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# Phytotherapeutics for parasite control in global fish aquaculture: a review of anti-monogenean agents and their mechanisms

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**Abstract –** With the intensification of fish cultivation, also increased threat of parasitic diseases to fish health, growth, production, and productivity. This has had huge negative impacts and necessitate alternative therapeutics for the control and treatment of diseases. Medicinal plants have been integral to human life, utilized as a natural source of bioactive compounds for use in veterinary and human medicine. These plants produce diverse chemical compounds, such as alkaloids, saponins, phenolic compounds, tannins, terpenoids, steroids, flavonoids, and essential oils, which have been used in fish aquaculture. Thus, the present study aimed to synthesize papers published within the last eight years on the efficacy of different extracts, essential oils, and bioactive compounds derived from medicinal plants, as well as their potential modes of action on fish parasites, with an emphasis on fish parasitic monopisthocotylans and polyopisthocotylans (formerly monogeneans). Data on phytotherapeutic products, phytochemicals, targeted parasites, and *in vitro* and *in vivo* experiment outcomes were extracted from the literature and summarized. Additionally, the mechanisms by which these phytotherapics act on parasites were shown and discussed. The bioactivity of essential oils and crude herbal extracts in controlling and eliminating parasites is directly linked to the action of their major components, which demonstrate parasiticidal and anti-monopisthocotylans and polyopisthocotylans activity, even when isolated. This provides a wide range of options. Phytotherapeutic agents are an alternative to chemotherapeutic agents because they pose no risk of acute or chronic toxicity to host fish, nor do they contaminate handlers. They also do not cause parasitic resistance and are environmentally friendly. Therefore, they are recommended for use in management strategies to control and treat parasite infections in fish aquaculture due to their anthelmintic and parasiticide properties. Lastly, although the economic and aquaculture viability of phytotherapeutic agents is unknown, the environmental benefits are evident compared to the widespread use of chemotherapeutics.

**Keywords:** Diseases / herbal / parasites / phytotherapy / treatments

## 1 Introduction

The global aquaculture industry recently reached an all-time high in seafood production, with an estimated 232.2 million tons valued at USD 313.0 billion. This production contributes over 57% of the protein-rich aquatic animal products consumed directly by the world's population (FAO, 2024). With the increasing of world human population, so does the demand for animal protein, a growing concern for aquaculture (FAO, 2024). Aquaculture is one of the fastest-growing food production industries and provides sustenance, food security, livelihoods, and poverty reduction for many populations in diverse regions worldwide (FAO, 2024; Acharya et al., 2025). Despite technological advancements, aquaculture continues to face severe disease problems, highlighting the importance of addressing these issues.

The rapid expansion of global aquaculture through intensified cultivation practices has led to frequent outbreaks of parasitic diseases due to inadequate animal health management, poor water quality, inadequate nutrition, poor sanitary conditions, and high stocking density in fish aquaculture (Valladão et al., 2015; Tavares-Dias and Martins, 2017; Mukaila et al., 2023; Liu et al., 2023; Acharya et al., 2025; Tu et al., 2025). Consequently, the continued growth of this global industry hinges on the use of chemotherapeutants to

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control and treat diseases in fish aquaculture worldwide because outbreaks of parasitic diseases are one of the major obstacles to the development of fish aquaculture (Valladão et al., 2015; Grano-Maldonado et al., 2018; Chong et al., 2020; Assane et al., 2022; Liu et al., 2023; Mukaila et al., 2023; Acharya et al., 2025; Tu et al., 2025; Alves et al., 2025; Baia et al., 2024). Parasitic infections directly and indirectly affect production costs in this industry on regional and global scales. Parasite infections generate costs for control and treatment, as well as for the massive mortality, reduced welfare, and growth of fish. Estimates of the economic and financial losses caused by diseases have been made for catfish production in Nigeria (Mukaila et al., 2023), and for fish aquaculture in Bangladesh (Faruk et al., 2004), Brazil (Tavares-Dias and Martins, 2017), and India (Haridevamuthu et al., 2024; Patil et al., 2025). These costs add up to tens of millions of dollars per year (Patil et al., 2025). Consequently, such economic losses may alter the supply and demand of food fish, thereby harming the livelihoods of fish farmers in developing regions. This occurs by decreasing their main source of income and their consumption of fish, which negatively impacts their health. Additionally, it increases the rate of unemployment and food insecurity because many populations in these regions rely on small-scale fish production for subsistence. Parasitic diseases are considered one of the major threats to global aquaculture production because they negatively affect this food production sector, leading to food and nutritional insecurity and decreasing livelihoods on a global scale (Liu et al., 2023; Patil et al., 2025).

Although the global impact of economic losses caused by outbreaks of parasitic diseases in fish aquaculture is unknown, Kumari et al. (2024) reported that parasites alone account for approximately 75% of diseases, resulting in annual losses ranging from USD 1.05 billion to 9.58 billion, regardless of aquatic organism species. Nevertheless, the global impact of economic losses on aquaculture is underestimated and needs to be updated because recent estimates of losses due to diseases in Indian aquaculture alone have been projected to reach USD 2.48 billion. Additionally, the global ornamental pet fish trade and production industry has grown by an average of 14% annually and is estimated to be worth USD 15 to 30 billion per year. However, this industry has suffered considerable economic losses due to massive mortality and morbidity caused by disease outbreaks, as well as the costs of control and treatment (Lian et al., 2020; Munguti et al., 2024; Larcombe et al., 2025), which are not currently estimated. Therefore, parasites should be recognized as a major challenge in fish aquaculture due to the difficulty of managing diseases caused by parasites. In addition, the economic losses from the negative impacts of parasitic diseases on the fingerling production sector are also unknown. Nonetheless, this information is crucial in providing a foundation for more accurate estimates of the true global economic impact of diseases in fish aquaculture, for which data are unavailable.

In fish aquaculture, these animals are frequently infected with a wide diversity of species protozoans, crustaceans, and helminths, including monopisthocotylans and polyopisthocotylans species (Valladão et al., 2015; Tu et al., 2021; Zhou et al., 2022; Mahdy et al., 2022; Rahmati-Holasoo et al., 2024; Khoris and Bileh, 2024; Kumari et al., 2025; Sharma et al., 2025; Jetithor et al., 2025; Tu et al., 2025; Acharya et al., 2025; Alves et al., 2025; Baia et al., 2024). Consequently, fish aquaculture has been constantly challenged by parasitic infections, so adequate control measures must be implemented to reduce economic losses due to massive fish mortality. Additionally, parasite control with therapeutic products should significantly improve production and productivity in fish aquaculture (Ji et al., 2025; Alves et al., 2025; Baia et al., 2024). For a long time, the control and treatment of various ectoparasitic diseases have been carried out using different chemicals or synthetic drugs (e.g., sodium chloride, cypermethrin, formalin, potassium permanganate, formalin, trichlorfon, emamectin benzoate, powdered quicklime, chloramine-T, triphenylmethane dyes, acriflavine, malachite green, powdered quicklime, emamectin benzoate, and copper sulfate). However, the use of these chemicals and synthetic drugs has often led to the development of parasite resistance, environmental contamination, and the accumulation of chemical residues in fish, which poses a risk to consumer health (Tu et al., 2021; Zhou et al., 2022; Rahmati-Holasoo et al., 2024; Silva et al., 2024; Sharma et al., 2025; Jetithor et al., 2025; Tu et al., 2025; Ji et al., 2025; Alves et al., 2025; Baia et al., 2024). Moreover, synthetic drugs may produce excellent results in most situations; however, their adverse effects are a serious concern.

