E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 76.37
(GIF) Impact Factor: 0.549
IJFAS 2025; 13(1): 10-22

www.fisheriesjournal.com
Received: 05-11-2024
Accepted: 07-12-2024

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Phytotherapy in ornamental fish aquaculture: A sustainable approach for disease management

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DOI: https://doi.org/10.22271/fish.2025.v13.i1a.3009

Abstract
In the Aquaculture industry, ornamental fish culture plays a very vital role due to their lucrative color which enhances the esthetic appeal in European countries. However, Ornamental fish aquaculture faces significant challenges for disease outbreaks because of their captive environment. It is very difficult to maintain a suitable environment both for the supplier and for the ornamental fish keeper. There are several chemical treatments available to address this disease outbreak challenge. Using chemical treatment is not environmentally friendly and contributes antibiotic resistance. To overcome these devastating challenges there is only way to introduce organic aquaculture with the nature-based solution by adopting phytotherapy in the ornamental fish culture. Phytotherapy is the way plant-based extract is incorporated in the feed of the ornamental fish which automatically increases the immunity of the fish. Phytotherapy has various natural compounds phenolic, antimicrobial, immunostimulants, etc. Despite the significance of the phytotherapy application in ornamental fish aquaculture, there is a huge gap in this research area. The present review investigated the research gap and lack of application of phytotherapy in ornamental fish culture especially in European countries. The result showed that there was a huge research gap and a lack of phytotherapy in ornamental fish culture in European countries. It was found that among the 240 publications, 12% were for ornamental fish and the rest of them are for consumable fish aquaculture. It also showed that most of the research conducted in Asian countries is only 12% in European countries. This review mirrors the importance of phytotherapy in ornamental aquaculture in European countries for eco-friendly solutions and economic sustainability by studying a comprehensive overview of the importance of research gaps, lack of application, and future research requirements.

Keywords: Phytotherapy, ornamental fish aquaculture, sustainable disease management, eco-friendly solutions, antibiotic alternatives

Introduction
According to Grand View Research (2023) [1] and Hoseinifar *et al.* [2], the ornamental fish industry in Europe was estimated to be worth USD 2.45 billion in 2023 and is expected to increase at a compound annual growth rate (CAGR) of 7.9% between 2024 and 2030. It was observed by Hoseinifar *et al.* [2] that ornamental fishes are referred to as "living jewels" due to their diverse and beautiful colors, behaviors, and shapes. The ornamental fishes are kept in garden pools or aquariums for aesthetic and amusement reasons. In recent decades the expansion of the ornamental fish market and farming has driven the demand for intensive and super-intensive ornamental fish aquaculture [2, 3]. Since the 1980s, aquaculture has expanded quickly to satisfy the world's need for fish and seafood, including both ornamental and consumable fish [4]. These days, more than 7000 aquatic species are cultivated and marketed as ornamental fish. Of them, about 1800 are marine species and 5000 are freshwater species [5, 6, 7]. Most freshwater specimens, as opposed to marine ones, are created in captivity [7, 8]. Around 60% of ornamental fish are produced in Asia and developing nations, which dominate the world's ornamental fish import/export market, which involves more than 120 countries and has an annual worldwide trade value of $15-30 billion [8, 9]. In particular, the ornamental fish industry has expanded significantly, driven by rising consumer interest and economic opportunities within this niche sector. However, like other forms of aquaculture, ornamental fish farming faces persistent challenges due to

pathogenic diseases that threaten fish health, increase mortality rates, and ultimately compromise product quality and profitability. Various Stress factors such as transportation, high stocking density, handling, and inadequate nutrition can compromise fish immune systems, thereby enhancing the effectiveness of pathogens[3]. Traditional methods of disease management rely heavily on antibiotics and synthetic chemicals, but these approaches are problematic. By promoting antibiotic-resistant bacteria and causing persistent contamination, they not only endanger the aquatic environment and fish physiology, but they also provide a risk to public health [10, 11, 12, 13].

In response to these problems, phytotherapy, the use of plant-based substances as environmentally benign substitutes for aquaculture disease management is gaining popularity worldwide. Because of their low risk of adverse effects, accessibility, and cost, medicinal plants are becoming more and more acknowledged as effective substitutes for pharmacological approaches in the treatment of fish illness and stress [13, 14]. Plant extracts with antibacterial, immune-stimulating, and anti-stress qualities, such as phenolics, alkaloids, and essential oils, are used in phytotherapy [15, 16, 17]. Aloe vera, neem, turmeric, garlic, and other plants have demonstrated potential in boosting immune responses, lowering pathogen burdens, and improving fish health in general. For ornamental fish farming, where the fish's visual health and vitality are crucial to their market value, phytotherapy is especially appropriate because it provides a sustainable, biodegradable, economical, and minimally harmful alternative to traditional chemical treatments [14, 15, 18, 19].

Despite these benefits, the successful application of phytotherapy in ornamental fish aquaculture is constrained by several research gaps. The requirements of ornamental fish are not well understood because most current research focuses on fish species that are meant for human consumption, such carp and tilapia. Neem leaf extract has an impact on the survival and general health of the zooplankton community, Nile tilapia (*Oreochromis niloticus*), and African catfish (*Clarias gariepinus*) [20]. Because ornamental fish are frequently housed in extremely regulated conditions and have particular health needs, this industry may require customized phytotherapy treatments. Furthermore, the uniform and safe use of phytotherapy across fish species is hampered by the absence of defined standards regarding dosages, application techniques, and treatment durations for various plant-based chemicals. The effectiveness of phytotherapy has been shown in short-term research, but nothing is known about its long-term impact on fish physiology, reproductive, and general health. In order to incorporate phytotherapy into regular fish health management and make sure it offers long-lasting advantages without side effects; it is crucial to comprehend these long-term effects.

Furthermore, aquaculture phytotherapy regulatory frameworks and quality control standards are lacking, particularly in Europe, where regulation could assist guarantee the efficacy and safety of phytotherapy products. In addition to promoting more investment in research and product development, clear regulatory requirements would facilitate the commercialization and broader acceptance of phytotherapy in the ornamental fish industry. In addition to meeting the increasing demand for healthy ornamental fish aquaculture, European ornamental fish aquaculture can increase resilience and reduce its environmental effect by adopting natural cures (Organic Aquaculture). In-depth analysis of phytotherapy in relation to European ornamental fish farming is the goal of this paper. The function of several plant-based chemicals in disease management will be investigated, along with the advantages and disadvantages of these strategies and their wider ramifications for sustainable aquaculture methods. This study aims to support ongoing efforts to promote ecologically responsible and efficient solutions in ornamental fish farming by highlighting recent developments and outlining potential future paths.

