Participants who included themselves in more than one capacity (i.e., both retailer and hobbyist, n = 19) were allocated to a group based on their expertise on the subject.

2.2. Statistical analysis

R statistical software [45] was used for all analyses, with the level of significance taken as $p < 0.05$. For close-ended questions with binary responses (yes/no), we used Generalised Linear Models (GLMs), with the 'binomial' family and 'logit link' function, using the 'lme4' library [46]. For close-ended questions with multiple choices (before/after/both), each choice was answered with yes/no individually in order to be able to perform binomial GLMs with the 'logit link' function for each option. Open-ended questions were converted into close-ended yes/no answers in order to detect the most popular responses where possible, and then two-proportion z-tests were performed between two responses for each individual question to detect the level of significance.

3. Results

Overall, 86% of the 350 respondents use treatments to deal with infectious diseases, with retailers (96.9%) using significantly more than hobbyists (77.3%, GLM; $p = 0.024$). Preference of treatments varied; the most commonly used treatments are listed in **Table 1**.

Retailers tended to use Myxazin® and Protozin® (from API Fish Care by Mars Inc., Chalfont, PA, USA; [47]) as their treatment of choice (two-proportion z-tests: z = 10.80, $p < 0.0001$, 95% CI [0.57, 0.76] and z = 11.16, $p < 0.0001$, 95% CI [0.60, 0.77], respectively). Hobbyists used a wider range of products but primarily used Melafix® and Pimafix® (from WaterLife Research Industries Ltd., Longford, England; [48]) and salt significantly more than retailers (two-proportion z-tests: z = −7.273, $p < 0.0001$, 95% CI [−0.48, −0.30]/z= −5.435, $p < 0.0001$, 95% CI [−0.32, −0.17]/z= −3.735, $p = 0.006$, 95% CI [−0.20, −0.07], respectively). Additional products mentioned were Stress Coat and Stress Zyme also from API, Waterlife products Octozin and Parazin P, ParaGuard™ (Seachem, Madison, GA, USA), Acriflavine and Interpret, and Love fish products. Chemical treatments like malachite green, methylene blue, and formaldehyde were only mentioned by a small proportion of participants (2.3%, 8/350). The composition of the treatments used varied extensively (**Table 2**).

When asked how the participants obtained their treatments, as predicted, there was a clear distinction between the two groups. Most hobbyists (73.7%) purchased treatments through pet stores and fish shops, but 26.3% bought treatments online because of greater variety and/or lower prices. Retailers obtained treatments internally from their company warehouse or directly from manufacturers.

Regarding treatment application, participants were asked if they treated fish prophylactically or after signs appeared. Hobbyists treated infectious diseases once signs appeared rather than prophylactically (GLM; $p < 0.0001$), and 94.5% treated all fish rather than just diseased fish (GLM; $p < 0.0001$). On the other hand, retailers treated fish both prophylactically and curatively (GLM; $p < 0.0001$), with 70.5% isolating the diseased fish compared to only 27.9% of hobbyists (GLM; $p < 0.0001$). However, even though retailers tended to isolate the diseased fish, all fish were treated irrespectively (93.7%). Interestingly, only about 50% of participants followed the course of treatment as recommended by the manufacturer, regardless of their capacity; the remainder stopped treating once signs disappeared or continued for a just few days afterwards, regardless of the treatment course.

When investigating other parameters potentially affecting fish disease susceptibility, transport was identified, mostly concerning retailers. When asked to state when clinical signs were observed (before, after, or both), 44.8% of retailers detected signs both before transport (when fish were being prepared for shipment) and after transportation, whereas the rest of the retailers reported signs only after transportation was concluded. For water quality, all groups stated that ammonia, nitrate, nitrite, pH, and oxygen levels were regularly checked, as often as three times per week for retailers, who followed the DEFRA (Department for Environment, Food and Rural Affairs) guidelines, and conducted regular water changes to restore and preserve water quality. Additionally, not overcrowding the system, maintaining constant temperatures, and providing an adequate air supply helped prevent infectious diseases [18]. Finally, as time of day likely plays a crucial role when treating infectious diseases [49], it was also included as a specific question in the survey. Retailers consistently treated fish in the evening (GLM; $p = 0.0003$), when stores/shops closed for the day and the lights were off. Hobbyists and researchers/experts, however, tended to treat when convenient throughout the day (GLM; $p = 0.0046$). A few participants treated when suitable for the water changes of the tanks, and others claimed to treat fish based on manufacturer instructions (even though no known products suggest time of treatment) (**Figure 1**).