Historically, medicinal plants have been extensively used in traditional medicine to treat various human diseases. The use of medicinal plants as therapeutics dates back to ancient times, as early as 4000–5000 BC, when the Chinese began using herbal preparations as medicines (Alves et al., 2025; Ji et al., 2025). Later, the utilization of medicinal plants and their derived compounds in the treatment of diverse diseases in veterinary and human medicine increased, especially in fish aquaculture, where extracts and essential oils of medicinal plants and their majority components are used (Rahmati-Holasoo et al., 2024; Sharma et al., 2025; Tu et al., 2025; Ji et al., 2025; Alves et al., 2025). These practices, which employ herbal medicines in ethnomedicine and ethnoveterinary care, have long been common in civilizations with a history of traditional use, such as China, India, South and Central America, and Southeast Asia (Yang et al., 2022; Ji et al., 2025; Sharma et al., 2025). However, they have also recently attracted significant interest from researchers and fish aquaculturists due to the tremendous diversity of medicinal plants and their potential applications.

Of the more than 250,000 species of medicinal plants, only around 60 have been tested in global aquaculture (Anjos and Isaac, 2020; Kuebutornye and Abarike, 2020; Akram and Mahmood, 2024). This indicates a significant potential for phytotherapy to boost the health of farmed aquatic animals, including fish, and to control and treat their diseases. Medicinal plant-derived products used as parasiticides to control and treat fish diseases offer a promising alternative to chemotherapeutants because they are safer, environmentally friendly, and less likely to promote resistance (Tavares-Dias 2018; Malheiros et al., 2020; Silva et al., 2024; Acharya et al., 2025; Sharma et al., 2025; Jetithor et al., 2025). Thus, a significant gap remains in innovations regarding parasiticides derived from medicinal plants for controlling and treating diseases in global fish aquaculture.

Although phytotherapy is an excellent alternative to chemotherapeutants, it consists of multiple bioactive compounds with synergistic (positively) or antagonistic (negatively) action. These compounds combat a wide variety of parasite species. However, their usage in fish aquaculture is limited (Tavares-Dias 2018; Malheiros et al., 2020; Sharma et al., 2025; Tu et al., 2025). Nevertheless, medicinal plant extracts, essential oils, and their majority components are strongly recommended for intensive fish aquaculture as an alternative to chemotherapeutants (Valladão et al., 2015; Tavares-Dias 2018; Tu et al., 2021; Jeyavani et al., 2022; Dadras et al., 2023; Liu et al., 2023; Silva et al., 2024; Acharya et al., 2025; Sharma et al., 2025; Jetithor et al., 2025; Tu et al., 2025). Phytotherapy can meet the current needs of fish aquaculture by providing direct and indirect support in the prevention, control, and treatment of protozoan and helminth infections, as well as immunostimulation (Fig. S1). Phytotherapy exerts therapeutic effects through various mechanisms that improve fish health and resistance to parasite diseases. One primary mechanism is the immunostimulatory properties of many herbal compounds, which enhance the immune response of fish. This is done by promoting the activity of immune cells, such as macrophages and lymphocytes; stimulating fibroblasts; increasing respiratory burst activity; and making it harder for leukocytes to move. This leads to increased resistance against parasite infections. Despite the widespread recommendation to utilize phytotherapy in fish aquaculture, there are no estimates of the global trade of medicinal plants and their derivative compounds used in aquaculture. However, for human consumption, the total global phytotherapy drug market is estimated at USD 62 billion and is expected to reach USD 5 trillion by 2050. This market, which includes herbal products and raw materials, has an estimated annual growth rate of 10.7% in recent years (Parvin et al., 2023), indicating significant growth potential.

Despite advancements in technology for fish aquaculture and the enormous potential of medicinal plant derivatives as therapeutic resources for fish aquaculture, they have some disadvantages compared to chemotherapeutants. For instance, there is limited information on the stability, bioavailability, and action mechanisms of phytotherapeutic agents on fish at the molecular level. There is also limited data on the toxicity and tolerance of fish species and the optimal concentration for parasite control and treatment in host fish. Additionally, there are few studies on the action mechanisms against parasite species. Therefore, significant challenges remain in controlling and treating parasitic diseases in fish aquaculture using phytotherapy (Valladão et al., 2015; Tavares-Dias, 2018; Kuebutornye and Abarike, 2020; Tu et al., 2021; Silva et al., 2024; Tu et al., 2025; Alves et al., 2025), which still needs to be refined and widely discussed.

Previous studies have indicated an increase in *in vitro* and *in vivo* studies evaluating the parasiticide activity of herbal extracts, essential oils or their majority components (Valladão et al., 2015; Tavares-Dias (2018). Furthermore, it was recommended that field studies be conducted to determine if essential oils can effectively reduce monopisthocotylans and polyopisthocotylans parasite infections and improve the well-being of host fish populations Additionally, the sustainability of these natural parasiticides must be evaluated before incorporating them into antiparasitic management plans for fish culture tanks. Thus, based on these previous studies, the primary aim of this review paper is to gather and discuss information on the control and treatment of parasitic diseases in fish aquaculture using medicinal plant extracts, phytochemicals, essential oils, and their derivatives over the last nine years, with a particular focus on anti-monopisthocotylans and polyopisthocotylans treatments. Second, it reports on the activities of medicinal plants and phytochemicals against fish parasites, their modes of action, and their potential applications in addressing the current challenges posed by outbreaks of parasitic diseases in global fish aquaculture.

## 2 Chemical composition of medicinal plant derivatives products with parasiticide and anthelmintic actions

Plants exhibit a complex phytochemical composition that varies among their different parts (e.g., aerial parts, sclerotia, stems, rhizomes, flowers, roots, seeds, leaves, rhizomes, fruits, wood, and bark), which are used for extraction of extracts and oils. This composition plays a crucial role in their ecological interactions and the practical applications of their phytochemicals, which also range in biological activity. The amounts of bioactive phytochemical compounds also vary, and the biological activities and effectiveness of these compounds as parasiticides and anthelminthics are influenced by a complex set of factors, including phytochemical profile and therapeutic potency. The activity of phytochemical compounds can be enhanced by constituents present in small amounts, thus improving the effectiveness of the majority components. Phytochemicals are bioactive compounds produced by plants through their primary and secondary metabolism via alternative pathways involving cellular metabolism, which are crucial for their existence, as they are utilized for pest repellence and growth regulation, and protection against predators, such as insects, and pathogens, such as fungi (Ranasingle et al., 2023; Miri, 2025; Girotto et al., 2025; Valerio and Ferdosh, 2025; Kilibarda et al., 2025; Valerio and Ferdosh, 2025; Mungwari et al., 2025). Medicinal plants contain several groups of phytochemical compounds (Fig. 1) with different biological and pharmacological properties that can contribute significantly to controlling and treating various parasitic diseases in fish from aquaculture. Thus, studies on phytotherapy have received increasing global attention currently.

Herbal extracts are substances obtained from various plant parts. Typically, in liquid form, they contain different bioactive phytochemical compounds extracted by a solvent method. Essential oils are volatile, hydrophobic liquids primarily composed of terpenoids (monoterpenes and sesquiterpenes) and phenylpropanoids biosynthesized in secretory cells of various plant parts. The characteristic odor of each essential oil depends on its source, and it can be extracted by different methods. The bioactive phytochemical compounds present in the essential oil depend on the plant species and the conditions used for its extraction (Almeida-Couto et al., 2022; Sahoo et al., 2023; Ranasingle et al., 2023; Miri, 2025; Girotto et al., 2025; Valerio and Ferdosh, 2025; Kilibarda et al., 2025; Valerio and Ferdosh, 2025). However, the efficient extraction of these phytochemicals is a fundamental step in harnessing better their therapeutic potential.