Methodology

By searching the available databases, including the ISI Web of Knowledge (https://www.webofknowledge.com/), Bio One (https://bioone.org/), Research Gate (https://www.researchgate.net/), Google Scholar (https://scholar.google.com/), and Get CITED (https://www.getcited.org), all pertinent articles about environmentally friendly methods and the function of phytotherapy in ornamental fish culture in Europe were found. Furthermore, a search was conducted on Google (www.google.com) to find scientific literature that was published in regional or local publications. "Phytotherapy," "ornamental fish culture," "plant compounds," "aquaculture," "eco-friendly solutions," "disease management," and "Europe" were among the terms chosen in the literature search.

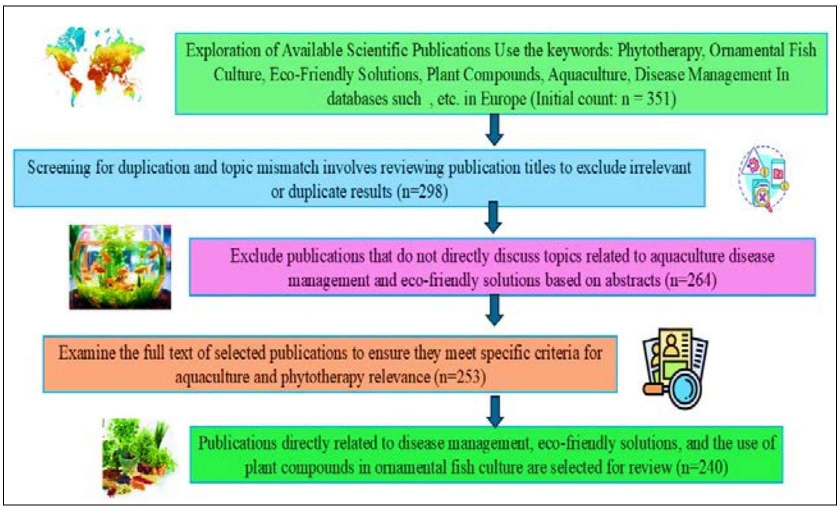

Fig 1: Research Paper Collection Process

All publications published in SCOPUS and the Web of Science were examined in order to gauge scholarly interest in this subject. 240 articles in all, published between 2004 and 2024, were found. We screened papers with more than two citations and compared them to the entire pool in order to concentrate on the most influential literature. Based on the nation of association of the initial author, publication trends over time and the geographic distribution of papers were examined.

Furthermore, only research pertaining to phytotherapy in ornamental fish production in Europe was kept after the publications were examined for subject relevancy and geographic focus. Three hundred fifty one (351) publications, including journal articles, conference papers, reviews, and book chapters, were found using this search. In accordance with Gurevitch *et al.* [21] methodology, we eliminated redundant and pointless research, eliminating articles that had pertinent keywords but lacked significant details. Reviews and book chapters without significant original content on phytotherapy for ornamental fish were also excluded.

After a full-text review, 240 publications met the following quality criteria for inclusion: (i) clear and rigorous methodologies, (ii) qualitative and quantitative data on phytotherapy applications in ornamental fish aquaculture, and (iii) insights into the effectiveness of plant-based compounds for disease management and fish health at a global scale. Data analysis was conducted by Microsoft excel and VOS Viewer 1.6.20 for network visualization of keyword co-occurrence and country to make the result clearer.

Result and Discussion

This study provides a comprehensive analysis of global trends and applications of phytotherapy in ornamental fish aquaculture, highlighting a growing research interest, distinct geographical patterns, prevalent phytotherapeutic plants, and the efficacy of diverse plant-based treatments. An important aspect to be considered in review study is the number of existing publications on the subject, including time trend and geographic distribution, in fact it is very well known that the number of publications serves as an indicator of the scientific community's interest on a certain topic.

Immunomodulatory Effects of Medicinal Plants in Aquatic Animals

Medicinal plants primarily influence immune organs such as the thymus, spleen, and kidneys, supporting their maturation and development. Within these organs, white blood cells and monocyte-macrophage systems play crucial roles in non-specific immunity. Furthermore, medicinal plants can directly stimulate antibody production, engaging in specific immune responses. Numerous therapeutic plants also promote the synthesis of cytokines, which are essential for both particular and non-specific immunological functions. These include interleukins, interferons, and tumor necrosis factors. Because of their varied secondary metabolites (SMs), which include essential oils, saponins, phenolics, tannins, alkaloids, polypeptides, and polysaccharides, medicinal plants have more biological activity than isolated substances [22]. By interacting with proteins and DNA and affecting recognition, binding, catalytic activities, and protein turnover, these SMs play a crucial role in stress responses, antioxidant defense, and immunological support [23]. Plant SMs can make covalent connections with proteins, peptides, and even DNA because they contain a range of functional groups, such as aldehyde and SH groups, epoxides, and non-configurational double and triple bonds [24, 25]. By blocking ligands or substrates, these bonds can change the binding or catalytic sites of receptors and enzymes, which in turn can change chemical reactions. This in turn affects binding mechanisms, catalytic effectiveness, and protein-protein interactions, making SMs adaptable "multi-target drugs" for a range of medical conditions [22].

Among these secondary metabolites, glycosides support immune enhancement by activating the reticuloendothelial and complement systems, stimulating immune cells, and inducing cytokine production. Alkaloids boost humoral and cellular immune responses while enhancing macrophage phagocytosis. Polysaccharides stimulate immune cell production. Some phenols and terpenoids, by binding to double bonds, can inhibit the formation of reactive oxygen species (ROS) and other free radicals in cells and tissues. For example, monoterpenes with phenolic hydroxyl groups may reduce ROS production by binding to SH groups in proteins, thus inhibiting bacterial and fungal growth [26, 27]. Additionally, phenylpropanoids and gallotannins, with numerous phenolic hydroxyl groups, have shown anti-inflammatory and antiviral effects through broad protein interactions in both microbes and animals [28, 29, 30]. Certain compounds in medicinal herbs, like *emodin*, *geniposide*, and *curcumin*, initiate antimicrobial and immune-boosting actions by binding to membrane protein receptors or ion channels [31, 32], which can, in turn, interact with SH groups in these proteins, receptors, and channels [26]. Botanical amines containing nitrogen atoms also have binding affinities for bacteria, fungi, and viruses [26, 28, 29, 30, 31, 32]. Lectins in herbal medicine further contribute by binding specifically to glycoproteins on pathogens, aiding in pathogen recognition [33].