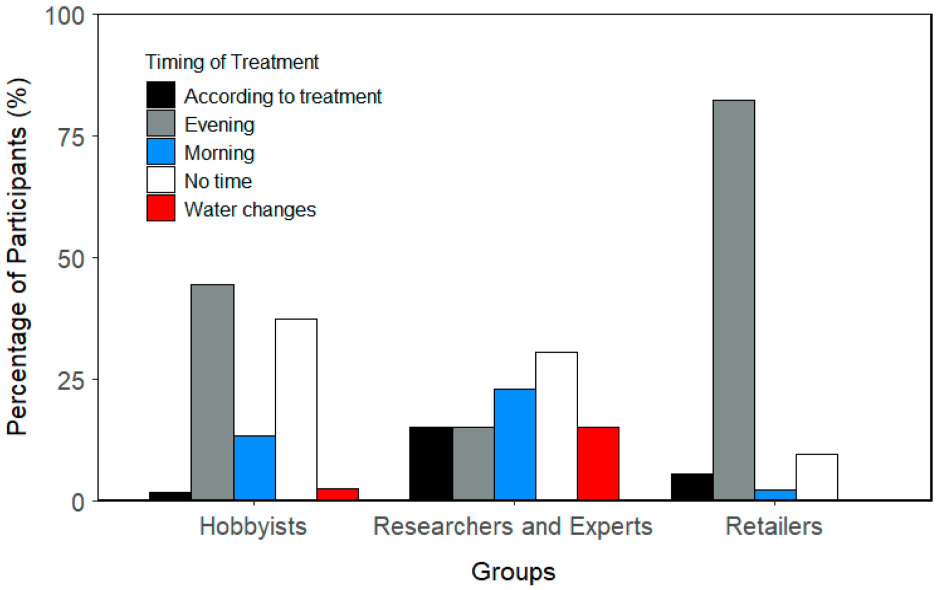

Figure 1 • UK survey responses on when participants treat their ornamental fish against aquatic infectious diseases throughout the day. Greater consistency was observed among retailers, as they tended to treat in the evening. Hobbyists and researchers/experts do not have a preference for timing of treatment.

Table 1 • Most common treatments used against fish pathogens across the three groups of survey participants: hobbyists, retailers, and researchers/experts.

Survey respondents	Melafix (API)	Pimafix (API)	Myxazin (waterlife)	Protozin (waterlife)	Salt	Esha products
Hobbyists	43.5%	26.2%	15.2%	13.1%	16.5%	13.1%
Retailers	5.7%	2.4%	81.3%	80.5%	2.4%	2.4%
Researchers/Experts	8.3%	8.3%	0%	8.3%	41.7%	0%

Table 2 • Most common treatments applied against infectious diseases of freshwater fish identified in the current study, along with manufacturer, constituent components, and targets of the treatments.

Treatment	Producer	Ingredients	Target
Melafix	API Fish Care by Mars Inc.	Cajuput (*Melaleuca cajuputi*) (50 g/L)	Bacterial infections
Pimafix	API Fish Care by Mars Inc.	West Indian Bay (*Pimenta racemosa*) (25 g/L)	Fungal infections
Stress Coat	API Fish Care by Mars Inc.	Aloe vera (*Aloe Vera*) leaves (0.005 g/L)	Healing of surface wounds and restoring lost mucus
Stress Zyme	API Fish Care by Mars Inc.	300 million live bacteria/teaspoonful	Reduction in buildup of organic waste and aquarium maintenance
Myxazin	Water Life Research Industries Ltd.	Malachite green ($C_{23}H_{26}N_2O$) and copper sulphate ($CuSO_4$)	Whitespot, oodiniasis, costiasis, trichodiniasis, and neon tetra disease
Protozin	Water Life Research Industries Ltd.	Malachite green and acriflavine hydrochloride ($C_{27}H_{25}ClN_6$)	Bacterial infections such as fin and body rot, ulcers, pop eye, raised veins, and 'redness'
Paraguard	Seachem Laboratories, Inc.	Glutaral ($C_5H_8O_2$) (25 g/L) and malachite green (0.04 g/L)	Parasitic infections like oodiniasis, fin rot, and fin and body flukes
Acriflavin		Fluorescent acridine dye ($C_{14}H_{14}ClN_3$)	Fungal and bacterial infections and open wounds
Esha 200 Esha Exit	Esha Laboratories Sea Horse IPC BV (Maastricht, Netherlands)		Wide range of fungal, bacterial, and parasitic infections, specifically all spot diseases (*lchthyophthirius*)
Salt		NaCl 5–25 mg/L	Parasitic infections