The yield of phytotherapy products depends on the solubility of most of the compounds in the extraction solvents because both extracts and essential oils may be fractionated. Current advances in instrumental technology have enabled the

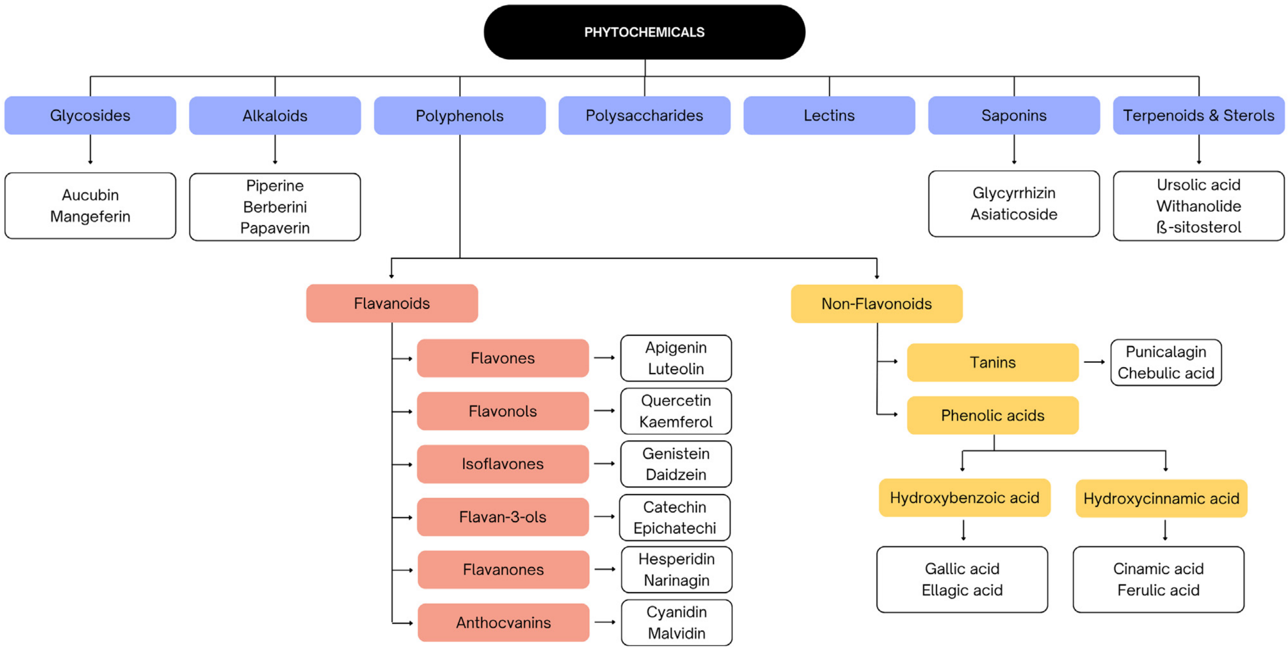


**Fig. 1.** Classification of the main phytochemical compounds.

identification, fingerprinting, and chemical characterization of individual compounds in plant extracts. For instance, separation techniques such as gas chromatography-mass spectrometry, liquid chromatography, high-performance liquid chromatography, and capillary electrophoresis are used to separate phytochemicals in crude extracts and identify each component. Spectroscopic detection technologies, such as mass spectrometry, infrared spectroscopy, and nuclear magnetic resonance, have also been used to analyze molecular structures. Emerging technologies, such as supercritical fluid extraction, microwave-assisted extraction, and ultrasound-assisted extraction, instant controlled pressure drop, pressurized liquid extraction and negative pressure cavitation have demonstrated improved yields, reduced solvent usage and enhanced sustainability (Ranasinghe et al., 2023; Mungwari et al., 2025). Thus, these techniques have expanded phytochemical analytics of extracts and essential oils and are contributing to studies aimed at extracting and identifying effective phytotherapeutic substances for combating fish parasitic diseases.

To obtain bioactive phytochemical compounds from different plants, the extraction method and conditions, plant matrix, and properties of the plant material must be considered, whether for herbal extracts or essential oils. The type of solvent used plays a fundamental role in the extraction of bioactive compounds. Consequently, extracts and essential oils obtained under the best extraction conditions defined in previous studies should be analyzed, especially regarding their composition and other properties (Almeida-Couto et al., 2022; Girotto et al., 2025; Valerio and Ferdosh, 2025; Kilibarda et al., 2025; Mungwari et al., 2025). This is because the type of solvent used can significantly affect the results. The composition of essential oils can also be largely affected by the extraction method, analysis conditions, and type of solvent used; therefore, it is essential to choose the most suitable method. Furthermore, abiotic and biotic factors that influence the chemical composition of essential oils have been widely discussed (for more details, see Tavares-Dias, 2018; Almeida-Couto et al., 2022; Miri, 2025). In a recent review, Almeida-Couto et al. (2022) discussed the advantages and disadvantages of four conventional and four alternative methods for extracting essential oils. Most of these conventional methods require long-term extraction and the use of high-quality solvents. In contrast, alternative methods reduce the extraction time and power consumption while increasing the essential oil yield and improving quality. However, regarding the therapeutic use of phytotherapy extracts in fish aquaculture, some issues remain to be discussed.

Ethanol and water are usually the most commonly recommended solvents for obtaining active compounds from herbal extracts to carry out sustainable processes, as they are highly efficient and non-toxic. When comparing the efficacy of ethanolic and methanolic extracts to that of other extracts (e.g., petroleum ether, chloroform, ethyl acetate, methanol, water, hydro alcohol, ethanol, dichloromethane, ethyl alcohol, petroleum ether, chloroform, ethyl acetate, acetone, glycerin, glycol, etc.), ethanol was the best because the majority of the lipophilic compounds affecting parasites are obtained through ethanol extraction (Girotto et al., 2025). On the other hand, alcoholic and methanol solvents have been shown to be more efficient at extracting secondary bioactive phytochemicals than water-based methods (Trasviña-Moreno et al., 2019; Yang et al., 2022; Kilibarda et al., 2025). Kilibarda et al. (2025) also found differences in the number of phenolic compounds when comparing an aqueous extract ($n = 25$) of *Hypericum perforatum* and a methanolic extract ($n = 35$), which had more compounds. Nevertheless, acetone, ethyl acetate, and hexane extracts of *Podocarpus lambertii* showed different yields but few differences in phytochemical composition because only tannins and triterpenoids were not identified in the acetone and ethyl acetate extracts (Bandeira et al., 2024). Therefore, the type of solvent used plays a crucial role in the extraction of bioactive phytochemicals from herbal extracts and can significantly interfere with the efficacy of parasiticides and anthelmintics.

Plant extracts obtained using different solvents demonstrate varying levels of parasiticide efficacy. Ikele et al. (2024) demonstrated differences in antiprotozoal activity in *Ichthyophthirius multifiliis* depending on the plant species and the solvent used to extract the plant material. Zoral et al. (2017) demonstrated that, although the majority of components in aqueous and ethanolic extracts of *R. officinalis* were similar, ethanolic extracts achieved 100% efficacy against *Dactylogyrus minutus* at lower concentration. Ethanol extracts of *Paris polyphylla*, *Capsicum annuum, Cinnamomum cassia*, and *Lindera aggregata* also exhibited higher anthelmintic activity against *Gyrodactylus kobayashii* than water, methanol, petroleum ether, and ethyl acetate extracts (Zhou et al., 2020). Similarly, Levy et al. (2015) found that ethanol extracts of *Z. officinale* were most effective in immobilizing *Gyrodactylus turnbulli* in vitro, as well as decreasing this parasite in the skin of *Poecilia reticulata* following therapeutic baths with aqueous and ethanol extracts. Baths with the ethanol extract of *R. officinalis* also reduced the intensity of *D. minus* in *Cyprinus carpio* gills compared to the aqueous extract (Zoral et al., 2017).

