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Use of medicinal plants in the control of fish parasites and problems related to their use in ethnoveterinary treatment-A review

Endalkachew Daniel

Wolaita Sodo University, Ethiopia, P. O. Box: 138. Daniel E. ORCID ID: https://orcid.org/0000-0002-2862-2368

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ABSTRACT

Recently, botanical extracts from temperate and tropical medicinal plants have been shown to manage terrestrial flora diseases and repel aquatic parasites and pathogens. The complex bioactivities of these compounds include alkaloids, flavoids, saponins, tannins, essential oils, and terpenoids. The antimicrobial functions of these phytochemicals depend on the specific environmental conditions at their secretion sites, with longer-lasting compounds to affect infestation cycles at various stages. Other agents can suppress ongoing infections using alternative methods. Examining the effects of phytosociograms in wet environments could yield new antimicrobial solutions with minimal adverse effects compared with synthetic while expanding our knowledge of the capabilities of traditional healers. Some chemicals can eliminate fish parasites, but they only bring benefits if they wipe out all wild fish populations and give rise to aquaculture. In some countries, parasite infestations and fish diseases limit aquaculture production growth. Utilizing herbs with healing properties for fish diseases and parasites is an eco -friendly, cost-efficient, and sustainable aquaculture strategy. The infection rates of fish can be reduced by treating them with certain plant extracts. These species are generally resistant to water-borne chemical pollutants. Despite their rarity, herbal plants and their products significantly aid in combating fish parasites. This review aims to highlight fish health management in aquaculture by emphasizing the traditional medicinal uses of plants to combat fish parasites.

Keywords: active compounds, alkaloids, ethnoveterinary, medicinal plants, parasites

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Introduction

Fisheries systems should adopt new antibiotics and immunoprotectants to address antibiotic resistance and the accumulation of antibiotics in the environment (Mthi et al., 2023). These compounds raise sustainability and environmental concerns. Pollutants can irreversibly change ecosystems (Yasin et al., 2023). Antibiotic resistance can be promoted using antibiotic residues from fish farms (Boti et al., 2023; Melchiorre et al., 2023). Antibiotic use in freshwater habitats alters host-parasite dynamics and increases disease incidence (Salma et al., 2022). Effective management of aqua-chemicals, including those possessing antibiotic properties, in aquaculture significantly decreases environmental and health risks to humans (Hadzevych et al., 2022). In ethnoveterinary practice, fish are treated with herbal remedies from medicinal plants. This method acknowledges and preserves local practices and traditional knowledge. Conventional fish cost-effectiveness infection treatments have driven their increasing adoption (Mariappan et al., 2023). This product boasts low cost, eco-friendliness, and strong consumer protection (Dasgupta, 2023). This method meets human consumption regulations because it does not contain detectable residues (Sophia et al., 2023). Communities' conservation and empowerment depend on preserving and expanding herbal treatments for fish (Radha, 2022). Mbokane and Moyo (2024) noted that although synthetic medications' high costs and inefficiency are notable concerns, the potential development of antibiotic resistance and environmental contamination pose even greater risks. These compounds inhibit bacterial and fungal growth (Hudecová et al., 2023). Aquaculture systems should seek alternative antibiotics and immunoprotectants to address antibiotic resistance and the environmental buildup of antibiotics (Mthi et al., 2023).

*Corresponding Author: Endalkachew Daniel
E mail: endalkachew.daniel@wsu.edu.et

Medicinal plants have been used in aquaculture since ancient times, with contemporary Western medicines based on their chemicals used to control fish parasites (Mariappan et al., 2023; Ranasinghe et al., 2023; Ezenyi et al., 2023). These compounds, including tannins, alkaloids, terpenoids, and flavonoids, act as antimicrobial agents, growth promoters, immune system enhancers, and stress relievers for fish, making them suitable alternatives to antibiotics and vaccines (Varshney et al., 2022). These medicinal plants exhibit promoting, antimicrobial, stress-preventive, appetite-stimulating, and immune-boosting properties, among others (Ranasinghe et al., 2023). Researchers have reported the potential of developing new antibiotics to combat antibiotic resistance and infectious diseases (Praseetha et al., 2023). Through research on medicinal plants, numerous anthelminic plants effective against gastrointestinal nematodes have been discovered (Ranasinghe et al., 2023). According to several studies, plant extracts from Piper betle, Leucas lavandulaefolia, and Moringa oleifera may be effective in treating parasitic conditions caused by fish parasites (Dezfuli and Scholz, 2022). Understanding the biology, ecology, and host interactions of fish parasites is essential for managing the health of aquatic organisms because the importance of ecological functions, intensification of aquaculture, climate change impacts, and growing commercial activities necessitate active attention (Jordan and Kreuels, 2022; Wright et al., 2023). This review aims to highlight fish health management in aquaculture by emphasizing the traditional medicinal uses of plants to combat fish parasites.

Common fish parasites

Fish parasites can be categorized as either external or internal based on location. These parasitic agents, Diphyllobothrium spp., Opisthorchis spp., and Anisakis spp. (Hutson et al., 2019), are the primary representatives of their kind. Examples of external fish parasites inhabiting the skin, gills, and fins include argulus, salminicolids, piscicolid, gyrodactylid, and dactylogyrids (Alhayali et al., 2023). These parasites are classified as fish lice, copepods, fish leeches, and monogeneans. Parasitic worms like nematodes, trematodes, cestodes, and acanthocephalans, inhabit various systems within fish, including their tissues, body cavities, digestive systems, and internal organs (Chong et al., 2023). According to Dykman (2023), such interactions can significantly impact species interactions, community structures, and ecosystem functioning. Their complex life cycles make them resilient against diverse environmental shocks. Several types of parasites, including digenean, cestodes, nematodes, isopods, fish lice, acanthocephalans, and monogenes, such as Dactylogyrus, Ergasilus, and Gyrodactylus, inhabit various fish species. Parasites can harm fish's gills, skin, and eyes, causing respiratory issues, impaired epithelial function, anemia, and elevated mucus production (Gardner et al., 2023).

Common ectoparasites in fish

Copepods: as minute crustaceans that infest fish, engendering diverse impacts. Al-Niaeem et al. (2015) identified six copepod species in Basrah Province: Ergasilus rostralis, E. mossulensis, E. ogawai, Ergasilus sp, Lernaea cyprinacea, and Mugilicola kabatai. Nagasawa (2015) also reported different copepod species, including Caligus fugu, C. lagocephalus, C. lalandei, C. latigenitalis, C. longipedis, C. macarovi, C. orientalis, C. sclerotinosus, C. spinosus, Lepeophtheirus longiventralis, L. paralichthydis, L. salmonis, Alella macrotrachelus, Clavella parva, Parabrachiella hugu, P. seriolae, Peniculus minuticaudae, Acanthochondria priacanthi, and Biacanthus pleuronichthydis, from marine fish in Japan. Among them, five species (C. orientalis, L. longiventralis, L. salmonis, C. parva, and A. priacanthi) are known to parasitize farmed fish in subarctic waters, whereas the remaining species infect farmed fish in temperate waters. At this point, there is a lack of information about copepods from fish raised in subtropical waters. According to Nagasawa (2015), the host fish comprise carangids, sparids, monacanthid, salmonids, scombrids, tetraodontid, pleuronectids, paralichthydis, and trichodontids. The parasitic copepod Helcogrammoides chilensis cohabits with Chilean triplefin fish without adversely affecting their size or health (Palacios-Fuentes et al., 2012). In Pengudang Village's aquatic ecosystems, seven copepod species, namely Callanus spp., Lucicutia spp., Macrosetella spp., Nauplius spp., Oithona spp., Rhincalanus spp., and Scolecithricella spp., were detected. Copepods supply energy to small fish during their larval stage (Sethi et al., 2013). 72 various fish species in Turkey, including wild and farmed carangids, sparids, and salmonids, were identified as hosts to parasitic copepods (Alaş et al., 2015). A total of 25 copepod parasite species have been identified in the gills of 14 different teleost fish species in Algeria (Boualleg et al., 2011). In the Mediterranean Sea, copepods belonging to the Corycaeidae, Calanoidae, Oithonidae, and Oncaeidae families have been found infected with Blastodinium spp., namely B. mangini, B. contortum, and B. spinulosum (Alves-de-Souza et al., 2011). A total of 34 copepod species were reported by Melaku et al. (2022) from South African freshwater habitats. Copepod species data for Ethiopia's freshwater fish populations are missing. Ethiopian research has primarily focused on breeding valuable fish species. Microalgae, rotifers, copepods, and cladocerans serve as live food for fish larvae (Cumberlidge and Clark, 2012). Researchers have also investigated Ethiopia's freshwater crab population. Mnisi and Dippenaar (2019) and Cumberlidge and Meyer (2010) reported discoveries of the new species Potamonautes kundudo and Potamonautes holthuisi in distinct regions of Indonesia. These discoveries underscore the necessity for further research on copepod species interacting with freshwater fish.