Fish species most prone to showing clinical signs of infection included mollies (*Poecilia sphenops*), guppies (*Poecilia reticulata*), platies (*Xiphophorus maculatus*), and swordtails (*Xiphophorus helleri*), all livebearers of the Poeciliidae family. Other fish identified were neon tetra (*Paracheirodon innesi*) and cardinal tetra (*Paracheirodon axelrodi*), among other *Tetra* species, clown loaches (*Chromobotia macracanthus*), various goldfish like Oranda (*Carassius auratus auratus*), and species of the *Betta* genus. The participants, however, stated that factors such as stock density, female/male ratio, and water quality had a greater impact on predicting disease susceptibility than the actual fish species.

Finally, when asked to comment on the most effective treatments used, the participants responded with the treatments that they were currently using. For hobbyists, this was Melafix and Pimafix as well as salt compared to retailers (two-proportion z-tests: $z = 5.787$, $p < 0.0001$, 95% CI [0.26, 0.46]/$z = 4.354$, $p = 0.0008$, 95% CI [0.13, 0.29] and $z = 3.740$, $p = 0.0062$, 95% CI [0.09, 0.21], respectively), who indicated greater efficacy of Myxazin and Protozin (two-proportion z-tests: $z = -6.649$, $p < 0.0001$, 95% CI [−0.48, −0.26] and $z = -7.778$, $p < 0.0001$, 95% CI [−0.58, −0.36], respectively). Overall, the participants expressed interest in prophylaxis advice as well as clear, concise guidance on treatments and their application to make the maintenance and treatment of fish easier and more effective.

4. Discussion

Aquatic infectious diseases of ornamental freshwater fish pose a significant threat to the retail industry [20]. Often caused by pathogens that are extremely common, spread rapidly, and manifest opportunistically in times of stress, parasitic infections need to be treated quickly and effectively [20]. Factors that increase fish disease susceptibility, by causing stress, such as poor handling and containment practices, such as stocking density and water quality, need to be closely monitored and considered for the maximum efficiency of treatments [42, 50]. Data collected from the current survey indicated how differently professionals and hobbyists deal with infectious diseases of ornamental freshwater fish, with the former following a strict approach to minimise economic losses and the latter relying more on natural treatments. Importantly, all users need to be reminded of the importance of completing a full course of treatment as recommended by manufacturer guidelines.

Hobbyists' knowledge of fish husbandry varies widely, impacting ornamental fish welfare. Despite legal requirements in the UK (Animal Welfare Act 2006) and accessible resources provided by organisations such as the OATA (Ornamental Aquatic Trade Association; [51]), hobbyists often struggle to access expert help for proper diagnosis and treatment of fish diseases. Many might be unaware of welfare needs, do not have direct access to aquatic vets, or even view professional care as unnecessary. As a result, this can lead to the use of unregulated treatments lacking verified safety, quality, or efficacy. Limited access to licenced fish pharmaceuticals, often sold in commercial-scale volumes, further complicates care. Consequently, fish are frequently exposed to multiple chemical treatments before receiving a proper diagnosis [51].