*Clematis chinensis* extracts obtained with ethyl acetate were more effective than those obtained with methanol and exhibited high activity against *D. intermedius*. Extracts obtained with ethyl acetate and petroleum ether followed, and water extracts exhibited the least activity. However, *Caesalpinia sappan* extract with chloroform exhibited the highest anthelmintic efficacy against *D. intermedius*, followed by the water extract, which was the next most effective and did not cause fish death. *C. sappan* extract with petroleum ether showed little anthelmintic activity against these parasites. Regarding *Artemisia argyi* and *Eupatorium fortune* extracts, the *A. argyi* extract with ethyl acetate displayed high anthelmintic activity, followed by the chloroform and petroleum ether extracts. The same was true for the *E. fortunei* extracts obtained with chloroform. However, extracts obtained with other solvents led to a low anthelmintic efficacy against *Dactylogyrus intermedius* (Huang et al., 2013). *Cortex meliae* extract with petroleum ether was effective against *G. kobayashii* infecting *C. auratus* at a lower concentration than methanol extract, though the same was not true for *Semen aesculi* extracts. In addition, *Macleaya cordata* extract was effective at a lower concentration when methanol was used as the solvent compared to ethyl acetate, water, and petroleum ether. Methanol and ethyl acetate extracts of *P. polyphylla* were the most effective against *G. kobayashii* in *C. auratus* compared to extracts with formaldehyde, water, or petroleum ether. *Capsicum annuum* extracts with methanol, petroleum ether, and ethyl acetate also displayed excellent anthelmintic activity, and caused no fish death. In contrast, the water extract of *C. annuum* displayed lower anthelmintic efficacy, leading to fish death (Zhou et al., 2017). Consequently, these results with different solvents also significantly influenced the median effective concentration ($EC_{50}$) for parasite species.

A comparison of the efficacy of some medicinal plants against *D. intermedius* using different solvents revealed that the extracts of *Polygonum multiflorum* in water (100 mg/L), methanol (12.5 mg/L), and ethyl acetate (25 mg/L) were the most effective. Their respective $EC_{50-48h}$ values were 1.9, 5.4, and 9.1 mg/L. Following those were the ethyl acetate (80 mg/L), chloroform (80 mg/L), and methanol (120 mg/L) extracts of *Dioscorea collettii*, with $EC_{50-48h}$ values of 19.7, 27.1, and 37.8 mg/L, respectively. Chloroform (100 mg/L) and ethyl acetate (125 mg/L) extracts of *Citrus medica* exhibited similar activity, with $EC_{50-48h}$ values of 58.7 and 51.3 mg/L, respectively. The ethyl acetate and methanol extracts of *Abrus cantoniensis* exhibited the lowest activity, with $EC_{50-48h}$ values of 279.4 and 64.3 mg/L, respectively (Hu et al., 2014). Fu et al. (2014) found that the minimum lethal concentration of ethyl acetate and acetone extracts of *Morus alba* against *I. multifiliis* was lower than that of methanol, chloroform, and petroleum ether extracts. These differences resulted in variations in $EC_{50}$ values and the time required to kill 100% of the ciliate (Fu et al., 2021; Ikele et al., 2024). Recently, Li et al. (2025) also reported differences in the in vitro efficacy of various *Psoralea corylifolia* extracts against *Tetrahymena pyriformis*. They ranked the extracts as follows: dichloromethane extract > methanol extract > acetone extract > ethyl acetate extract > cyclohexane extract > *n*-hexane extract, with corresponding $EC_{50-24h}$ values of 7.2, 7.5, 7.8, 11.0, 11.6, and 12.3 mg/L, respectively. The ethyl acetate extract of *Cnidium monnieri* was more effective against *G. kobayashii* than the methanol and petroleum ether extracts of *Evodia rutaecarpa* and *Sophora flavescens*, with an $EC_{50-48h}$ value of 11.0 mg/L (Lian et al., 2020). These differences in anti- monopisthocotylans and polyopisthocotylans activity for the same medicinal plant are due to the different extraction methods of the phytochemical compounds. Other studies worthy of note and requiring further discussion have also been reported.

Compounds frequently found in different species of aromatic plants include citral, eugenol, $\beta$-caryophyllene, terpinen-4-ol, limonene, geraniol, neral, dillapiole, zingiberone, zingiberene, zingerone, and safrol, which are often related to parasiticidal and anti-monopisthocotylans and polyopisthocotylans activities (Huang et al., 2013; Gómez-Rincón et al., 2014; Boijink et al., 2015; Bandeira Jr et al., 2017; Meneses et al., 2018; Santos et al., 2018; Pereira et al., 2020; Queiroz et al., 2022; Santos et al., 2023; Yilmaz and Yildiz, 2023; Vercellini et al., 2024; Kim et al., 2025). Several medicinal plants contain compounds that exhibit anti- monopisthocotylans and parasiticide activities. Dialpiole, cinnamaldehyde, carvone, cinnamic acid, $\alpha$-terpinene, *p*-cymene, sabinene, (E)-caryophyllene, and limonene oxide, compounds present in several medicinal plants, exhibit anti-monopisthocotylans and parasiticide activity (Huang et al., 2013; Ling et al., 2015; Nizio et al., 2018; Morales-Serna et al., 2019; Brasil et al., 2019). Menthol, a majority component of several medicinal plants, has also been shown to be effective against monopisthocotylans and other parasite species (Huang et al., 2013; Ferreira et al., 2019; Attia et al., 2022; Vercellini et al., 2024). Carvacrol, thymol, *p*-cymene, carvone, $\beta$-pinene, and $\gamma$-terpinene are compounds found in various medicinal plants that exhibit anthelmintic activity against nematodes and monopisthocotylans (Huang et al., 2013; Gómez-Rincón et al., 2014; Soares et al., 2017a, b; López et al., 2018; Brasil et al., 2019; Özil, 2023; Santos et al., 2023; Yilmaz and Yildiz, 2023; Les et al., 2024). 10-gingerol, 6-dehydroshogaol, and

6-dehydro-10-gingerol are the majority constituents of *Zingiber officinale* extract and have high parasiticide efficacy, with 10-gingerol showing the lowest $EC_{50}$ (Fu et al., 2019). The (-)-globulol, one of the majority constituents of *Hyptis mutabilis* essential oils, has parasiticidal efficacy (Cunha et al., 2017). Thymol and lavender are the chemical majority constituents in *T. vulgaris* and *Lavandula angustifolia* extracts, respectively, and exhibit parasiticide activity (Hassan et al., 2024). The chemical structures of molecules with promising parasiticide and anthelmintic activities derived from medicinal plants vary (Fig. S2). The effects of different phytochemicals from essential oils and herbal extracts on fish parasites also vary depending on the parasite species (Tab. 1), among other factors.

Interestingly, Tu et al. (2025) reported that thymoquinone, a monoterpene isolated from *Nigella sativa*, exhibits low toxicity to *Carrassius auratus*. Similarly, the $EC_{50}$ of ononin, a compound extracted from *Spatholobi caulis* and tested against *Dactylogyrus intermedius*, was 0.6 mg/L, and 100% anthelminthic activity was achieved with 3 mg/L. The lethal concentration ($LC_{50-96h}$) for *C. auratus* was 4.3 mg/L; however, only 3 mg/L was tolerated during therapeutic baths. Zoral et al. (2017) reported that of the five majority constituents of *Rosmarinus officinalis* extracts, 1,8-cineole, $\alpha$-pinene, $\beta$-pinene, camphor, and camphene, 1,8-cineole was the most toxic to *Dactylogyrus minutus*, achieving 100% *in vitro* efficacy at a lower concentration than the other constituents. In addition, all of the majority constituents of *R. officinalis* had higher efficacy at lower concentrations than the extracts, except for camphene, which had no therapeutic efficacy at any concentration tested.

Currently, studies on phytotherapics combine traditional wisdom with contemporary scientific evidence, encouraging further research and discussion on phytochemicals for fish aquaculture. These studies have great potential for developing effective herbal therapies and more sustainable strategies for controlling and treating parasitic infections in farmed fish.