Argulus (Fish lice): Fish lice are crustacean ectoparasites also known as Argulus spp. A. japonicus, A. foliaceus, and A. coregoni are worldwide distributed and harm many fish species (Budijono et al. 2022; Burdukovskaya and Dugarov, 2023). Fish lice (Argulus spp.) attack various fish species, including goldfish (Carassius auratus) (Shukla et al., 2022; Radkhah and Eagderi, 2022), koi carp (Cyprinus carpio) (Budijono et al., 2022), Common carp (Cyprinus carpio L.) (Gallardo-Escárate el al., 2019), and carp (C. carpio) (Nurani et al., 2020; Hunt et al., 2021). Aalberg et al. (2016) and Chang et al. (2023) reported the A. foliaceus in Pike-perch (Sander lucioperca L.), Brook trout (Salvelinus fontinalis M.), and Sea-run Arctic charr (Salvelinus alpinus). Researchers observed coinfection of Pike-perch with A. foliaceus and A. japonicus (Wafer et al., 2015). Argulus spp. were collected from the goldfish's (C. auratus) caudal and anal fins (Koyun, 2011). This crustacean ectoparasites cause significant financial losses in fish farms through their attachment to hosts, feeding, and mass mortality (Misganaw and Getu, 2016; Johnson et al., 2019; Sikkel and Welicky, 2019). Sea lice, including Lepeophtheirus salmonis, Caligus clemensi, and C. rogercresseyi, significantly affect wild and farmed finfish by infecting wild salmon and serving as vessels for fish-infecting viruses (Rochat et al., 2023).

Fish leech: Research on fish leech has been conducted in Australia, New Zealand, and Lake Saint. Clair is from Michigan and Japan, not New South Wales. 14 fish-leeches species unique to Australia and New Zealand have been identified by scientists (Burreson, 2019). The researchers proposed and identified the three leech species, including Actinobdella pediculata, Placobdella montifera, and Myzobdella lugubris, in Lake St. Clair (Schulz et al., 2011). Aloto and Eticha (2018) detected seven leech species, including Crangonobdella maculosa, Johanssonia arctica, Limnotrachelobdella okae, Platybdella olriki, Stibarobdella bimaculata, Taimenobdella amurensis, and Trachelobdella livanovi, in fish in Japan. In various regions, fish leeches pose a threat to many fish species. Researchers identified fish leeches from the species Acipenserobdella volgensis on fish belonging to the families Acipenseridae, Cyprinidae, Salmonidae, and Esocidae (Bolotov et al., 2022). In total, 1.63% of graylings and trouts were found to host Piscicola pojmanskae (Cichocka et al., 2018). In the Southern Ocean, crocodile icefish like Chaenocephalus aceratus, Champsocephalus nunnari, and Chionodraco rastrospinosus (Parker et al., 2020), host trypanosomes spread by leeches, as do South American armored catfish. According to Lemos et al. (2015), these parasites are abundant. In various water environments, several fish species are prone to leech infestations, as indicated by these findings (Pomposini et al., 2019; Parker et al., 2020).

Monogeneans (Platyhelminthes): Fish monogeneans impact various fish species, including common carp (C. carpio), soldier bream (Argyrops filamentosus), common bream, and roach (Dedić et al., 2023; Alghamdi et al., 2023; Vorel et al., 2023). This group includes dactylogyrid/diplectanid, gyrodactylid, capsalid, and polyopisthocotylea parasites. In substantial quantities, these parasites can cause significant fish diseases. Parasites predominantly inhabit external areas of fish, such as the gills, skin, nostrils, mouth, esophagus, cloaca, and urinary tract. Monopisthocotyleans irritate the skin and gills, wheras polyopisthocotylea cause severe blood loss and anemia. Monogenean infections exhibit varying intensities among various fish species and their hybrids. Host-parasite co-evolution determines the number of monogenean species infecting a fish (Mendlová and Šimková, 2014). Fish monogeneans affect many fish types, such as the common carp (C. carpio) (Vorel et al., 2023), soldier bream (Argyrops filamentosus) (Alghamdi et al., 2023), common bream, and roach (Dedić et al., 2023). The monogenean parasite Sparicotyle chrysophrii causes extensive health issues and financial damage in Mediterranean fish farms by attaching to gills and multiplying within sea cages (Mladineo et al., 2024; Riera-Ferrer et al., 2022). Vorel et al. (2023) reported the presence of Eudiplozoon nipponicum in common carp gills and Abdel-Gaber et al. (2023) discovered Haliotrema susanae in soldier bream fish gills. Nitta and Nagasawa (2023) identified Dactylogyrus and Bivaginogyrus species in the gills of freshwater fish from Japan. Dedić et al. (2023) conducted a study focusing on the gills to determine monogenean infection levels between parent fish species and their hybrids. Monogeneans usually infect fish in their gills and skin, but cases of infection in other areas like nostrils, mouth cavities, food pipes, waste openings, and urinary tracts are uncommon (Chong, 2022; Newton and Ritchie, 2022). In fish harboring multiple parasites, monogeneans favor select hosts, inflicting severe diseases (Félix et al., 2022). The combined presence of multiple monogenean species in a host enhances studies reporting higher infection rates and parasite prevalence (Louizi et al., 2023; Ieshko et al., 2024). Fish monogeneans have a broad host range; therefore, comprehending and managing, these parasitic infections in aquatic environments is crucial (Bakke et al., 2002; Rohde, 2002; Shinn et al., 2023).

Common endoparasites in fish

Digeneans (Tr ematod es):Digeneans are worms that parasitically infect fish (Pantoja et al., 2022; Yanagi et al., 2022; Allam et al., 2023). Different species of digenean trematodes inhabit various fish species (Romanova et al., 2023; Prasadan et al., 2023). These parasites exhibit intricate life cycles, with mollusks serving as middle hosts and vertebrates serving as end hosts, and include stages such as eggs, miracidia, sporocysts, rediae, cercariae, metacercariae, and adults (Krupenko et al., 2022). Research in Saudi Arabia, Russia, and Brazil has demonstrated the significance of understanding a parasite's genetic structure and distribution. Locating new host species and mapping digenean trematode habitats are essential for controlling and preventing infection in fish populations. The significance of ongoing research is emphasized because these families (Diplostomoidea, Clinostomidae, and Heterophyidae) causing diseases in fish (Pantoja et al., 2022). Certain digenean can infect humans, making them dangerous zoonotic agents. These fish-dwelling trematodes include Tylodelphys clavata, Diplostomum spathaceum, and Paracoenogonimus ovatus. Fish can contract postodiplostomosis or ichthyocotylurosis from trematode infections. In South Georgia, 111 fish from eight species contained harmful digenean trematodes such as Pseudoamphistomum truncatum, Apophallus muehlingi, and Rossicotrema donicum (Romanova et al., 2023). All Notothenia rossii fish were infected by Elytrophalloides oatesi (Zdzitowiecki and White, 1992). 19 fish species in the Taega River were found to host various digenetic larval trematodes, such as Clonorchis sinensis, Cyathocotyle orientalis, and Metagonimus species (Joo et al., 2001). In the intestines of Clarias gariepinus, Orientocreadium batrachoides, Masenia bangweulensis, and digenetic trematodes were found, while Cyanodiplostomum spp. was present in the skin and muscles (Attia et al., 2021). In 2021, research revealed that fish infected can experience inflammation and tissue displacement (Bullard and Overstreet, 2008). Researchers have identified coccidian in 60 families of marine fish, including Eimeria and Goussia species (Saraiva et al., 2023). In the eastern Gulf of Mexico, a new digenean species, Achorovermis testisinuosus, was found living in the heart of the smalltooth sawfish Pristis pectinata (Warren et al., 2020).