In our study, hobbyists most commonly used Melafix® (43.5%) and Pimafix® (26.2%), both by API® [47]. Melafix contains essential oil from *Melaleuca cajuputi*, known for its antimicrobial, antiseptic, and anti-inflammatory properties [52, 53], and it is used as a broad-spectrum treatment for bacterial infections [54]. Pimafix, derived from *Pimenta racemosa*, exhibits antiviral, antifungal, and larvicidal activity [55–58]. Other API products cited included Stress Coat and Stress Zyme, mainly used prophylactically by both hobbyists and retailers. Stress Coat, a water conditioner applied before or after handling, transport, or netting, aids the healing of surface wounds, restores mucus, and reduces erratic swimming and aggression without affecting water quality [59]. Stress Zyme contains live bacteria that reduce organic waste and ammonia buildup, functioning as a biological filter and widely used as an aquarium additive [60, 61]. Another commonly used natural treatment was salt, effective, inexpensive, and widely applied across all user groups (41.7% among researchers/experts), to treat freshwater parasitic infections. A 5 g/L salt regime over two weeks helped *Maccullochella peeli* and *Tandanus tandanus* recover from *Ichthyophthirius multifiliis* infections [62]. Elevated salinity reduced the in vitro survival of ectoparasites *Gyrodactylus bullatarudis* and *G. turnbulli*; a short-term, high-concentration (25 g/L) salt bath removed 72% and 100% of these parasites, respectively, from *Poecilia reticulata* [63]. However, the efficacy of natural treatments is often strain-specific [64, 65] and may vary with seasonality and where the ingredients are sourced from [65].

Treatments favoured by UK retailers were Protozin (80.5%) and Myxazin (81.3%) by Waterlife® [48]. Even though little has been published about the efficacy of these chemical-based treatments, both contain malachite green, which has shown great efficacy against parasitic infections in the past [66]; for example, it was the most effective treatment (0.005–0.008 mg/L) against oomycetes such as *Aphanomyces invadans* when compared to 48 other compounds [67]. Further treatments mentioned were ParaGuard (Seachem) and Acriflavine, the latter widely used to treat external fungal and bacterial infections in ornamental fish [68]. The effectiveness of Acriflavine has been confirmed against *Trichodina centrostrigeata protozoa* and *Centrocestus formosanus* metacercariae, with 95.6% and 91.1% parasite reduction observed in fish exposed to 10 mg/L for seven days [69]. Esha products were also mentioned in the responses, with Esha Exit and Esha 200 being the most popular as they have a broad spectrum of activities against fungal and bacterial infections by promoting wound healing and the protection of mucous membranes. Product availability and cost may have also influenced retailers' treatment choices, especially in larger operation settings.

Therefore, according to the responses of the participants regarding the most and least effective treatments, hobbyists tend to use natural treatments based on plant extracts, whereas retailers seem to have a synthetic-based approach. As expected, retailers seem to follow a stricter approach, focusing on prophylaxis as much as cure and taking any precautionary steps required, such as isolating diseased individuals and treating them separately. This aims to minimise the development and spread of infectious diseases and increase the chances of maintaining fish welfare. Conversely, most hobbyists tend to minimise the exposure of fish to treatments to avoid 'unnecessary' stress. So, it would appear that hobbyists make the decision to use more environmentally friendly, natural products to deal with infectious diseases.

Fish species reported to be most prone to infections in our survey coincided with those reported in the literature [70, 71]. Previous studies have indicated that the most common ornamental species within the pet trade include cyprinids (Cyprinidae), cichlids (Cichlidae), livebearers (Poeciliidae), characins (Characidae), hatchetfish (Gasteropelecidae), and catfish (Loricariidae) [70, 71]. In addition, a survey conducted in 2015 indicated that the ornamental fish trade mainly entails 312 species from 14 orders and 56 families, with Cichlidae (38%) and Cyprinidae (13%) being the dominant families [72]. More specifically, guppies and goldfish are two of the most common global aquarium fish species [10, 73], and these along with other commonly stocked species like mollies, platies, and swordtails experience the highest incidence of infectious diseases. Interestingly, poeciliids (mollies, guppies, and platies), tetras (Characidae), and goldfish (Cyprinidae) were also reported by the participants of our survey as the most susceptible. This could partially be due to increased inbreeding and selective breeding for traits unrelated to health, like epidermal colouration, which may have inadvertently decreased disease resistance [74, 75]. Selective breeding for disease resistance could be attempted, as in aquaculture [76], but it is unlikely to be practical or cost-effective within the ornamental trade [77].