## 3 Medicinal plants and phytochemicals used as parasiticides to control and treat fish infections in aquaculture

Fish are the most species-rich taxon of vertebrates on the planet. There are around 32,000 species of fish, which is 40% of all vertebrate species worldwide. In other words, there are more species of fish than all other vertebrates combined. They inhabit most global aquatic environments and exhibit greater abundance and diversity of parasites than any other group of vertebrates. Since most fish-parasite relationships have endured for thousands of years, remarkable host specificity or low specificity can be observed. Hence, fish can be infected with a wide diversity of parasite species from different taxonomic groups, such as protozoans, helminths, and crustaceans (Gobbin et al., 2023; Ng, 2024; Silva et al., 2025). In this co-evolutionary race between parasites and their host fish, parasites have advantages. Consequently, many parasite species can overcome the immune resistance strategies of host fish. Treatments with chemotherapeutants such as ivermectin, praziquantel, formalin, formaldehyde, trichlorfon, etc., are required to control parasite infections, which can lead to disease outbreaks in fish aquaculture (Ng et al., 2024). Despite advancements in technology aimed at understanding and treating parasite diseases, chemotherapeutants remain a major challenge for fish aquaculture due to their limitations. Thus, there is increasing global interest in natural, plant-derived therapeutic medicines for use as parasiticides to control and treat parasitosis caused by protozoans and metazoans in fish aquaculture (Valladão et al., 2015; Tavares-Dias, 2018; Tu et al., 2021; Yilmaz and Yildiz, 2023; Acharya et al., 2025; Meng et al., 2025; Alves et al., 2025) due to their promising perspectives. Fish aquaculture is a major agrobusiness industry worldwide and an important part of the economy in developing countries, playing a crucial role in eradicating poverty in many of these countries.

Previous reviews studies listed the *in vitro* and *in vivo* efficacy of different essential oils and herbal extracts against *Ichthyophthirius multifiliis* (Valladão et al., 2015; Tavares-Dias 2018). Subsequent studies have examined herbal extracts, essential oils, and medicinal plant-derived compounds. 10-gingerol, isolated from *Z. officinale*, exhibited *in vitro* and *in vivo* efficacy against *I. multifiliis* (Fu et al., 2019). Similarly, extracts of *Punica granatum* (Rahmati-Holasoo et al., 2024), *Nelumbo nucifera*, *Glycines testa*, *Agrimonia eupatoria* (Meng et al., 2025) and *Chelidonium majus* (Alijanpour et al., 2022), as well as berberine (Huang et al., 2022), and essential oils of *Hyptis mutabilis*, *Varronia curassavica*, *Salvia officinalis*, *Lavandula officinalis*, *Origanum onites* and *Z. officinale* (Cunha et al., 2017; Nizio et al., 2018; Özil, 2023;) demonstrated high efficacy against *I. multifiliis*. The mixed extract of *Cynanchum atratum* and *S. flavescens* (Fu et al., 2021), as well as the extracts of *Thymus vulgaris*, *Mentha piperita*, and *Z. officinale* (Rahmati-Holasoo and Nassiri, 2025), showed *in vitro* efficacy against *I. multifiliis*. This demonstrates that a combination of different extracts has the potential to be used in the treatment of *I. multifiliis* infections in fish aquaculture. Similarly, sophoraflavanone G, which was isolated from *S. flavescens*, demonstrated *in vitro* and *in vivo* efficacy against *I. multifiliis* in *Ctenopharyngodon idella* (Fu et al., 2022). Extracts of *Allium sativum*, *O. onites,* and *T. vulgaris* also exhibited the killing capacity against theronts of *I. multifiliis in vitro*, in contrast to extracts of *Coriandrum sativum* (Mathiessen et al., 2021). *Thymus vulgaris* and *L. angustifolia* extracts were effective against *I. multifiliis* theronts (Hassan et al., 2024), while extracts of *Anacardium occidentale* and *Vernonia amygdalina* were moderately effective. Extracts of *Garcinia kola*, *Cymbopogon citratus,* and *Ocimum gratissimum* were minimally effective (Ikele et al., 2024).

Therapeutic baths containing *Moringa oleifera* extracts reduced infection levels of *I. multifiliis* in the gills and skin of *Clarias gariepinus* (Chika et al., 2020). Extracts of *Eclipta alba*, *Arctium lappa*, *Terminalia catappa*, *Tanacetum vulgare*, and *Sargentodoxa cuneata* have also demonstrated in vitro efficacy against *I. multifiliis* (Lesniak et al., 2021; Puk and Guz, 2021; Yazdani et al., 2021; Hu et al., 2023). Similarly, Sharma et al. (2025) demonstrated that azadirachtin, a bioactive compound derived from *Azadirachta indica*, was also effective against *I. multifiliis* in vitro. However, the essential oils of *Lippia origanoides* and *Lippia sidoides* were ineffective against *I. multifiliis in vitro* (Soares et al., 2017a, b). Dietary supplementation with *Artemisia annua* is a potential

**Table 1.** Median effective concentration ($EC_{50}$) of majority components in essential oils and herbal extracts on parasites of fish.