Cestod es:Many fish species host cestodes, which are parasitic worms. According to Svensson et al. (2022), three-spined sticklebacks (Gasterosteus aculeatus) infected with the cestode Schistocephalus solidus express reduced antipredator behaviours. Diniz et al. (2021) reported the influence of Grillotia carvajalregorum and Contracaecum helminth larvae on Percophis brasiliensis's serosa, stomach, intestine, liver, and gonads. Polyakova and Gordeev (2020) examined the cestode species Bothriocephalus antarcticus, Parabothriocephalus johnstoni, and Onchobothrium antarcticum in Antarctic and Subantarctic fish. Zuchinalli et al. (2016) identified commercial fish species, such as Oligoplites saurus and, Pterobothrium crassicollis in Brazil. Marine fish species, such as Seriola dumerili, Pseudocarans dentex, Epinephelus haifensis, and Mycteroperca rubra, were found to be infected Callitetrarhynchus gracilis, Callitetrarhynchus speciosus, Protogrillotia zerbiae, and Grillotia brayi (Morsy et al., 2022). Cestodes of Trypanorhyncha order infected various fish species. Parasites negatively impacted marine fish, that leading to customer rejection (Palm et al., 2009; Morsy et al., 2022). The following infected fish species have been identified: gray triggerfish (Balistes carolinensis), mottled grouper (Mycteroperca rubra), common sole (Solea vulgaris), greater amberjack (Seriola dumerili), gulley jack (Pseudocaranx dentex), Haifa grouper (Epinephelus haifensis), and various marine teleosts and elasmobranchs (Morsy et al., 2023; Morsy et al., 2022; Ziarati et al., 2022). Joo et al. (2001) and Saraiva et al. (2023) identified Gymnorhynchus isuri, Pseudotobothrium dipsacum, Heteronybelinia estigmena, Callitetrarhynchus gracilis, Callitetrarhynchus speciosus, Protogrillotia zerbiae, and Grillotia brayi as cestodes found in various fish species. Monitoring and controlling these parasites are crucial for maintaining fish safety and minimizing the possibility of zoonotic diseases transmitted to humans.

Nematodes: Nematodes can negatively impact fish populations, leading to health issues, financial losses, and reducing marketability (Indrayati, 2017). Researchers identified Anisakis simplex, Hysterothylacium aduncum, Hysterothylacium reliquens, Hysterothylacium fabri, and Dichelyne pleuronectidis from various teleost fish, such as snowy grouper (Hyporthodus niveatus), Brazilian flathead (Percophis brasiliensis), European pilchard (Sardina pilchardus), chub mackerel (Scomber japonicas), anchovy (Engraulis encrasicolus), bogue (Boops boops), spinycheek grouper (Epinephelus diacanthus), and orange-spotted grouper (Epinephelus coioides)

(Ramdani et al., 2022; Pereira and González-Solís, 2022; Martin-Carrillo et al., 2022; Wuwei et al., 2023). Nematodes have been discovered in various fish body parts, including the intestine, body cavity, mesenteries, stomach, liver, spleen, gonads, and kidneys (Hussein et al., 2020). Some nematodes like A. simplex and Hysterothylacium spp. affect human health (Saglam, 2013). Studies have shown that nematodes impact fish economics. They can make fish sick, cause economic looses, and change how people view fish as food (Indrayati, 2017). Third-instar larvae of Contracaecum, Terranova, Hysterothylacium deardorffoverstreetorum, and Raphidascaris infect Hyporthodus niveatus (Menezes et al., 2023). According to Diniz et al. (2021), Grillotia carvajalregorum larvae and various nematodes were found in the organs of Percophis brasiliensis. Nematodes from Hysterothylacium and Anisakis infected European pilchards (Fuentes et al., 2022). Scientists identified Anisakis typica and Anisakis pegreffii in chub mackerel, anchovy, and bogue (Aldik et al., 2023). Hysterothylacium spp. nematodes infect Epinephelus diacanthus and Epinephelus coioides (Bannai and Jori, 2022).

Acanthocephalans: Studies identified 13 types of acanthocephalans as fish parasites across diverse oceanic habitats (Polyakova and Gordeev, 2021). In New Zealand, the researchers reported Gorgorhynchoides queenslandensis for the first time, together with at least two new species identified by Bennett et al. (2023). Sclerocollum rubrilabris inhabits the intestines of S. rivulatus. Acanthocephalans help fish cope with toxic metals. A study by Hassanine and Al -Hasawi (2021) revealed that lowering of Cadmium (Cd) and Lead (Pb) levels in fish livers and reductions in liver enzymes, glucose, triglycerides, and urea in fish blood occur. Researchers identified five types of acanthocephalans, including Acanthocephalus johni and Breizacanthus azhari (Hernández-Orts 2019), from Argentina's Patagonian continental shelf and seven species, including Neoechinorhynchus agilis and Longicollum pagrosomi (Panchani, 2021), in the Bizerte lagoon, Tunisia. These parasites infect various fish species, such as Sutorectus tentaculatus, Xenocypris davidi, Acreichthys sp., Clarias batrachus, Hylarana sp., Leiognathus equulus, Anabas testudineus, Heteropneustes fossilis, and Mystus gulio (Smales et al., 2019). These parasites display unique proboscis structures, hook patterns, and host preferences (Perrot -Minnot et al., 2023). The prevalence and modes of infection with acanthocephalans vary among fish species. Some species are more susceptible to specific acanthocephalan species. Fish can acquire acanthocephalans via paratenic transfer or post-cyclic transmission (Dimitrova et al. 2008). The chromosome structures of Pomphorhynchus kashmirensis and Neoechinorhynchus manassasensis from Schizothorax and Cyprinus species were determined (Ahmad et al., 2015). These parasites, known to kill fish, alter blood parameters, and disrupt fish populations (Dezfuli and Scholz, 2022; Öktener and Bănăduc, 2023), are capable of causing mass fish mortalities (Öktener and Bănăduc, 2023). Degradation of water quality, human activities, and environmental isolation can influence parasite population, diversity, and density. Monitoring and safeguarding freshwater ecosystems require a thorough understanding of the interactions of fish parasites with their hosts. In nature, fish and their parasites maintain an equilibrium. Pollution and new fish parasites can adversely affect fish populations and alter fish communities (Pravdová et al., 2023). Parasites significantly impact species interactions, community structures, and ecosystem functions through their reliance on host organisms (Thieltges et al., 2024). Similarly, alterations in host species and quantities can impact the durability of parasites (Dykman, 2023). The examination of fish parasites provides insights into the status of freshwater ecosystem health and pollution levels (Öktener and Bănăduc 2023). Understanding the types and behaviors of fish parasites in their habitats is essential for effectively monitoring environmental changes and managing freshwater ecosystems (Srivastava et al., 2022; Giari et al., 2022).

Medicinal plants and their properties

Parasitic diseases can be effectively treated using medicinal plants. These plants possess antibacterial, antifungal, anticancer, and anti-inflammatory properties (Ahmad and Karmakar, 2023), however, they face challenges in conservation due to habitat loss, uncontrolled wild harvesting, and commercial over-extraction (Sharma et al., 2023). We must intentionally domesticate and cultivate identified plant species (Kumar and Singh, 2023) to maintain a consistent supply (Kumar and Singh, 2023). Experts predict that the global herbal medicine market, driven by medicinal plants, will reach $550 billion by 2030. The global popularity of Ayurvedic medicine, which employs natural herbal products, because of its effectiveness and minimal adverse effects (Obahiagbon and Ogwu, 2023). For thousands of years, plants have been used as a significant medicinal resource (Begum et al., 2023).