When considering other variables that impact disease susceptibility, the transport process is often neglected, especially when considering fish health and welfare [66]. Mechanical disturbance during routine fish transport could lead to stress-induced immunosuppression, increasing the chances of infections [78]. This stressor mostly concerns retailers, with 44.8% observing signs of infection both before and after transport. Fish preparation usually involves three stages: prophylactic treatment, starvation, and pre-packaging, all of which can stress the fish, facilitating opportunistic pathogens to take hold [79]. Moreover, transport can last up to 48 h, especially if international, during which multiple fish are typically kept in plastic bags with no feed, filtration, nor stable temperature [79–81]. Handling and netting, water quality deterioration due to ammonia accumulation, and high stocking density involved in fish transport are also directly linked with increased disease susceptibility [82, 83], and if a single fish dies, this greatly decreases the quality of the water. Adding salt to the water when transporting several species of food fish is effective in reducing fish stress and mortality [84]. Similarly, when guppies were packed in saline water (1%, 3%, 9%) and stocked in their respective salinities for recovery (with 30% daily dilution with freshwater) after shipment, the fish in all three treatments displayed a significantly lower mortality rate than the control group at 7 days after transport [78]. The effective concentration of salt, however, is species-dependent [84]. Clearly, emphasis needs to be placed on both the preparation before and the recovery of fish after shipment [78].

Water quality, crucial during transport and general maintenance, significantly influences fish disease susceptibility. Key parameters such as hardness, salinity, pH, temperature, ammonia, nitrate, nitrite, oxygen, and carbon dioxide [81] must be closely monitored and maintained within species-specific ranges. While fish may tolerate suboptimal conditions, stress diverts energy from essential metabolic functions, increasing vulnerability to opportunistic pathogens [81, 85]. Survey results show that all three groups regularly monitor water quality, with retailers testing up to three times weekly for pH, nitrate, nitrite, and oxygen levels, along with performing routine water changes. Consistent monitoring and minimizing fluctuations in physical conditions are therefore critical before and during treatment for infectious diseases.

Nearly 80% of retailers reported treating fish in the evening, while hobbyists and researchers/experts typically treated when convenient. A small proportion claimed to follow manufacturer instructions, despite no treatment specifying a particular time of day, suggesting that some participants may have provided socially desirable responses. Combined with evidence that most retailers and hobbyists do not complete full treatment courses, this indicates that treatment practices may lack consistency and thoroughness. Evening treatment by retailers may reflect time constraints, after-hours convenience, avoidance of visible tank discoloration during the day, or reluctance to expose diseased fish to customers. However, treatment timing may be important, as growing interest in chronotherapy highlights the role of circadian rhythms and light conditions in drug efficacy [86]. Treatment outcomes can be influenced by infection-altered host behaviour [87] and by variations in drug absorption and metabolism across the day [88]. Additionally, light intensity, duration, and wavelength (closely tied to time of day) can trigger species-specific physiological responses, warranting consideration in disease management [89].

Other key factors, not mentioned in the survey, are handling, stocking density, and enrichment. Within the supply chain, fish are handled quite frequently and excessively, which can elicit a strong stress response [90, 91], especially if the stressor is repetitive [92]. The stocking density of fish also impacts stress, which again is species-specific and can vary with the tank style [14]. The stress levels of zebrafish (*Danio rerio*), for example, are increasingly elevated in crowded conditions [42], whereas in tilapia (*Oreochromis niloticus*), increased levels of aggression between individuals are observed at lower densities, acting as a potent chronic social stressor [93]. Finally, there is an increasing level of interest in the benefits of tank enrichment (colour and structural variation, including gravel substrate, flowerpots, reeds, and tubing [81]) for fish health and welfare [94], as fish from aquaria with enrichment are more resistant to pathogen infection and have reduced pathogen load compared to those from barren tanks [95].

5. Conclusions

Data from this UK survey provided information on how people deal with fish pathogens, with hobbyists relying more on plant-based treatments and retailers using more synthetic treatments and taking more precautionary measures, presumably to avoid great economic losses. This study also highlighted various factors that should be taken into consideration to maximise treatment efficacy. This is particularly key considering the importance of the aquatic ornamental trade on a global basis, moving the greatest numbers of animals worldwide annually [12].

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Author contributions

E.A.A.: conceptualization, methodology, investigation, validation, formal analysis, writing—original draft; J.C.: conceptualization, methodology, supervision, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interes.

Data availability statement

Data supporting these findings are available upon request.

Informed consent statement

The questions were answered anonymously, no identifiable data was collected, and participation was voluntary; consent was assumed following survey completion.

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