| Essential oils | Parasite species | $EC_{50}$ |
|---|---|---|
| *Mentha piperita* | *Piscinoodinium pillulare* | 79.5 mg/L (4 h) |
| *Mentha piperita* | *Dawestrema cycloancistrium* | 38.0 mg/L (4 h) |
| *Mentha piperita* | *Piscinoodinium pillulare* | 79.5 mg/L (4 h) |
| *Hyptis mutabilis* | *Ichthyophthirius multifiliis* | 20.0 mg/L (48 h) |
| *Ocimum gratissimum* | *Gyrodactylus* sp. | 37.8 mg/L (5 h) |
| *Lippia sidoides* | *Cichlidogyrus tilapiae* | 40.0 mg/L (24 h) |
| *Piper aduncum* | *Dawestrema cycloancistrium* | 80.0 mg/L (24 h) |
| *Piper hispidinervum* | *Neoechinorhynchus buttnerae* | 0.5 mg/L (24 h) |
| *Piper hispidum* | *Neoechinorhynchus buttnerae* | 1.7 mg/L (24 h) |
| *Piper marginatum* | *Neoechinorhynchus buttnerae* | 0.7 mg/L (24 h) |
| *Piper callosum* | *Neoechinorhynchus buttnerae* | 2.2 mg/L (24 h) |
| *Cinnamomum cassia* | *Dactylogyrus intermedius* | 59.7 mg/L (48 h) |
| *Mentha piperita* | *Dactylogyrus* sp. | 2.5 μL/mL (5 min) |
| *Citrus limon* | *Dactylogyrus* sp. | 0.7 μL/mL (5 min) |
| *Melaleuca alternifolia* | *Dactylogyrus* sp. | 0.3 μL/mL (2 min) |
| *Dioscorea zingiberensis* | *Dactylogyrus* spp. | 3.4 mg/L (48 h) |
| *Ginkgo biloba* | *Dactylogyrus* spp. | 3.5 mg/L (48 h) |
| *Origanum compactum* | *Anisakis simplex* | 0.34 mg/L (48 h) |
| *Cymbopogon citratus* | *Argulus* sp. | 67.9 μg/L (24 h) |
| *Cymbopogon citratus* | *Dolops discoidalis* | 59.5 μg/L (24 h) |
| *Illicium verum* | *Lernaea cyprinacea* | 25.0 μg/mL (1 h) |
| *Melaleuca alternifolia* | *Anisakis simplex* | 4.3 μg/L (48 h) |
| *Satureja montana* subsp.1 | *Anisakis simplex* | 151.7 mg/L (48 h) |
| *Satureja montana* subsp.2 | *Anisakis simplex* | 106.3 mg/L (48 h) |
| **Herbal extracts** | **Parasite species** | **$EC_{50}$** |
| *Cinnamomum cassia* | *Dactylogyrus intermedius* | 0.5 mg/L (48 h) |
| *Cinnamomum cassia* | *Dactylogyrus intermedius* | 6.3 mg/L (48 h) |
| *Euphorbia fischeriana* | *Dactylogyrus vastator* | 13.6 mg/L (48 h) |
| *Piper aduncum* | *Anacanthorus spathulatus*, *Notozothecium janauachensi* and *Mymarothecium boegeri* | 79.0 mg L (24 h) |
| *Pseudolarix amabilis* | *Dactylogyrus intermedius* | 4.3 mg/L (48 h) |
| *Caesalpinia sappan* | *Dactylogyrus intermedius* | 15.6 mg/L (48 h) |
| *Lysima chiachristinae* | *Dactylogyrus intermedius* | 17.2 mg/L (48 h) |
| *Cuscuta chinensis* | *Dactylogyrus intermedius* | 8.5 mg/L (48 h) |
| *Artemisia argyi* | *Dactylogyrus intermedius* | 70.2 mg/L (48 h) |
| *Eupatorium fortunei* | *Dactylogyrus intermedius* | 84.9 mg/L (48 h) |
| *Zingiber officinale* | *Ichthyophthirius multifiliis* | 3.7 mg/L (4 h) |
| *Psoralea corylifolia* | *Tetrahymena piriformis* | 1.92 mg/L (24 h) |
| *Zingiber officinale* | *Ichthyophthirius multifiliis* | 5.5 mg/L (4 h) |
| *Punica granatum* | *Ichthyophthirius multifiliis* | 1.4 g/L (96 h) |
| *Zingiber officinale* | *Ichthyophthirius multifiliis* | 5.7mg/L (4 h) |
| *Thymus vulgaris* | *Ichthyophthirius multifiliis* | 40.0 mg/L (4 h) |
| *Lavandula angustifolia* | *Ichthyophthirius multifiliis* | 40.0 mg/L (4 h) |
| *Cynanchum atratum* | *Ichthyophthirius multifiliis* | 8.4 mg/L 4 h) |
| *Zingiber officinale,* | *Ichthyophthirius multifiliis* | 2.5 mg/L 4 h) |
| *Cynanchum paniculatum* | *Ichthyophthirius multifiliis* | 6.4 mg/L 4 h) |
| *Allium cepa* | *Dactylogyrus* spp. | 3.4 g/L (96 h) |
| *Allium sativum* | *Dactylogyrus* spp. | 0.4 g/L (96 h) |
| *Allium cepa* | *Gyrodactylus elegans* | 4.7 g/L (3 min) |
| *Allium sativum* | *Gyrodactylus elegans* | 8.4 g/L (3 min) |
| *Evodia rutaecarpa* | *Gyrodactylus kobayashii* | 24.0 mg/L (4 h) |
| *Sophora flavescens* | *Gyrodactylus kobayashii* | 224.4 mg/L (4 h) |
| *Cnidium monnieri* | *Gyrodactylus kobayashii* | 11.1 mg/L (4 h) |
| *Madhuca latifolia* | *Argulus foliaceus* | 16.4 mg/L (36 h) |

strategy for controlling *I. multifiliis* infections and increasing the *C. auratus* survival after parasitism by this protozoan (Wu et al., 2017). These results demonstrate the increasing number of experimental studies with phytochemicals against this ciliate parasite because this cosmopolitan pathogenic ciliate protozoan causes ichthyophthiriosis, threatening the global fish aquaculture production (Fu et al., 2021; Mathiessen et al., 2021; Huang et al., 2022; Rahmati-Holasoo et al., 2024; Rahmati-Holasoo and Nassiri, 2025).

Previous review studies listed the *in vivo* efficacy of different herbal extracts against *Trichodina* sp. (Valladão et al., 2015). Feeding *C. carpio* with different concentrations of *Lippia sidoides* had no effect on infection levels by *Trichodina reticulata*, *Trichodina heterodentata*, and *Trichodina* sp., in the gills of this host fish (Brasil et al., 209). However, baths with *A. sativum* oil showed efficacy against trichodinds on *Arapaima gigas* gills (Oliveira-Lima et al., 2025). Similarly, dietary supplementation with *O. vulgare* essential oil also prevented infection by *Ichthyobodo salmonis* and *Trichodina truttae* in *Oncorhynchus keta* reared in small tanks or outdoor hatchery ponds (Mizuno et al., 2018). Vercellini et al. (2025) demonstrated that eugenol reduced the abundance of *Trichodina* spp. in gills and skin of *Cnesterodon decemmaculatus*. Baths with *M. piperita* essential oil also reduced *Piscinoodinium pillulare* infections in *Colossoma macropomum* gills (Ferreira et al., 2019), as did baths with essential oils of *Aloysia triphylla, Lippia grata*, and *Piper aduncum* (Santos et al., 2023). 2′,4′-Dihydroxychalcone and tomatine exhibited *in vitro* effects on the motility of *Amyloodinium ocellatum*, in contrast to exposure to 7-hydroxyflavone, artemisinin, camphor (1R), diallyl sulfide, esculetin, eucalyptol, garlicin 80%, harmalol hydrochloride dihydrate, palmatine chloride, piperine, resveratrol, rosmarinic acid, sclareolide, and umbelliferone (Tedesco et al., 2020). *Allium sativum* extract immobilized 100% of *Cryptocaryon irritans* stages. However, supplementation with garlic powder and baths with garlic extract, as well as combined treatment involving feeding and bathing, failed to cure *P. reticulata* of the infection, though reduced infection intensity on the caudal fin but not in the gills of fish (Hyun-Kim et al., 2019). Honokiol, magnolol, oleanolic acid, and matrine, all *Magnolia officinalis*-derived phytochemicals, exhibited antiparasitic activity against *C. irritans* theronts (Zhong et al., 2019; Guo et al., 2025). Similarly, extracts of *Camellia sinensis* and their majority chemical component, epigallocatechin, presented high *in vitro* and *in vivo* efficacy against *C. irritans* in *Larimichthys crocea* (Yuan et al., 2025). Curcumin was identified as an effective agent against *Chilodonella uncinata* among 26 tested phytochemical compounds (Han et al., 2024). Tang et al. (2024) reported the *in vitro* parasiticide efficacy against *Tetrahymena piriformis* of 21 medicinal plant extracts.

Argulosis is a serious parasitic disease in fish aquaculture and ornamental fish rearing (Kumari et al., 2019; Haridevamuthu et al., 2024; Acharya et al., 2025; Sharma et al., 2025; Shaikh, 2025). It has caused estimated losses of USD 62.5 million in Indian fish aquaculture alone (Haridevamuthu et al., 2024). *Azadirachta indica* extracts presented *in vitro* efficacy against *Argulus japonicus* and *Argulus foliaceus*; however, no efficacy against *A. japonicus* on *C. auratus* was observed (Kumari et al., 2019; Shaikh, 2025), while *Madhuca latifolia* extracts had *in vitro* and *in vivo* efficacy against *A. foliaceus* of *C. carpio* (Acharya et al., 2025). *Curcuma longa* essential oil has also been shown to be effective against species of *Argulus* that infect *C. auratus* (Saengsitthisak et al., 2023). The essential oil of *Cymbopogon citratus* showed in vitro efficacy against both *Argulus* sp. and *Dolops discoidalis* (Pereira et al., 2020), as did azadirachtin against *Argulus* sp. (Sharma et al., 2025). The alkaloid pellitorine was effective at preventing infestations by species of *Argulus* in *C. auratus* (Boopathi et al., 2024). *Illicium verum* extracts were effective in vitro against *Lernaea cyprina*cea (Attia et al., 2022). Extracts of *Artemisia* sp. were also effective against *Argulus coregoni* and *L. cyprinacea* infestations in *Cyprinus carpio* (Khoris and Bileh, 2024). The juices of *A. sativum* and *A. cepa* were effective *in vitro* against *Lernantropus kroyeri*. In contrast, *Carica papaya* seed juice was ineffective against *Argulus indicus* in *C. auratus* (Sari et al., 2024). A recent study demonstrated the *in vitro* antiparasitic efficacy of synthesized silver nanoparticles with *A. indica* extract (Green synthesis) against the adult and copepodite stages of *A. siamensis* (Kumari et al., 2025). These positive results are due to structural alterations in the argulid body structure caused by phytotherapeutic compounds, which induce the generation of reactive oxygen species (ROS) and damage the parasites' tegumentary cells (Pereira et al., 2020; Boopathi et al., 2024). Citral has also demonstrated *in vitro* efficacy against the myxosporidean *Enteromyxum leei* (Kim et al., 2025).