Medicinal plants have both medicinal and economic value because they are in high demand in local and international markets (Olsen, 2005; Sher et al., 2014). This knowledge has led people to discover new things and make informed health decisions. Native Americans have an intricate understanding of medicinal plants and their therapeutic properties. According to Sivaramakrishna et al. (2023), these groups documented the traditional use of these plants. This involves creating medication from various plant parts and addressing various health concerns. Traditional ecological knowledge of edible and medicinal plants influenced indigenous livelihoods. Economic opportunities have been created, and food security has been secured (Mohd Salim et al., 2023). Myths, taboos, and traditional leadership contribute to the conservation of genetic resources (Anand et al., 2023). Indigenous plant-based medical practices vary in their usage, depending on the specific plant and ailment (Kola, 2022).

Active compounds in medicinal plants

Chemical compounds found in medicinal plants affect fish health management (Singh et al., 2022; Garcia-Oliveira et al., 2022; Mariappan et al., 2023). These substances, including phenols, terpenoids, alkaloids, and flavonoids, help fish grow, handle stress, and fight diseases (Faheem et al., 2022). Zhang et al. (2023) and Ahmad et al. (2023) noted that saponins and flavonoids fight inflammation and bacteria; phenolic substances can treat inflammatory conditions (Ramdani et al., 2023). These secondary metabolites in plant extracts noted their use as alternative anthelmintic drugs to treat parasitic diseases in fish without harming the host (Mariappan et al., 2023).

Research is needed to identify appropriate doses of these drugs to reduce parasites and ensure the safety of fish (Bashir et al., 2022). In addition, active ingredients in medicinal plants boost the immune system, enhance immune responses, and improve overall fish health (Pulkkinen et al., 2010). Fish farmers can use medicinal plants and their byproducts as a cheaper and safer option instead of using artificial chemicals, vaccines, and antibiotics. Antioxidants in medicinal plants protect fish against oxidative stress and physical problems. Experts recognize these plant-based substances as safe for fish, humans, and the environment (Singh et al., 2022; Mariappan et al., 2023; Mbokane and Moyo, 2024), and offer a good way to improve fish health and control diseases in fish farming.

Alkaloids: Alkaloids comprise a huge group of organic nitrogen compounds found in nature; scientists have spotted over 20,000 different types. They are weak bases with a positive charge on the nitrogen atom and are found in plants as organic acid salts. These compounds have toxic effects on cells and kill insects, fungi, and bacteria. Their ability to fight parasites in fish health management is well-known (Winzer et al., 2015; Srivasatava, 2022; Alfianna and Situmorang, 2023; Faisal et al., 2023). Plants often contain alkaloids (Tiwari et al., 2023; Ravichandran et al., 2023). Three alkaloids tested for their worm-fighting power against Haemonchus contortus caused 100% paralysis (Espino Ureña et al., 2023). People use alkaloids to treat fish diseases because they relax fish muscles and act like anesthetics. Alfianna and Situmorang (2023) reported that these compounds have narcotic-like effects on parasites and influence the central nervous system, and enhance the fish's immune system. Alkaloids also display interesting biological traits, like anti-inflammatory and anti-cancer effects, and show potential as treatments (Varela et al., 2023).

The specific drug pathways through which alkaloids are used to treat cancer cells have been identified. These routes involve controlling key signaling pathways involved in cell growth, cell cycle, and cancer spread (Mariappan et al., 2023). Alkaloids might be a treatment option for fish diseases because of their possible effects on the immune system, parasites, and central nervous system. Some alkaloids are toxic to fish parasites (Ukwa et al., 2023). The neem tree (Azadirachta indica) contains alkaloids with anti-insect and antiparasitic properties. This explains why people use the neem tree to manage fish in some areas (Rani et al., 2023).

Saponins: The plant families that contain saponins include Leguminosae and Ginseng. They affect the parasites gyrodactylids and monogeneans. Because saponins interfere with the cell membranes of parasites, they aid fish in eliminating them from their bodies, gills, and fins. Fish illness risk is decreases when germs are eliminated (Abdelrahman and Jogaiah, 2020; Nguyen et al., 2020). It has been demonstrated that terpenoids taken from the leaves of Virola surinamensis are effective against Loma salmonae, a parasite that causes kidney illness in salmon and associated species (Štrbac et al., 2022). These findings highlight the importance of investigating the effects of medicinal herbs on fish diseases and parasites. While protecting the environment, the study aims to reduce the number of chemicals used to cure fish.

Saponins are present in various plant parts, including seeds, roots, stems, bark, grains, leaves, and flowers, and have a wide range of biological activities such as immunomodulatory activity, anti-inflammatory activity, and hypoglycemic properties (Mehta et al., 2023; Shen et al., 2023). It is worth noting that Solanum torvum and other plants possess a high amount of the substance saponin, which makes them to have therapeutic value (Ren et al., 2024). According to Shen et al. (2023), plant saponins are involved in activating the growth and development of immune organs in the body, stimulating the activity of immune cells and the production of cytokines and antigen-specific antibodies, and thus bear an effect of regulating immune response. Gadallah et al. (2024) stated that saponins have been effective in the control of protozoan parasites in aquaculture, including Ichthyophthirius multifiliis and Cryptocaryon irritans. Over the years, saponin extracts in different constituents have addressed numerous fish parasites with P. granatum extract achieving total loss of Neobenedenia girellae at a concentration of 62.5 mg/L (Liu et al., 2021), while Moringa oleifera and Piper betle extracts have offered remediation for Lernaea sp., Argulus sp. and Ergasilus sp. infections (Mariappan et al., 2023). Saponins could be a more eco-friendly option when compared to artificial chemicals employed in aquaculture practices, but negative effects such as cell toxicity and bitterness associated with saponins might limit their application in fish farming (Timilsena et al., 2023).

Flavonols: These bioactive compounds have health benefits, including reduced inflammation, cancer, fungus, infections, and high blood pressure (Nagar et al., 2022; Prasad et al., 2023). It also exhibits antioxidant and germicidal qualities that improve fish health and have a major impact on natural foods, pharmaceuticals, and cosmetics (Barreca et al., 2023). The heterocyclic ring configurations of flavonoids, such as anthocyanins, isoflavone, flavonols, flavanols, flavones, and flavanones, differ from each other (Mancarz et al., 2023). These plant-derived substances support pigmentation, signaling, defense, growth, and UV protection in living world (Rodriguez et al., 2022).

Flavonoids, plant compounds produced through a complex process that can be influenced by flavonoid gene alterations, play protective and preventive roles against numerous diseases. According to Prasad et al. (2023), these compounds affect the NF-κB signaling pathway. Scientists have explored potential health benefits. Flavonoids have been linked to antioxidant, anti-inflammatory, anticancer, and neuroprotective effects according to numerous studies (Crupi et al., 2023; Hussain et al., 2022; Rodriguez et al., 2021). Singh et al. (2023) reported that, these substances lower the risk of long-term health problems, such as type II diabetes, heart disease, and certain cancers. These compounds have antibacterial properties and can aid in the treatment of infectious diseases (Singh et al., 2022). The researchers found that the intervention enhanced both blood fat levels and heart health (Calderaro et al., 2022). Flavonoids act as natural food additives, conferring health benefits (Li et al., 2023).

It has been established in previous studies that flavonoids exert several beneficial effects on fish, especially in zebrafish (Danio rerio) and rainbow trout (Oncorhynchus mykiss). Flavonoids present in the zebrafish studies may also act as a co-agent in the prevention and control of the obesity condition, and in doing so tackle metabolic complications resulting from the deposition of excessive fat. Obesity-related complications are dealt with through pathways that deal with inflammation and lipid metabolism, processes which are key (Montalbano et al., 2021). According to Daya et al. (2021), flavonoids of Leea Indica inhibited orofacial pain in fish to levels similar to those caused by standard pain relief drugs while increasing the mobility of fish that were treated with the flavonoids. It is additionally related to neuroprotection, as well as the regulating effects of neuroinflammation and oxidative stress, both of which are significant in neurodegeneration (Mhalhel et al., 2023).