Role of Phytotherapy in Aquaculture

Phytotherapy

Involves using plant-derived compounds to enhance immunity and manage diseases in aquatic organisms. It is an eco-friendly alternative to synthetic chemicals and antibiotics, offering several benefits [15, 16, 17]:

Cost-Effective

Inexpensive compared to conventional treatments.

Non-Specific Immunity Boosting

Stimulates general immune responses in fish.

Antimicrobial and Antistress Effects

Various plant compounds exhibit properties that help manage stress and control infections.

Growth Promotion and Appetite Stimulation

Enhances the overall health and growth of fish.

The medicinal plant contains potent antioxidant compounds that effectively neutralize free radicals, which can otherwise impair normal cellular functions. Accumulated free radicals in tissues are associated with chronic diseases such as cancer, cardiovascular disease, diabetes, and arthritis [34]. *Ethnomedicinal* plants including *Cinnamomum zeylanicum*, *Andrographis paniculata*, *Eugenia polyantha*, *Curcuma xanthorrhiza*, *Angelica sinensis*, and *Orthosiphon stamineus* are widely recognized in Asia for treating various ailments, from fevers to metabolic disorders [35, 36]. Many herbal plants also contain antimicrobial agents that have shown potential in combating a wide range of pathogens [37].

Medicinal plants are rich in bioactive compounds such as steroids, proteins, tannins, saponins, terpenoids, and alkaloids. These phenolic compounds have demonstrated effectiveness against various bacterial pathogens (*Salmonella typhi, Bordetella pertussis, Corynebacterium pervum, Klebsiella pneumoniae, Mycobacterium, Escherichia coli*), fungi (*Aspergillus flavus, Aspergillus fumigatus, Fusarium solani,* and *Pseudomonas aeruginosa*), and viruses (*retroviruses, simian-virus*) [38, 39]. Historically, medicinal plants have been screened to isolate commonly used antibiotics like tetracycline, terramycin, and ampicillin [40].

Table1: Experimental inclusion of medicinal plants in aquatic animal health management

SL	Experimental Animal	Plant	Preparation of Plant Materials	Pathogen	Administration	Experiment Duration	Reference
1	Tilapia fingerling	Garlic	Crushed clove extract	*Trichodina sp. and Gyrodactylus sp.*	Bath	24 h	[41]
2	*Ictalurus punctatus*	*Galla chinensis*	Pentagalloylglucose	*Ichthyophthirius multifiliis*	Bath	-	[42]
3	*Piaractus mesoptamicus*	*Toddalia asiatica*	Chelerythrine, chloroxylonine	*Ichthyophthirius multifiliis*	Bath	72 h	[43]
4	Freshwater angelfish	*Allium sativum*	Ajoene (E,Z)-4,5,9-trithiadodeca-1,6,11-triene 9-oxide)	*Spironucleus vortens*	Oral	-	[44]
5	*Piaractus mesopotamicus*	*Melaleuca alternifolia*	Essential oil	*Ichthyophthirius multifiliis*	Bath	2 h day−1 for 5 days	[45]
6	Carassius auratus	*Allium sativum*	Ethanolic extract of bulb	*Trichodina sp.*	Bath	4 days	[46]
7	Grass carp Ctenopharyngodon idella	*Curcuma longa*	Curcumin	*Ichthyophthirius multifiliis*	Bath	4 h	[47]
8	Fingerlings of Colossoma macropomum	*Varronia curassavica*	Essential oil - α-pinene, sabinene, and -caryophyllene	*Ichthyophthirius multifiliis*	Bath	1 h	[48]
9	European sea bass	*Allium cepa and Allium sativa*	Juice	*Lernantropus kroyeri*	Oral/ Bath	5, 10, 15, and 20 min	[49]
10	Clarias gariepinus	*Moringa oleifera*	Aqueous leaf extract	*Ichthyophthirius multifiliis*	Bath	1 h	[50]
11	Koi carp	A. calamus and I. aspalathoides	Rhizome extract	*A. hydrophila*	Bath and powder in feed	-	[51]

Several ornamental fish species are highlighted for their response to natural treatments against common parasites (Table 1 and Table 2). For goldfish (*Carassius auratus*), extracts from *Semen aesculi* and *Radix angelicae* demonstrated significant effectiveness against the gill parasite *Dactylogyrus intermedius*. Additionally, a synergistic treatment combining compounds from *Dioscorea zingiberensis* and *Ginkgo biloba*—notably gracillin—enhanced anthelmintic efficacy against *Dactylogyrus* infections in goldfish [12, 52], Guppies (*Poecilia reticulata*), which are susceptible to the gill parasite *Gyrodactylus turnbulli*, benefited from immersion in ginger (*Zingiber officinale*) extract, which effectively controlled this monogenean infestation [12,53]. Meanwhile, zebrafish (*Danio rerio*) responded well to treatments with *Azadirachtin*, an extract from neem (*Azadirachta indica*), which provided protection against wheelworm (*Trichodina sp.*) infestations without mutagenic effects and remained safe for use at specific concentrations [12]. These findings support the potential of herbal extracts in managing parasitic infections in ornamental fish, offering a natural and safe alternative to chemical treatments.

Table 2: Examples of Phytotherapy's Positive Impact on Fish

Fish Species	Plant Used	Effects
Carassius auratus [54]	*Phyllanthus niruri*	Reduced blood glucose level
Clarias gariepinus [55]	*Artemisia cina*	Increased growth parameter and immune response
Oreochromis aureus [56]	*Trifolium pratense*	Improved growth rate and feed utilization
Oreochromis niloticus [57]	Dietary Ginseng Herb	Enhanced growth performance, diet utilization efficiency, and haematological indices

With growing concerns over antimicrobial resistance in aquaculture, which affects fish health, aquatic habitats, and indirectly, human health, medicinal plants offer a promising alternative for disease prevention in fish [58]. Beyond chemotherapeutic applications, medicinal plants can serve as feed additives in aquaculture due to their functional nutrients and bioactive compounds, which promote growth, reduce stress, enhance appetite, and boost immunity in fish [59].