*In vitro* exposure to essential oils of *Mentha piperita*, *L. alba*, *Piper hispidinervum*, *P. hispidum*, *P. marginatum*, *P. callosum,* or *Z. officinale* was highly effective against the acanthocephalan *Neoechinorhynchus buttnerae* (Santos et al., 2018; Costa et al., 2020). Supplementing *C. macropomum* with essential oils from *L. grata*, *L. origanoides*, *M. piperita*, or *O. gratissimum* controlled *N. buttnerae* infections, unlike feeding supplemented with essential oils from *L. alba* or *Z. officinale* (Costa et al., 2020; Oliveira et al., 2024). Conversely, essential oils of *Origanum compactum*, *O. syriacum*, *M. alternifolia*, *Nepeta cataria*, and *Tagetes minuta*, as well as their majority constituents, carvacrol and thymol, were effective against *Anisakis simplex* larvae (López et al., 2018; Faria and Silva, 2021), as were both *Satureja montana* subsp. *montana* and subsp. *variegata* essential oils, as well as wood creosote (Les et al., 2024; Pereira et al., 2025). *Verbesina alternifolia* extracts were more effective at inducing *in vitro* mortality of *Clinostomum phalacrocoracis* metacercariae than *M. piperita* extracts (Mahdy et al., 2022), and *V. alternifolia* and *M. piperita* extracts also exhibited *in vitro* efficacy against *Euclinostomum heterostomum* metacercariae (Mahdy et al., 2017). Therapeutic baths with *A. indica* extract are effective against *Centrocestus formosanus* metacercariae infecting *Oreochromis niloticus* (Radwan et al., 2024). In constrast, eugenol has not efficacy against metacercarie of Echinostomatidae gen. sp. *Ascocotyle* sp., *Pygidiopsis* sp. and *Saccocoelioides kirchnerii* on *C. decemmaculatus* (Vercellini et al., 2025).

Feeding *A. gigas* with *P. aduncum* essential oil demonstrated anthelmintic efficacy against *Hysterothylacium* sp. larvae (Corral et al., 2018). Extracts of *A. indica* and *Aframomum melegueta*, as well as a mixture of both, exhibited *in vitro* efficacy against acanthocephalans *Tenuisentis* sp., cestodes *Wenyonia* sp. and *Electrotaenia* sp., and nematodes *Procamallanus* sp. (Ukwa et al., 2024). *Azadirachta ipotential* and *Nephrolepis biserrata* extracts, and fractions of *N. biserrata* extracts showed potential action against leech *Zeylanicobdella arugamensis* (Shah et al., 2020, 2021; Maran et al., 2021) as well as *R. officinalis* solution against *Zeylanicobdella* sp. in *Epinephelus fuscoguttatus x Epinephelus lanceolatus* hybrids (Zahra et al., 2023). Therefore, controlling these helminth parasites with phytotherapeutic agents that are effective and present significant anthelmintic potential may be a safer therapy option in fish aquaculture.

Given that various phytotherapeutic agents have shown parasiticide effectiveness results against several parasite species, the need for chemotherapeutants in fish aquaculture will consequently decrease. This is a good alternative to chemotherapeutic agents. Further studies are needed on different phytotherapics with parasiticide activity to increase their use in local, regional, and global fish aquaculture, providing more effective and less harmful control and treatment of parasite disease outbreaks. Nevertheless, there are some limitations regarding phytotherapy. For instance, there is a lack of proper information on phytochemical composition, toxicity, and the adequate dosage and effectiveness of extracts and essential oils. There is also a lack of information on the action mechanisms of these products against most parasites. The use of phytotherapeutics in large-scale fish aquaculture production is also limited by factors such as low yield (e.g., essential oils), high processing costs, and low purity of phytotherapeutic extracts. These are significant challenges that must be overcome (Liu et al., 2023). These significant advances in managing parasitic diseases using phytotherapics as parasiticides should increase economic sustainability and improve the livelihoods of many fish producers globally. This could help the global fish aquaculture industry avoid enormous economic losses caused by parasite disease outbreaks, which are not restricted to developing countries.

## 4 Medicinal plants and phytochemicals used for controlling and treating infections by monopisthocotylans and polyopisthocotylans in fish from aquaculture

The increase in intensive production systems in global fish aquaculture has also increased the occurrence of diseases cause by Monopisthocotyla and Polyopisthocotyla species, which can infect the skin, fins, gills, mouth cavity, and nostrils of freshwater, marine, and brackish water fish hosts. Most parasite monopisthocotylans and polyopisthocotylans are browsers that move freely on body surface, fins and gills, and can be transmitted within a population speedily due to their direct life cycle and short-generation time (Grano-Maldonado et al., 2018; Morales-Serna et al., 2019; Zhou et al., 2020; Lian et al., 2020; Tedesco et al., 2020; Tu et al., 2021; Assane et al., 2022; Leis et al., 2023; Liu et al., 2023; Ávila-Castillo et al., 2024; Jetithor et al., 2025; Tu et al., 2025). Recently, Brabec et al. (2023) suppressing Monogenea class as the conventional terminology, and suggested Monopisthocotyla and Polyopisthocotyla as new classes. These parasites can detect different species of fish in aquatic environments through sensory structures, facilitating direct transmission among host fish, especially in intensive fish aquaculture. These parasites belong to approximately 3,000 species, which are distributed among 240 genera and 15 families, which infects a wide array of fish species that can exhibit different levels of susceptibility to them (Morales-Serna et al., 2019; Hoai, 2020; Doan et al., 2020; Lian et al., 2020; Liu et al., 2023; Ávila-Castillo et al., 2024; Tu et al., 2025; Alves et al., 2025; Baia et al., 2024). Several species of Dactylogyridae, Gyrodactylidae, Diplectanidae, Capsalidae, and Ancyrocephalidae are pathogenic to fish, while Polystomatidae and Microcotylidae have great potential to cause diseases (Morales-Serna et al., 2019; Trasviña-Moreno et al., 2019; Hoai, 2020; Mladineo et al., 2021; Tu et al., 2021; Liu et al., 2023; Ávila-Castillo et al., 2024; Caña-Bozada et al., 2024). Thus, such parasites are a major concern worldwide because the diseases they cause affect the viability of fish aquaculture (Hoai, 2020; Liu et al., 2023; Reda et al., 2024; Rahman et al., 2024; Alves et al., 2025; Baia et al., 2024), especially as the world tends towards this food production industry.