Flavonoids have a number of benefits concerning their use in aquaculture, but their use has its limitations as well. Phagocytosis, immune response, and antioxidant capacity in fish can be improved with the application of flavonoids, nonetheless, their effectiveness might be affected with different species as well as environmental conditions (Wang et al., 2007; Ponomarev et al., 2020; Shohreh et al., 2023; Affandi and Diniariwisan, 2024). It has been shown that some flavonoids can have positive impacts on growth rates, as for instance, the supplementation of dihydroquercetin to tilapia resulted in a 26% productivity gains (Ponomarev et al., 2020). Evidence exists however suggesting that such compounds may not have such effect on physiologically different fish species (Taştan and Salem, 2021).

Medicinal Plants to Control Fish Parasites

Many of the herbs act as prophylactic agents against different fish parasites. Phytomaterials have been demonstrated to have antiparasitic activity against more than 15 invasive plant species, including Alpinia, Allium sativum, Calotropis procera, Coriander sativum, Datura stramonium, Gymnema sylvestre, Houttuynia, Momordica charantia, Ricinus communis, Solanum xanthocarpum, Aframomum melegueta, Moringa oleifera, Azadirachta indica, Zingiber officinale, and Vitex, among other infected plants. These plants have been poorly researched (Ranasinghe et al., 2023; Kuzminac et al., 2023; Ukwa et al., 2023). They have undertaken in vitro and in vivo experiments against any known or probable parasitic disease related to or instigated by these plants, and the results have been supportive. In addition to having an anti-parasitic effect on Echinococcus granulosus, which causes hydatid disease of echinococcosis disease (Özil, 2023), Allium sativum also fortifies the immune system against the invasive parasite. Studies of garlic (Allium sativum) have been tested and demonstrated antiparasitic properties. Studies were conducted to determine the effects of trophosts, which are is the vegetative stage of Ichthyophthirius multifiliis, a ciliated protozoan parasite of freshwater fish (Liang et al., 2015; Muahiddah and Diamahesa, 2023).

Reports also indicate that garlic may be more potent against parasites, particularly nematodes, such as Ascaridia sp. found in goldfish (Carassius auratus), and the significant aquarium pathogen Gyrodactylus turnbulli, which invades the guppy (Poecilia reticulata) (Schelkle et al., 2013; Galisteo et al., 2022). The compounds present in garlic, such as ajoene, alliin, and allicin, exhibit bactericidal, virucidal, and parasiticidal activity, as well as antioxidant properties (Valenzuela-Gutiérrez et al., 2021). Studies examined onion (Allium cepa) and its extracts could eliminate various fish parasites. It was found to expel nematode infections (Kouamé et al., 2021; Filgueiras et al., 2023). Research indicated that A. cepa extracts, both crude and ethanol extracts, keep in check Saporlegnia parasitica and Ichthyophthirius multifiliis (Özil, 2023; Elgendy et al., 2023).

Yildiz et al. (2019) found that when adult copepods (Lernantropus kroyeri) were exposed to 100% garlic juice in a cage-cultured European sea bass (Dicentrarchus labrax), every copepod was lethally affected within 5 minutes. It is also known that organosulfur compounds in garlic oil, such as diallyl disulfide and diallyl trisulfide, have strong actions against nematodes, because of their nematicidal properties (Yildiz et al., 2019). Delgado et al. (2023) also showed that garlic enrichment in fish feed contributes to better immunological responses, such as enzyme activity and antibody synthesis, in considerable amounts of mass-reared fish of various species. However, this promising result of using garlic as an anti-parasitic drug should be further investigated in terms of its effect on reducing the number fish parasites, which is certainly an undesired infection (Abdel-Hafez et al., 2014). However, this promising result of using garlic as an anti-parasitic drug should be further investigated in terms of its effect on reducing fish parasites, which surely is an undesired infection (Abdel-Hafez et al., 2014).

Elgendy et al. (2023) reported the nutritional effects of A. cepa-supplemented diets on growth performance and immunity against S. parasitica infection by lowering oxidative stress and fish mortality due to S. parasitica infection and cadmium immunotoxicity in Oreochromis niloticus. Furthermore, A. cepa can help minimize the body burden of cadmium and boost IL-1β and IFNγ expression (Elgendy et al., 2023). Dietary supplementation with A. cepa also has immune-stimulatory effects, and the researchers recommend it as a prophylactic treatment aiming at the management of saprolegniasis and enhancing cadmium's adverse effects (Ahir et al., 2023). Similarly, other studies on the antiparasitic action of A. cepa essential oil were conducted, and its antiparasitic action was studied in greater detail. This essential oil showed 94% efficacy against Ichthyophthirius multifiliis triphones with an exposure time of about sixty minutes at an optimal concentration (Özil, 2023). Rachmawati et al. (2022) reported the significance of the conventional clearness of foods with the addition of extract from garlic on the resistance capacity and survival of Nilem fish (Osteochillus hasselti) against Aeromonas hydrophila bacterium. In the present study, however, consumption of 20 g/kg garlic extract did improve the health of the angled fish, as evidenced by the increased white blood cell counts. Further studies are warranted to evaluate the cost-benefit of including garlic extract in Nile tilapia feed.

Ukwa et al. (2023) evaluated the effectiveness of herbs like Aframomum melegueta, Moringa oleifera, Azadirachta indica, Zingiber officinale, and Allium sativum in treating praziquantel and other herbal treatments against parasites affecting various fish species. Aframomum melegueta either alone or in its blends exhibited replacement efficacy for parasites, especially Electrotaenia spp., with increasing exposure time. Similarly, Azadirachta indica is effective against Tenuisentis spp. and other Acanthocephalan spp. (Ukwa et al., 2024). Azadirachta indica is known to inhibit the development of Argulus spp. (Kumari et al., 2023).

Active plant extracts obtained from Momordica charantia, such as momordicatin, have promising anti-parasitic activities (Phiri et al., 2023). This indicates new medicines against parasitic infections originating from the studied plants and their constituents. Houttuynia cordata and Allium sativum show effects against parasite-compromising plants (Harish et al., 2022; Özil, 2023). Koi Carp treated with Houttuynia extract for Gyrodactylus turnbulli had fewer parasites in total than those without the extract (Mariappan et al., 2023). Houttuynia cordata ethanol extract effectively halted biofilm formation in pathogenic organisms including Fusobacterium nucleatum, Streptococcus mutans, and Candida albicans. It was also responsible for a slight attenuation of tree borne bacteria in the mouth. More importantly, none of these compounds was cytotoxic to gingival fibroblasts challenged with Porphyromonas gingivalis lipopolysaccharide to stimulate interleukin-8 and CCL20 production (Sekita et al., 2016). In addition, Allium sativum oil extract wiped out many the external parasites of Argulus foliaceous (Radkhah, 2017). Such discoveries are long overdue because of the current scientific trend, which emphasizes the use of traditional plants. This approach not only provides physicians with more options for the management of patients (Ranasinghe et al., 2023) but also improves the efficacy and longevity of of plant-based therapies. It is important to note that several plants, including various parts of these plants, exhibit anti-gut parasite activity both in vitro and in vivo (Kuzminac et al., 2023). Many studies have demonstrated that these specific plants can be used comfortably in combination with or even in the replacement of known anti-parasitic drug therapies. Mentioned above, molecules from herbal sources have also been found to possess the capability to combat infectious agents. Aquatic plants with many of these therapeutic elements, such as natural antibiotics, can cure infectious diseases. However, a more aquatic plants live in-depth, and consideration of targeted medicinal plant compositions and their further elucidation is required. Because there are still no positive results encouraging treating such infections with the plant materials in question, as previously stated, considerable effort will still have to be made (Tiwari et al., 2023; Dar et al., 2023).

Mechanisms of action

Once the host fish consumes compounds from medicinal plants, these compounds are passed to the parasite through the bodily fluids of the host fish, including blood, as mentioned by Mbokane and Moyo (2024). These helpful compounds then interact with enzymes to digest food within the parasite's feeding vacuole (Olanrewaju et al., 2023). This disruption of digestion processes within the food vacuole may lead to starvation of the parasite (Pravdová et al., 2023). Furthermore, the active compounds also affect the parasites during their growth early growth stages, disrupting their life cycles (Mrugała et al., 2023). Research has demonstrated that various herbal remedies can combat fish parasites effectively by impeding the capacity to cause infections effectively. This discovery has implications for crafting preventive and management strategies centered on herbal remedies. These substances may affect parasite cells, leading to dysfunction and deformities in the organelles (Özil, 2023).