According to research, bioactive substances such flavonoids, glycosides, phenolics, saponins, alkaloids, terpenoids, tannins, and steroids are responsible for the positive effects of medicinal plants. Because of their availability and ease of use, medicinal herbs can help intensive aquaculture adopt sustainable practices that improve fish output and health. These plants can be used in a variety of ways, such as crude extracts, active extracts, or in conjunction with live beneficial bacteria, yeast, and other items originating from animals [60].

Publication Trends and Geographical Distribution of the Research

Asian nations, particularly China and India, have been the main drivers of the significant rise in publications over the past 20 years, according to the temporal trend study (Fig. 2). This expansion into aquaculture is consistent with these nations' long-standing dependence on medicinal herbs. The strong cultural acceptance of herbal medicine in Asia supports the region's leading position in phytotherapy for ornamental fish.

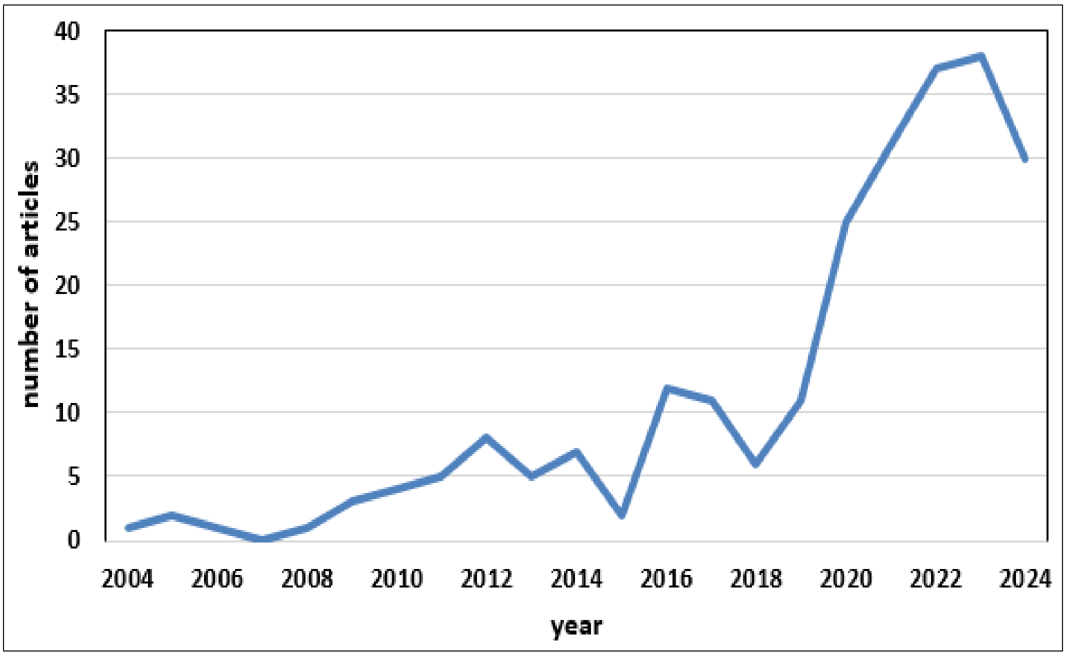

Fig 2: Time trend of published articles

The geographical distribution of these studies (Fig. 3 and Fig. 4) further underscores Asia's dominant position, with other continents showing comparatively limited research focused on specific aspects, such as ornamental fish culture and medicinal plants for disease management. A deeper look into Asia's research landscape (Fig. 4) reveals a balanced distribution across various research categories, indicating an integrated approach that combines disease management, growth enhancement, and aesthetic improvement for ornamental fish

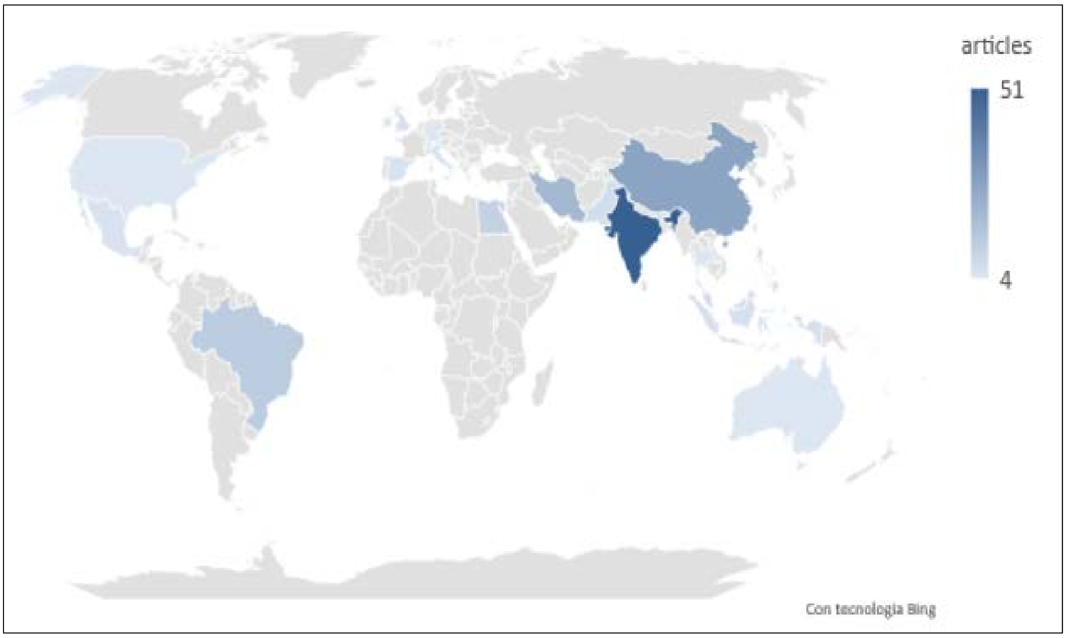

Fig 3: Geographical distribution of published articles

Asia, spearheaded by China, is the dominant continent for both traditional and ornamental aquaculture. Within the continents is particularly dominant in the categories of phytotherapy and medicinal plants for fish disease management, highlighting the region's significant interest in traditional medicine applications within aquaculture. The strong focus on phytotherapy in Asia could be attributed to a deep-rooted cultural acceptance and historical use of medicinal plants. Other continents, including Europe, Africa, South America, North America, and Oceania, display relatively modest levels of publication activity across all categories.