Herbal extracts in their natural form have demonstrated success in fighting parasites like Gyrodactylus kobayashii. The use of substances such as dioscin can temporarily remove parasites from fish while altering the surface of their tegument (Dawood et al., 2021). In general, when it comes to how natural remedies from plants function in dealing with parasites in fish, it is by entering their cells and disrupting their structure and normal functions. Alternatively, some medicinal herbs release chemicals, like alkaloids and saponins, which can be harmful to fish, depending on the dosage given. These elements may affect the kidney and blood systems of the fish being treated. Therefore, it is important to research the various types of secondary compounds found in medicinal plants and their impacts on fish, as well as the correct dosages to minimize the risk of overdose and incorrect application (Camilo et al., 2022; Mbokane and Moyo, 2024).

Efficacy and Safety Considerations

Other related studies have shown that medicinal plants are safe for use in aquaculture because they are effective in eradicating parasites in fish. Researchers have found that onion, sage, menthe, garlic, lavender, and oregano essential oils are effective against Ichthyophthirius multifiliisis trophones (Özil, 2023). Mbokane and Moyo (2024) conducted a meta-analysis and revealed the fact that there is evidence to suggest that fish such as carp, trout, African catfish, and tilapia can have their immunity and disease resistance enhanced by the use of medicinal herbs. Some plants that are commonly found in this area are Piper betle, Leucas lavandulaefolia, Moringa oleifera, Morinda citrifolia, Allium sativum, Galla chinensis, Mucuna pruriens, and Carica papaya. The ethanol extracts of Astragalus membranaceus, Thunb (Dryopteris setosa), Gan Cao (Glycyrrhiza uralensis), danshen (Salvia miltiorrhiza), and pomegranate (Punica granatum) have also been proven to be effective in controlling Neobenedenia girellae (Liu et al., 2023).

Medicinal plants are safe, easily available, and cost-effective, and they have the least impact on the environment; therefore, they are an important tool in the treatment of fish infections. When using plant extracts on fish, it is important to be cautious so as not to transfer it to human tissues (Mariappan et al., 2023). A study has shown that Syzygium aromaticum and Punica granatum are effective in treating fish diseases such as saprolegniales (Mostafa and Yassin, 2022). Abou-Taleb et al. (2022) stated that the medicinal plant extracts are not toxic to fish; hence, they may be safe and environmentally friendly agents that can be used in the prevention of diseases. These medicinal plants may be used as natural and non-toxic feed supplements that enhance the immune response and disease tolerance of fish (Muahiddah and Diamahesa, 2023). Medicinal plants have been effective in boosting the immune and disease-resistant status of most commonly cultured freshwater, fish such as Tilapia mozambique (Oreochromis mossambicus), African catfish (Clarias gariepinus), trout (Oncorhynchus mykiss), and cyprinids (Labeo rohita, Cyprinus carpio, and others) (Mbokane and Moyo, 2024). Mbokane and Moyo (2022) observed that the phytochemicals in papaya leaves increase immunological competencies and possess antibacterial properties in fish. Some studies have proposed that adaptation employing natural immune stimulants, like cyanobacteria, higher plants, and seaweeds, might be effective not only to prevent diseases but also in enhancing overall aquaculture production. Supplementation of fish diets with medicinal herbs increases growth performance, feed conversion ratio, immunity, disease resistance, and reproductive potential in Clarias gariepinus and Oreochromis mossambicus (Mbokane and Moyo, 2022).

Fish health experts and researchers have widely embraced the use of plant extracts as an alternative therapy for fish parasites. Nevertheless, some serious challenges need to be considered when utilizing plant extracts for fish health management. First, one has to analyze whether exposure to the extract is safe and if the extract works (Ribeiro et al., 2023). Secondly, the bioactivity in plant extracts has to be elucidated (Özil, 2023), and the conditions of extraction and storage of the extracts should be regulated. Presumably, for the treatment of fish diseases, it is necessary to use different types of extracts and methods (Mariappan et al., 2023). In addition to, efficiency, factors that have significance for the acceptability of the extract and its compatibility with other agents, as well as the dose and length of therapy, should also be taken into account (Harish et al., 2022). Medicinal plants have also been utilized as antibiotic and immunoprophylactic substitutes in aquaculture practices. Carotenoids, oligosaccharides, and anthocyanins have been applied to enhance the immune status of fish (Plaskova and Mlcek, 2023). The focus of this report is on the use of plant extracts in fish health management; however, some fish species, extract types, and application techniques require careful evaluation before use.

Traditional approaches to administering natural plant products for fish health management are considered to be more human, animal, and environmentally friendly. However, the indigenous knowledge and practices of plant extracts used in fish health management are gradually declining. Further, there is a need to conduct more research studies on this vital area of ethnoveterinary medicine, especially in Sri Lanka, where there has been documented evidence of the use of medicinal rice by indigenous people and other developed practices. To prevent further loss in this area, documentation of Indigenous knowledge of traditional medicines, species used in traditional medicines, and local partnership in the propagation of medicinal plants is also required (Pulkkinen et al., 2010; Kumar et al., 2022; Singh et al., 2022; Mariappan et al., 2023).

It is of great importance for future generations to preserve and utilize the limited traditional knowledge regarding the utilization of medicinal plants for animal health care. The current generation demonstrated to lack of interest in understanding this significant concern, which is ethically unacceptable. Limited by evolutionary constraints, the community cannot acquire complete knowledge and effectively disseminate it. Therefore, the conservation of indigenous knowledge requires proper documentation, identification of plant species, and herbal preparation. However, more scientific research is required to confirm the performance and effectiveness of medicinal plants to enhance the value of traditional fish health management practices (Mariappan et al., 2023). Improving key areas and fundamental components of traditional knowledge regarding medicinal plants in animal care systems will enable the preservation and long-term viability of this knowledge for future use (Chen et al., 2016; Jacob et al., 2024).

Challenges and limitations of ethnoveterinary medicine

Although ethnoveterinary manufacturing validation and standardization are still uncertain in low-income countries (Nodza et al., 2022), its affordability permits its use, even at the excessive costs of allopathic medicines and chemotherapy (Farnsworth, 2021). The widespread adoption of traditional medicinal plants for animal treatment is hindered by the lack of validation and standardization of conventional drug practices, particularly in low-income countries with extremely high livestock disease prevalence (Nwafor and Nwafor, 2022), even though these plants grow abundantly. The changing socio-economic and technological environment surrounding Gashaka Gumti National Park may compromise the preservation of knowledge about ethnoveterinary practices for controlling fish parasites (Dey et al., 2020; Kolarova et al., 2022).

Lack of scientific valid ation: To preserve and potentially utilize ancient healing methods, a merging of traditional knowledge and scientific validation is vital (Ouma, 2022). To prevent resistance, overuse, and contamination from evidence-based fish health treatments, demographic triangles should be defined, and drug delivery should be used carefully (Madrid et al., 2021). Biologists and scholars of conventional medicine learned from ethnoveterinary practices that Sphagnum moss (S. phoenix) effectively treats ulcerative lesions at the base of salmon saddle sores.

These sphagnum mosses, which exhibit antimicrobial properties against wound infections, serve as potential model chemotherapeutic and medicinal plants for disease treatment.

An aquaculture unit's exploration of traditional remedies for diseases could lead to advanced disease management solutions and alternative strategies for mitigating fish ailments (Rakesh et al., 2023). Despite the substantial validation of traditional medicinal plant knowledge for human diseases, there is still a minimal connection between scientific data supporting medicinal plant activities and traditional practices (Mthi et al., 2023). Preserving traditional knowledge within communities where it remains relevant. The integration of non-codified traditional systems of medicine, including local health traditions and ethnomedical practices, is urgently needed (Sukumaran and Keerthi, 2023). Goel and Srikanth (2023) stated that indigenous knowledge systems, which local use to sustainably manage plants, contribute to biodiversity conservation. Kola (2022) advocated conserving and recording indigenous knowledge for future use. Sardar and Giri (2022) conducted research on traditional medicine and plant utilization in the Sundarban mangrove forest and positioned them for future scientific investigations within a Natural Tropical Area (NTA) inhabited by ethnic groups. Due to urbanization and migration, the validation of tribal knowledge and remedies has become challenging (Ouma, 2022). The integration of traditional knowledge with modern scientific validation is essential to conserve and possibly harness ancient remedies.