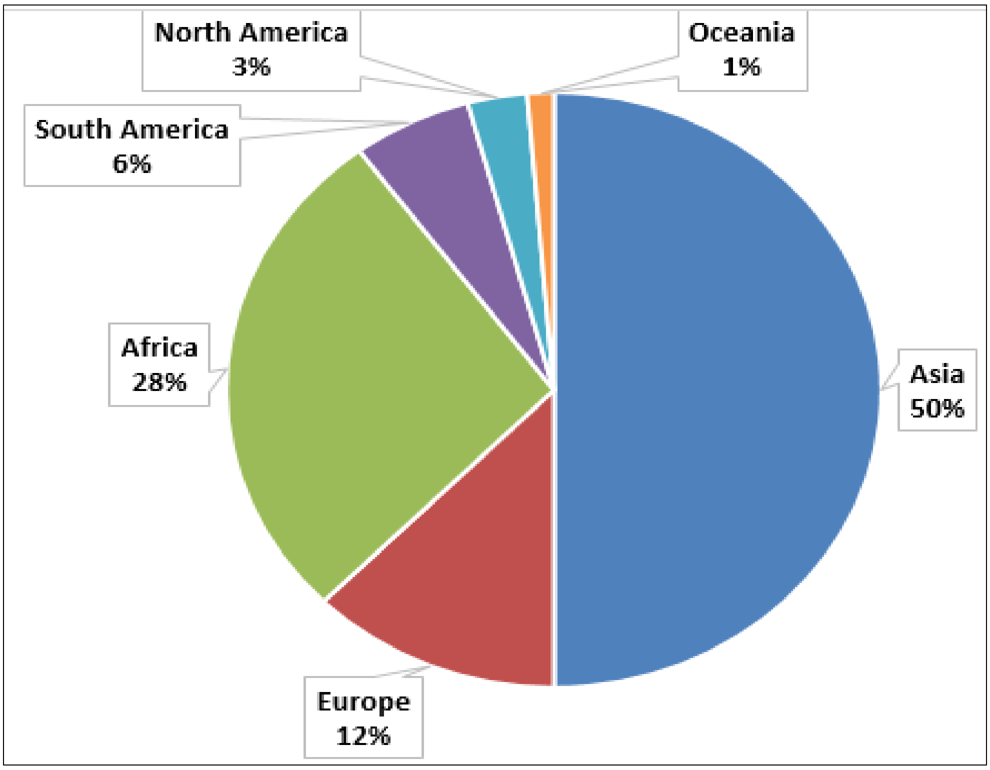

Fig 4: Geographical distribution of published articles, by continent

Within Asia (Fig.5), there is a relatively balanced distribution among the four research categories. This suggests that the research landscape in Asia covers a broad spectrum of topics within phytotherapy, likely reflecting an integrated approach that includes both practical disease management applications and ornamental aquaculture. In other continents, the majority of research is mainly focused on ornamental fish culture and medicinal plants for disease management. This distribution may indicate a narrower application of phytotherapy research outside of Asia, where studies may be more sporadic and less foundational.

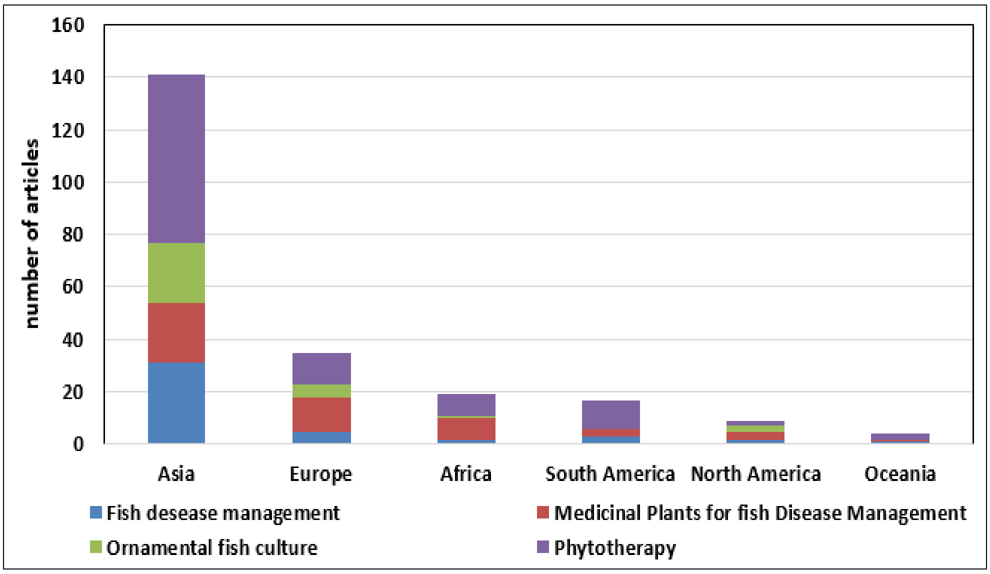

Fig 5: Geographical distribution of published articles, by continent and subjects

Quality and Influence of Research

There is a clear correlation between the total number of articles and citation rates within the same country (Fig. 6), indicating the dissemination of high-quality scientific literature in these nations. This trend contrasts with other areas of rapid growth in aquaculture research, such as artificial intelligence. In fields like AI, countries such as India and South Korea often produce high number of publications with comparatively lower citation rates. Comparatively, phytotherapy in ornamental aquaculture showed by a more stable scientific foundation.

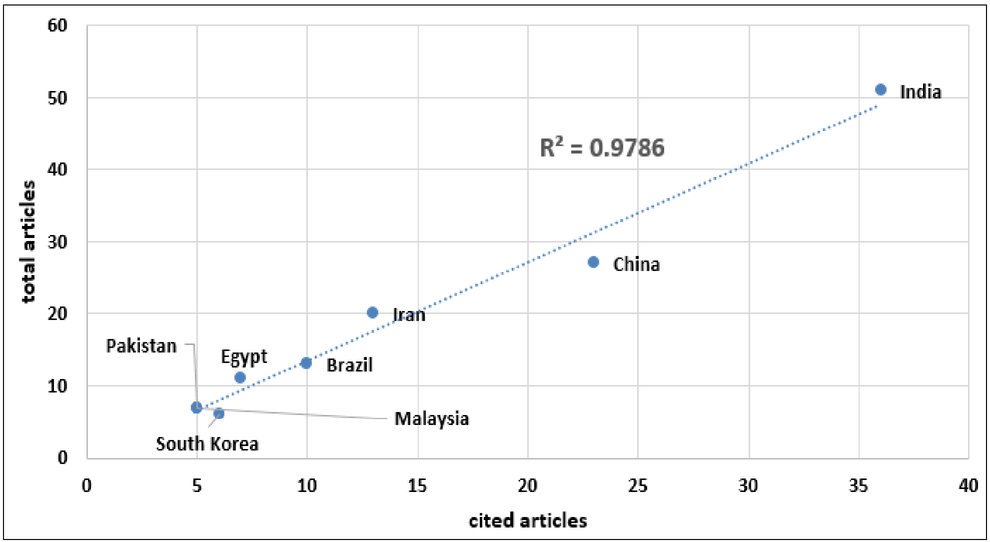

Fig 6: Relation between total number of articles and cited ones (considering the 8 most relevant countries)

Network visualization illustrates the global collaborative landscape in phytotherapy research for ornamental fish aquaculture, highlighting strong international partnerships centered around a few key countries. India, China, and Brazil emerge as major hubs, indicated by the large size of their nodes and the numerous connections linking them with other countries. India serves as a pivotal hub with dense connections to countries such as Egypt, Malaysia, and South Africa, demonstrating its leadership role in phytotherapy research and its extensive collaborative efforts across Asia, the Middle East, and Africa. China and Iran also show substantial involvement, particularly in the Asia-Middle East region, with prominent links to countries like Malaysia and Saudi Arabia. This suggests regional cooperation and shared interests in advancing sustainable fish health practices (Fig.7).

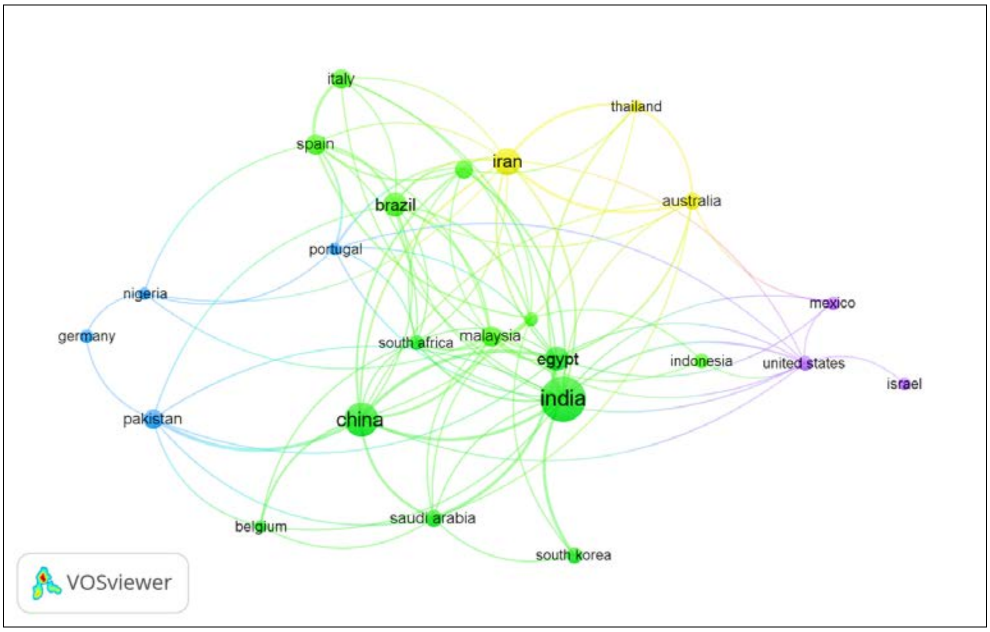

Fig 7: Network Visualization of International Research Collaboration in Phytotherapy for Ornamental Fish Aquaculture

In Europe, Italy and Spain display moderate engagement in phytotherapy research, frequently collaborating with countries such as Brazil and Iran, while Germany and Belgium show more limited connections, possibly reflecting a growing but not yet fully developed interest in this field within Europe. The United States and Australia have fewer ties compared to other regions, which might indicate a less intensive focus on phytotherapy for ornamental aquaculture in these countries or a preference for independent research rather than cross-country collaborations. Overall, this network highlights a strong foundation of research partnerships concentrated among countries in Asia, the Middle East, and Latin America. These partnerships could be crucial for promoting phytotherapy as a sustainable alternative to conventional fish health management on a global scale, enabling knowledge-sharing and innovation across borders.

The keyword co-occurrence network map provides a visual summary of the primary research themes in phytotherapy for aquaculture, highlighting connections between key concepts in this field. At the center of the network, "aquaculture" acts as the focal point, illustrating that the studies predominantly revolve around fish health and phytotherapy applications within this industry. Branching out from this core, we see significant clusters that reflect distinct areas of research emphasis. A prominent cluster consists of "antioxidants," "essential oils," and "biological activity," all of which are associated with "immunity." This category indicates a major emphasis on the ability of plant-based antioxidants, like those in essential oils, to boost fish immunity and fight oxidative stress, which is a problem that is key to preserving fish health in aquaculture settings.

A further important area is represented by the cluster that links "growth," "disease resistance," and "Aeromonas hydrophila." This correlation suggests that phytotherapy is being investigated for its potential to support fish growth and resistance to particular infections in addition to its immune-boosting benefits. The pathogen "Aeromonas hydrophila," which is commonly seen in aquaculture, demonstrates the usefulness of phytotherapy in the treatment of disease. Additionally, the network has a cluster devoted to "fish," "medicinal plants," and "immune response," highlighting the interest in employing chemicals derived from plants to improve immune function in both farmed and ornamental fish species (Fig.8).