Ethnoveterinary medicine and ethnopharmacognosy have focused on medicinal plants from diverse cultural backgrounds (Grundmann et al., 2023). Traditional medicinal plants have been validated for treating some human diseases, according to Mthi et al. (2023). Preserving traditional pharmaceutical knowledge from natural heritage areas like the Himalayas is crucial for human health in the face of industrialization and urban development (Chebii et al., 2023). In developing countries, there is a significant need to conserve medicinal plants (Shaheen et al., 2023). Ex-situ conservation of medicinal plants through a global strategy is crucial for preserving traditional medicine and authenticating ethnomedicinal plant information (Clair et al., 2023). Recording traditional plant remedies is indispensable because they represent the ordinary origins of drug production and drug access (Jha and Mughees, 2023). Ex-situ and in-situ methods should be applied to the conservation of medicinal plants for this era (Devi et al., 2023).

Availability and sustainability of medicinal plants: Novra et al. (2023) reported the opportunities that exist in rural economic development through the cultivation of medicinal plants, as they are rich source plants and also due to their abundance in nature; sustainability is economically significant. With the loss of medicinal plant habitats as a result of environmental changes, habitat destruction, and economic demand, many global communities recognize the need to act. Unsustainable harvesting, industrialization, and human lifestyle have all, which have altered the fish scarcity we face today (Shaheen et al., 2023; Shukla, 2023). One of the principal reasons for concern is that there are profound increases in extinction rates among medicinal plants because human interference has a multiple impact, such as habitat destruction and over-exploitation leading to rapid climate change (Novra et al., 2023).

For several medicinal plant resources, a combination of in-situ and ex-situ conservation strategies is needed to achieve sustainable use (Mofokeng et al., 2022; dos Santos et al., 2023). The best way to maintain medicinal plants and ensure their health benefits for future generations is through cultivation, conservation, and biotechnological utilization. To combat the crisis for future generations, strategies like in-situ and ex-situ conservation efforts using conventional cultivation practices as well as sustainable management of resources have been put into place (Ndawonde, 2022; Halder and Jha, 2023). Conservation measures and the adoption of sustainable harvesting methods are the means to avoid overharvesting, thus ensuring that medicinal plants are accessible for medical treatment.

Kola (2022) also agreed that traditional indigenous skills have a high risk of coming under extreme threat due to the reduction in population among Indigenous communities, forced migrations caused by deforestation, and acculturation. Indigenous knowledge systems are important for the sustainable utilization and preservation of medicinal plants in traditional medicinal practices. The conservation of indigenous medicinal practices can place some vulnerable species, like traditional tribal rare plants, at higher risk of extinction (Ouma, 2022). The erosion of traditional knowledge due to changing lifestyles makes documentation and protection more important than a welfare measure (Sukumaran and Keerthi, 2023). In place of viewing nature as a deficient purveyor that must be fixed and set right, conservation might consider how to better manage the world we inherit so it can continue to circulate among options (Anand et al., 2023).

Regulatory and legal considerations: A report by the Department for International Development revealed a significant lack of a regulatory category for traditional remedies in India and rules governing veterinary pharmaceuticals, thereby restricting the development of products accessible to livestock owners with limited resources. Ethnoveterinary practices are widely used in rural areas of Indian states such as Haridwar, Jammu, and Kashmir, as well as in the northern laterite regions of the country. The primary botanical market emphasis of this proposal represents just one of the broader market opportunities for these types of medications: the optimization of the existing inventory of underutilized medicinal plants. The culture conservatory in floristic taxonomy heavily depends on the preservation of indigenous plant conservation efforts. The use of plants as medicine for livestock is especially crucial in areas where veterinary services are scarce or non-existent, with several studies (Sharma et al., 2022; Wani et al., 2022; Mandal, Sand, & Rahaman, 2022; Dutta et al., 2022) supporting this necessity.

As Claire et al. (2023) pointed out, traditional remedies should be placed within a separate regulatory scope, which will lessen the burden of documentation, approval, and control of importation. Such a comprehensive management strategy that incorporates all these aspects without compromising ownership appears to be an ideal short-term strategy. To incorporate herbal and other unconventional therapies into the veterinary profession, policy reforms need to be implemented (Remirez, 2022). It is unlikely that this will happen soon. Prioritize equal treatment for different cultures and simplify regulations to effectively integrate traditional remedies.

The policies that govern ethnovehicle tend to overemphasize pharmaceutical treatment rather than the use of ethnopathic methods (Varshney et al., 2022). Smallholders and traditional medicine practitioners may lack the means to meet such stringent provisions because of restrictions on the accurate dosage of every treatment, including herbal medicine, and the requirement for treatments to be target-specific (Chitra and Arivoli, 2022). There is a demand from regulatory agencies for provisions of both quality and the market for traditional and complementary medicine (Kumar et al., 2022). There is a need for regulations that do not restrict the management of small-scale livestock keeping and allow for the protection of traditional practices in the use of ethnoveterinary medicine (Jarvis, 2022).

Ethno-cure, in a way, blends the modern treatment with the sacred cure. In this regard, traditional healing techniques such as the religious and mystic approaches should have complied because they are part of the cultural heritage that ought to be legally protected and that has health benefits for society (Nirmal et al., 2022). Even though ethnoveterinary approaches, provide effective solutions for animal disease treatment, thus less antibiotic abuse and progression of novel therapies of drug development for humans are possible (Varshney et al., 2022).

Future directions and research opportunities

The future direction of medicinal plant research is to look at complex biological regulation networks through multi-omics studies (Yang et al., 2023). By employing plant tissue culture techniques and elicitors, we can enhance bioactive metabolism production in vitro. Focusing on systematic investigations, spatial and temporal studies, and the exploration of core microbiomes is essential for sustainable agriculture research on medicinal plant microbiomes (Peter and Sharangi, 2022). Biotechnological interventions such as plant tissue culture, genetic modification, and metabolic pathway engineering are transforming medicinal plant research, supporting conservation, and addressing concerns related to habitat destruction and genetic diversity loss (Wang et al., 2022). Through these strategies, it is possible to study plant metabolites using innovative methods, increase bioactive compound yields, and promote eco-friendly medicinal plant applications.

To ensure quality and consistency in developing standardized products, analyses using techniques such as thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), spectrophotometry, and standard samples are paramount, especially with the increased interest in herbal medicinal products (Castka, 2020; Shchepochkina et al., 2020; Kurkin, 2022). It has also been indicated that standard samples for drug standardization ensure the quality of the drugs, especially with the significant rise in the use of herbal medicinal products (Shchepochkina et al., 2020). Initiatives have begun to focus on culturing plants in controlled environments with local substitutes to resolve differences in potency caused by differing environmental factors. Sustainability practices that focus on and support traditional knowledge can support sustainable practices, thereby ensuring that the use of plants as treatment methods are being followed (Aronov et al., 2019). Again, incorporating medicinal plants into fish parasite treatments becomes better, transparent, quality-assured, and conforms to ethical treatment practices.

Traditional healers identifying location-based cures indicate anti-parasitic plants from existing species of plants (Kumar et al., 2019). The understanding of traditional healers from several locations worldwide has the potential to identify anti-parasitic plants for further drug development (Ranasinghe et al., 2023). Focusing on a plant family known for anti-parasitic properties is potentially a cost-effective approach for drug discovery, whereas molecular breeding and genomic approaches increase the discovery of new targets for medicinal plant treatment. The Eastern Himalayan region, particularly northeast India, can provide ample opportunities (Singh et al., 2019; Adhami et al., 2018). This could allow the discovery of anti-parasitic medications from neglected plant species.