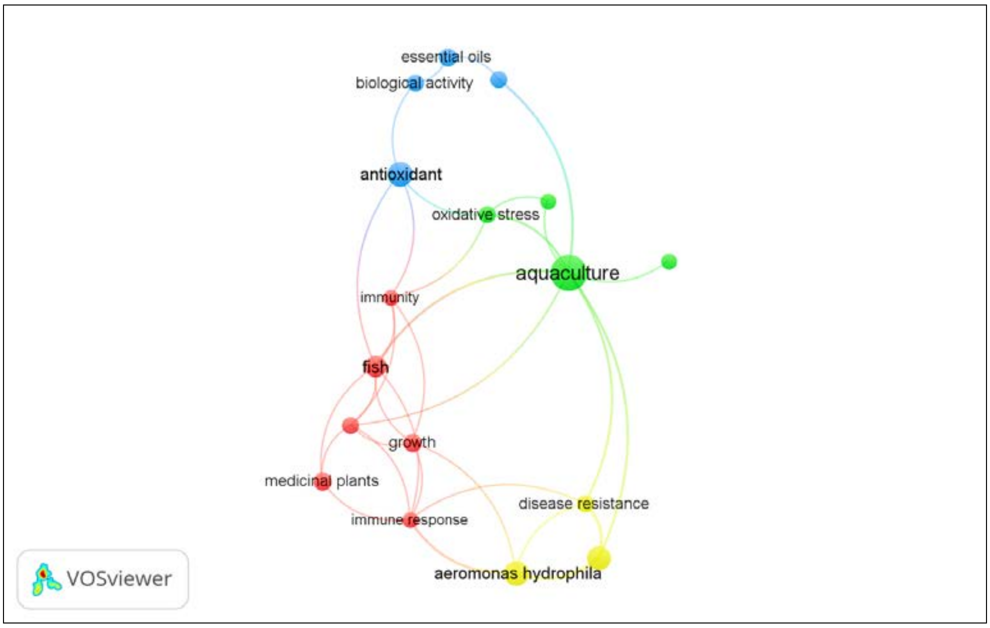

Fig 8: Keyword Co-occurrence Network in Aquaculture Phytotherapy Research

With a focus on natural, plant-based treatments to improve growth, increase immunity, and provide disease resistance, this network demonstrates the diverse function of phytotherapy in aquaculture research. By reducing environmental impact and promoting fish health, these results support the notion that phytotherapy provides a sustainable, environmentally friendly substitute for traditional chemical treatments, which is in line with the larger objectives of sustainable aquaculture.

Efficacy of Phytotherapy for Ornamental fish Antimicrobial Disease Management

With an emphasis on their modes of action and uses in treating different aquatic species, the use of antibiotics and other antimicrobial agents in fish disease management is essential in aquaculture. Despite the potential effectiveness of these medications, it is crucial to weigh the advantages and disadvantages, especially in light of antibiotic resistance and the wider environmental impact [60]. The potential of natural substances and extracts to enhance fish development and health has also been investigated. A 2% chamomile supplement, for instance, dramatically increased growth and biomass in comparison to controls ($p<0.05$) in a study on chamomile extract in zebra fish (Danio rerio), while having no discernible effect on antioxidant enzyme activities. This implies that zebra fish may benefit from chamomile extract in terms of growth and antioxidant health [61]. A natural substance called emodin showed remarkable effectiveness in lowering Cyprinid Herpesvirus (CyHV-3) reproduction in koi carp. Emodin treatment reduced virus-induced damage and increased koi survival. It boosted antioxidant enzyme activity and lowered inflammatory indicators including TNF-α and IL-6 by activating the Nrf2/Keap1-ARE and NF-κB pathways. This demonstrates how emodin may strengthen the immune system and shield koi carp from viral infections [62]. Tannin supplementation at 1.75% was well accepted by grass carp and had no negative effects on growth. However, at 1.25%, tannin improved the utilization of carbohydrates while impairing the digestion of proteins and the deposition of fats. This demonstrates that in order to maximize grass carp nutritional outcomes, tannin levels must be carefully adjusted [63]. The creation of clove oil nanoemulsions for fish anesthetic is one example of further progress. Goldfish were put to sleep in just 4 minutes by nanoemulsions containing 10-20% clove oil and polysorbate 20, which is quicker than with conventional clove oil solutions, although recovery periods were comparable. According to these results, nanoemulsions may offer a quicker and more efficient substitute for fish anesthetic [64]. Compounds made from brown seaweed have also been investigated for their possible medical benefits. The use of brown macroalgae in natural aquaculture medicines is supported by research on these natural chemicals, which show great potential in treating a range of fish ailments [65]. A study on the pathogenicity of Lactococcus garvieae in pompano, which resulted in a cumulative 70% mortality rate in infected fish, demonstrated the importance of pathogen management in aquaculture. This emphasizes how important it is to closely monitor and manage this virus in aquaculture operations [66]. Furthermore, it was discovered that henna (*Lawsonia inermis*) extract improved infection control and immune responses in common carp (*Cyprinus carpio*) infected with Aeromonas hydrophila, indicating its potential as a fish immune booster [67]. Moringa leaf extract (MLE) has been shown to be helpful in promoting the growth and development of lettuce. Although this study was primarily concerned with agriculture, its results also suggest that Moringa may be utilized in aquaculture to promote the growth of other species [68]. Aquaculture may be impacted by the cultivation of non-food species for natural products. Understanding biological elements, such as potential symbiotic connections between species, is essential for success in this type of farming [69]. Research on extracts from medicinal plants has shown promise in managing the common fish parasite Ichthyophthirius multifiliis. According to Yi *et al.* [70], methanol extracts from a variety of plants have demonstrated potential as environmentally friendly treatments for *I. multifiliis* infections in goldfish. Nettle extract was also shown to improve the growth and reproductive health of convict cichlids, indicating that it could be a cost-effective addition to aquaculture to improve results [71]. According to Lü *et al.* [72], the pathogenic strain Aeromonas veronii in goldfish has been found to be resistant to several antibiotics, highlighting the significance of efficient disease management techniques to avoid resistance. The most often used medicinal plants as phytotherapies in the culture of ornamental fish are depicted in Figure 9 and Table 3.

Fig 9: Most common medicinal plants are used as phytotherapy in aquatic health management

The immune-boosting properties of seaweeds like Sargassum cinereum and Ulva lactuca have been demonstrated to improve koi carp survival rates against bacterial infections when added to diets [73]. According to Wang *et al.* [74], zebrafish have also been identified as suitable models for evaluating essential oils, demonstrating their value in determining the safety and bioactivity of these oils, which may be helpful in fish health products.Diseases linked to A. hydrophila have caused problems for Malaysia's ornamental fish sector. Monitoring and controlling these infections in the sector is crucial, according to a study of disease control techniques [75]. High concentrations of Cymbopogon citratus' volatile oil increased the production of reactive oxygen species (ROS) and caused apoptosis in zebrafish embryos, according to research on the antioxidant and toxicity effects of the plant in zebrafish. Lower doses, however, did not show any toxicity [76]. Furthermore, it was discovered that roselle microencapsulated anthocyanins enhanced goldfish growth and pigmentation, providing an alternate, natural pigment source for the aquaculture sector [77]. Last but not least, goldfish treated with curdione derived from Curcuma zedoaria showed encouraging antiparasitic activities against Gyrodactylus kobayashii, resulting in structural damage to the parasites and suggesting its potential as a natural remedy for parasitic illnesses in aquaculture [78]. In summary, although antibiotics are still a vital tool for treating fish illnesses, new research on natural substances, plant extracts, and creative approaches like nano emulsions points to a bright future for environmentally responsible and sustainable disease control in aquaculture. These results highlight the value of both conventional and non-traditional therapies in preserving fish populations.

Table 3: Application of medicinal plants on ornamental fish culture

Plant Name	Fish Species	Reference
Moringa oleifera	Guppy (*Poecilia reticulata*)	[79]
Ulva lactuca & Sargassum cinereum	Koi Carp (*Cyprinus carpio*)	[73]
Lavandula angustifolia	Female Goldfish (*Carassius auratus)*	[80]
Pellitorine (from Piper longum)	Goldfish (*Carassius auratus*)	[81]
Emodin	Koi Carp (*Cyprinus carpio*)	[62]
Azadirachta indica	Goldfish (*Carassius auratus*)	[82]
Terminalia catappa	Angelfish (*Pterophyllum scalare*)	[83]
Cymbopogon citratus	Zebrafish (*Danio rerio*)	[84]
Urtica dioica	Convict Cichlid (*Amatitlania nigrofasciata*)	[71]

Research Gap in the Field of Phytotherapy in Ornamental Fish Culture

The present study revealed that medicinal plants are used in health management for ornamental fish culture at a rate of only 12%, whereas their application as phytotherapy in consumable aquaculture reaches 88%. These findings indicate that the use of medicinal plants in ornamental fish culture is notably limited. When it comes to implementing phytotherapy as a common practice, the ornamental fish industry is lagging behind the food fish industry. More focused studies on dosage, effectiveness, and safety in ornamental fish species are desperately needed.

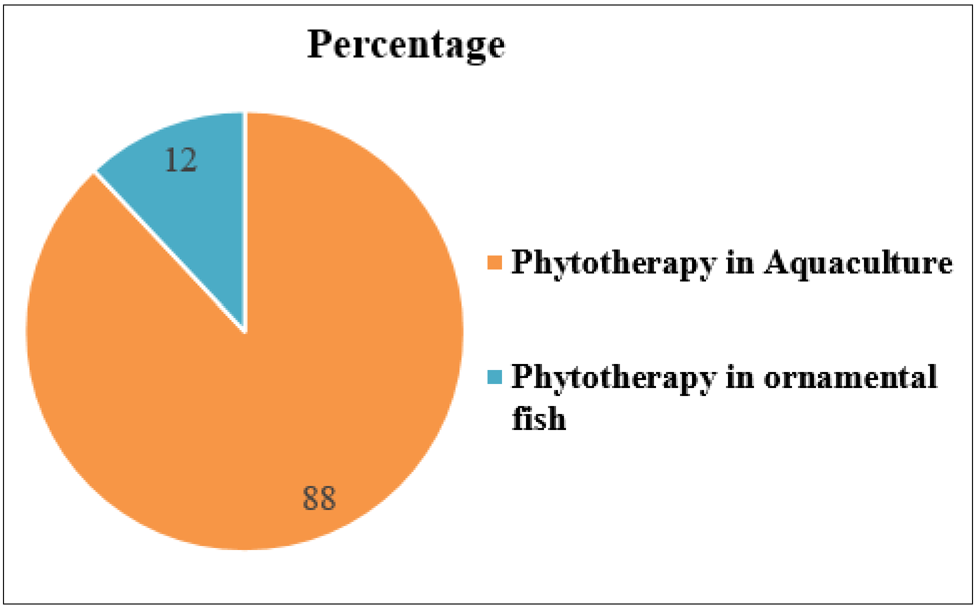

Fig 10: percentage of research work on phytotherapy in ornamental fish culture

Key Challenges and Recommendations for Future Research

Although phytotherapy has a lot of potentials, issues including dosage uniformity, regulatory compliance, and different administration techniques prevent it from being widely used. Strict laws restrict the extensive use of phytotherapeutic treatments, especially in Europe. More research is necessary to develop uniform treatment procedures and safety regulations if phytotherapy is to become a global standard in ornamental aquaculture.

Conclusion

In ornamental fish aquaculture, phytotherapy presents a viable, environmentally responsible substitute for chemical and antibiotic-based therapies. Its application of substances derived from plants has shown effective in improving immunity, controlling illnesses, and fostering the general well-being and development of fish. Common medicinal plants that have little effect on the environment include turmeric, neem, and garlic. These plant-based remedies support the objectives of sustainable aquaculture while addressing important issues like antibiotic resistance.

However, issues including dosage uniformity, species-specific requirements, and legal limitations continue to limit the use of phytotherapy in ornamental fish culture, especially in Europe. Although its use in edible fish has been thoroughly investigated, there is not enough research on ornamental species. Furthermore, the wider application of phytotherapy is hampered by the absence of established protocols for its administration.

More study is required to develop consistent treatment procedures, evaluate long-term effects, and guarantee regulatory compliance before phytotherapy may fully realize its potential in ornamental aquaculture. Filling in these gaps will open the door for phytotherapy to be incorporated into standard procedures, providing a sustainable, eco-friendly, and successful method of managing illnesses. The European ornamental fish business may improve fish health, lessen its negative effects on the environment, and satisfy the increasing demand for robust and colorful ornamental fish by adopting these natural solutions.

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