Exploration of untapped medicinal plants: Aquatic animals from the 21st century provide important sources of premium animal protein. The expansion of aquaculture promotes the creation of nutritionally complete, cost-effective, and ecological aquatic feeds (Kumar et al., 2024). Biotechnological tools are revolutionizing fish production, increasing the nutritional value of fish products, providing food security with premium animal proteins, and having potential industrial applications (Glencross et al., 2023; Cropotova et al., 2023). The growing global need for protein sources has led to increased interest in the sustainable use of underutilized seafood resources (Han et al., 2022). It accounts for 15% of all animal protein consumed worldwide and exceeds 50% in some underdeveloped countries (Issifu et al., 2022). Aquaculture plays an important role in meeting food needs while supporting sustainable food systems (Cropotova et al., 2023). Environmental concerns, including resource overuse and greenhouse gas emissions, limit the sustainability of global aquaculture (Jiang et al., 2022). Addressing sustainability in aquaculture requires cross-sectoral governance and policy interventions (Viji et al., 2018). Aquaculture can sustain growth and ensure global food security through sustainable practices and innovative solutions (Pradeepkiran, 2019).

Botanical antiparasitics are reported to control gastrointestinal parasites in fish and other organisms and represent a new chemotherapy for parasitic infections (Saxena, 2023). Ultrasonically assisted extraction (UAE) and microwave-assisted extraction (MAE) are the two most advanced modern extraction techniques that can be used to efficiently isolate bioactive molecules (Dar et al., 2023). Many plants have been used for years to treat parasites in humans and other animals, but few have been extensively studied and documented for use in fish. More than 1,500 European plant species have been used in traditional herbal medicine, but many treatments are reserved only for local herbalists, and their studies are limited. It would be possible to study thousands of plants to identify other anti-parasite plants, but little research has been conducted in this area. Many recent studies have emphasized the need to study medicinal plants for antibacterial, antifungal, and antiprotozoal activities that could lead to the treatment of human diseases (Jamil et al., 2022; Ranasinghe et al., 2023; Suaza-Gaviria et al., 2023).

In addition to being useful for ecosystem management, traditional ecological knowledge (TEK) also contributes to the global conservation of environmental ecosystems, particularly through practices transmitted by traditional fishers (Hartel et al., 2023). Indigenous knowledge effectively contributes to the conservation of genetic resources of wild fish and increases the productivity of aquaculture (Obiero et al., 2023). The traditional knowledge of fishing communities in the management of marine resources highlights the importance of customary practices, including fishing rights and maritime tenure, for effective fisheries management and the valorization of traditional knowledge (de Sousa et al., 2022). Medicinal plants are gradually replacing antibiotics in aquaculture because of their safety and effectiveness in boosting immunity (Lako et al., 2023). Community service projects in aquaculture have demonstrated the effectiveness of herbal probiotics, while some medicinal plants, such as garlic, ginger, turmeric, and green tea, have antioxidant and immune properties that support fish health and ecological aquaculture practices (Soeprapto et al., 2022; Mariappan et al., 2023). Collaboration with local communities and indigenous knowledge holders presents valuable opportunities for ethnoveterinary research to assess the effectiveness of conventional herbal medicines in improving fish welfare.

Development of standardized plant products: Fish parasites are a major concern for fish health and fish farm performance (Castro et al., 2023; Ghorbani and Garedaghi, 2023). Chemical drugs can kill these parasites, but can also harm the environment. Instead, the use of natural plant-based substances is safer for controlling fish parasites (Dezfuli and Scholz, 2022; Buchmann, 2022). Ahmad et al. (2023) and Castro et al. (2023) reported that plant compounds, such as tannins, alkaloids, phenols, and saponins can fight many fish parasites. Proteases from fruits, such as figs, pineapples, papayas and kiwi can also help control animal parasites, bugs, and worms that damage plants (Özil, 2023). Although these plant substances have great potential, only a few have been extensively studied for their ability to fight parasites (Liu et al., 2023). Few studies have examined the effectiveness of herbal preparations against fish parasites. Further studies are needed to maximize the benefits of plant-based parasite control in fish as alternatives to synthetic drugs and pesticides that provide safety and convenience.

Concerns are growing about the problem of antibiotics' poor performance and their impact on the environment. This has led to increased interest in using plants to produce natural medicines to control fish parasites (Özil, 2023; Ribeiro et al., 2023). Finding the right parts of these natural products to make good antiparasitic drugs is important, but it can take a long time and costs (Geisshirt et al., 2023). Scientists need to find new methods to use plants as medicines for fish parasites by studying plant parts that can fight these parasites (Ranasinghe et al., 2023). Fish farms can reduce the use of antibiotics and vaccines by using active plant parts, such as essential oils and other natural substances as a safe and effective way to control parasites. Medicinal plants, which are full of active substances, have been proven to keep fish healthy, help them grow, allow them to better cope with stress, and prevent diseases (Singh et al., 2022). These plants provide fish with immune-boosting and antioxidant benefits for less money and with less harm than usual treatments, which helps fish remain healthier overall (Nunez et al., 2022). Because more people are buying herbal medicines, there is not much information about plants that can fight parasites in fish, which is stopping them from being used more in fish farming. More research is needed on the use of medicinal plants to fish healthy because this is still a new idea.

Collaborative research and sharing the knowledge: Understanding the importance of traditional methods in controlling animal parasites, the World Association for the Advancement of Veterinary Parasitology is working together to bridge the gap between veterinarians and traditional animal care practitioners (Riyaz and Ignacimuthu, 2023). These traditional practices, which are part of local customs and have been taught from one generation to the next, provide useful information on the use of medicinal plants for animal health (Güneş et al., 2022). Herbal treatments help manage different health issues associated with these practices (Wani et al., 2022). It's important to maintain and mix traditional animal healing knowledge with current veterinary methods to improve animal care in rural areas.

Working with traditional animal health workers and veterinarians is important for confirming the value of traditional knowledge and developing treatments for animals that are based on evidence. Through clinical trials, this partnership can evaluate the effectiveness of traditional herbal treatments (Nwafor and Nwafor, 2022). Knowledge passed down through generations from indigenous communities plays a significant role in livestock disease treatment (Gandasari et al., 2023). Documenting and verifying traditional practices such as the use of turmeric and cinnamon to enhance poultry care could improve farming methods (Sujeetha and Ashokan, 2022). It is crucial to preserve and share indigenous knowledge on the diagnosis and treatment of cattle diseases (Asefa et al., 2022).

Encouraging cooperation between those who hold traditional knowledge and veterinarians can help manage animal parasites, which is beneficial for both developing and developed countries. There is an increasing worldwide interest in traditional plant-based therapies (Casagrande et al., 2023). In many cultural groups, traditional medicine is very important (Musa et al., 2023). To combine traditional plant treatments with scientifically proven therapies, we need to work together and share information (Scherrer et al., 2023). Teaching about the environment is important for keeping knowledge about traditional medicinal plants alive for future generations, according to research (Yusransyah et al., 2023). The importance of connecting traditional knowledge with scientific understanding to create effective plant-based treatments is becoming increasingly evident as research in this area grows (Singh, 2022). Bringing together and sharing traditional knowledge can help improve scientifically supported plant-based therapies.

Conclusion

Using plants to treat fish diseases has been successful in traditional farming methods. This plant extracts, which have been used for generations to fish healthy in fish farms, represent a valuable resource. It is important to keep these traditional health practices alive so that future generations can benefit from these natural health care systems. Farmers can determine the best plant-based treatment for specific fish parasites by trying different methods, even though the effectiveness of these plants can change due to different factors like the type of active substance when they are available, how they are prepared, and the amount used. More research is needed to understand how these plant treatments work and the effects they have on the environment. More studies need to be conducted to decide whether medicinal plants should be used as purified substances or as live extracts and to find the best way to give them to animals. It is also important to acknowledge the traditional knowledge of animal care that has been passed down through generations. It is suggested that using medicinal plants will benefit fish health and reduce the need for chemical treatments.

Author Contribution

A single author completed all the studies (literature searches and edited and reviewed the manuscript).

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Conflicts of Interest

The author declares no conflict of interest.

Acronym/Abriviations

CPs: Cysteine proteases,; HPLC: high-performance liquid chromatography; MAE: Microwave-assisted extraction; NTA: Natural Tropical Area; TEK: Traditional ecological knowledge ; TLC: Thin-layer chromatography; UAE: ultrasound-assisted extraction.

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