Some species oh these parasites attach to and feed on the gills of host fish, which can result in excessive mucus secretion, hemorrhages, tissue loss, and different inflammatory reactions. These reactions can provoke massive fish mortality, especially in heavy infections (Morales-Serna et al., 2019; Trasviña-Moreno et al., 2019; Hoai, 2020; Mladineo et al., 2021; Tu et al., 2021; Liu et al., 2023; Ávila-Castillo et al., 2024; Caña-Bozada et al., 2024; Rahman et al., 2024). For instance, species of Gyrodactylidae, which frequently infect the tegument of fish, cause significant damages to the epidermis of hosts, favoring secondary infections with other pathogens. These secondary infections can increase fish mortality, leading to considerable losses in intensive aquaculture (Zhou et al., 2021; Liu et al., 2023). One of the most common effects of high infection rates by monopisthocotylans and polyopisthocotylans in fish is gill damage because gills are important respiratory organs (Grano-Maldonado et al., 2018; Morales-Serna et al., 2019; Hoai, 2020; Doan et al., 2020; Tavares-Dias et al., 2021a; Ávila-Castillo et al., 2024; Tu et al., 2025; Hanna et al., 2025). Consequently, diseases by monopisthocotylans and polyopisthocotylans can negatively impact the health and welfare of fish population, posing significant risks to global fish aquaculture production by reducing growth and causing morbidity and mortality, resulting in substantial economic losses through direct and indirect costs, which are difficult to project on a regional scale (Doan et al., 2020; Hoai, 2020; Lian et al., 2020; Liu et al., 2023; Ávila-Castillo et al., 2024; Tu et al., 2025). These impacts are also unknown globally because such estimates are very complex. However, massive mortality of marine and freshwater fish in aquaculture had a large economic impact in some countries, provoked by epizootic outbreaks of these ectoparasites. Hoai (2020) recently listed the costs of controlling and managing such parasites, which was responsible for economic losses of more than USD 700 million. Therefore, parasitosis principally by monopisthocotylans is a major global concern because it affects the viability of fish production, especially as the world tends towards fish aquaculture. Consequently, these problems requiring control and treatments, which usually have been made using chemotherapeutants.

Since some of these chemotherapeutants were formulated over half a century ago, so the resistance emergence in these parasites worms is inevitable, leading to enormous concern (Trasviña-Moreno et al., 2019; Hoai, 2020; Lian et al., 2020; Doan et al., 2020; Tu et al., 2021; Ji et al., 2025; Alves et al., 2025). This resistance is usually caused by excessive and frequent use of the same chemotherapeutants, which lead to genetic changes in the parasite populations in response to the antiparasitic chemicals. This impairs the control and treatment of monopisthocotylans and polyopisthocotylans in fish aquaculture (Ranasinghe et al., 2023). Several chemotherapeutic agents that are effective against monopisthocotylans and polyopisthocotylans also leave fish vulnerable to reinfection (Trasviña-Moreno et al., 2019). Parasitosis by monopisthocotylans and polyopisthocotylans can also result in secondary infections with other pathogenic microorganisms (Lian et al., 2020; Silva et al., 2024), making their control in fish aquaculture difficult. These unsatisfactory results make the discovery of new, effective, and safer drugs urgent to combat these parasites (Tu et al., 2025; Alves et al., 2025). Thus, herbal therapy is pursuing new avenues. Phytotherapy has not only been used recently in fish aquaculture, but also in veterinary medicine to treat various ailments in other animal species, because ethnoveterinary medicine is crucial in rural areas with limited access to modern drugs. People living in these remote areas rely on traditional therapies to treat domestic animals (Ranasinghe et al., 2023), including fish.

Diverse studies have been conducted on different herbal products to evaluate their efficacy against monopisthocotylans or polyopisthocotylans, with varied results. For example, *A. sativum, A. cepa*, and *Carica papaya* extracts were not effective *in vitro* against *Neobenedenia* spp., unlike *Z. officinale*, *Castela tortuousa,* and *Ocimum basilicum* extracts (Trasviña-Moreno et al., 2019). *Allium cepa* and *A. sativum* extracts showed low effectiveness against *Gyrodactylus elegans* in *C. carpio* (Yildiz and Bekcan, 2020). *In vitro* studies with *Glycyrrhiza uralensis* extracts, curcumin, emodin, and 10-gingerol also demonstrated that these did not kill 100% of *Neobenedenia girellae* (Liu et al., 2021). *In vitro* trials using two commercial products based-allicin of *A. sativum* (Aquagarlic-A and Aquagarlic-P) showed 100% efficacy anti-*Neobenedenia girellae* and *Zeuxapta seriolae* (Ingelbrecht et al., 2020). Essential oils from *L. origanoides* and *L. sidoides* were ineffective against *Anacanthorus spathulatus, Notozothecium janauachensis,* and *Mymarothecium boegeri* in *C. macropomum* gills (Soares et al., 2017a, b). Similarly, extracts of *Allium macrostemon* and *Polygonatum odoratum* were also ineffective against *G. kobayashii* in *C. auratus* baths, whereas extracts of *Periploca forrestii*, *C. paniculatum*, *Cynanchum atratum*, *Rohdea japonica*, *Lilium brownie*, *Tribulus terrestris*, *Solanum nigrum*, *Trigonella foenum-graecum*, *Trillium tschonoskii*, *Periploca calophylla*, *Curcuma longa*, *Aspidistra elatior*, *Asparagus cochinchinensis*, *Hosta plantaginea*, *Anemarrhena asphodeloides*, *Marsdenia tenacissima* and *Dioscorea polystachya* (Lian et al., 2020; Zhou et al., 2021) and the essential oil from *Syzygium aromaticum*, *O. vulgare*, *Pimpinella anisum*, *Mentha sachalinensis*, *Foeniculum vulgare*, and *Citrus limon* showed low efficacy (Zhou et al., 2022). Vercellini et al. (2024) reported that baths with 20 mg/L of eugenol decreased the abundance of *Diaphorocleidus* sp. in *Cheirodon interruptus*, while 125 mg/L of menthol had no therapeutic efficacy. Steverding et al. (2005) reported that *M. alternifolia* oil and Tween 80 as an emulsifier exhibited activity against *Gyrodactylus* spp. in *Gasterosteus aculeatus*.

Thirty days of dietary supplementation with *R. officinalis* extract (60–100 mL/100 g/ feed) for *C. carpio* resulted in a significant decrease in the intensity of *Dactylogyrus minutus* (Zoral et al., 2017). Similarly, supplemented diets (by 20 or 30 days) with *R. officinalis* (168.5 mL/kg) and *A. sativum* extracts (10 g/kg), and *R. officinalis* essential oil (0.1 mL/kg) prevented infection and reduced abundance of *Z. seriolae* in *Seriola lalandi* (Ingelbrecht et al., 2020). Two types of feed supplemented with different concentrations (1–4 kg/ton) of commercial phytotherapeutic agents containing *Curcuma longa*, *Allium sativum* and *Ocimum sanctum* and *Terminalis bellerica* for four weeks reduced infection rates by 40.0% in the skin and gills of *O. niloticus* by *Dactylogyrus* sp. (Hanna et al., 2025). Similarly, supplementing diets with 3% *A. sativum* powder for 30 days had 45.6% efficacy against *Cichlidogyrus thurstonae*, *C. sclerosus*, *C. halli*, and *C. tubicirrus* in the gills of *O. niloticus* (Salgado-Moreno et al., 2025). However, feeding *C. carpio* with different concentrations of *L. sidoides* had no effect on *Dactylogyrus minutus* and *D. extensus* infection levels in the gills of this host fish (Brasil et al., 2019).

Previous review studies have listed few herbal extracts, essential oils or majority constituents with anthelmintic potential against several monopisthocotylans and polyopisthocotylans species (Valladão et al., 2015; Tavares-Dias, 2018). This step is fundamental to determining the anthelmintic potential of these substances for use in fish aquaculture. However, only eight of the 12 essential oils or their majority constituents tested in therapeutic baths against monopisthocotylans and polyopisthocotylans were found to be effective (Tavares-Dias, 2018). In present study, we found that has been used *in vitro* screening of phytotherapeutic agents against monopisthocotylans and polyopisthocotylans from 41 plant species, including 25 essential oils, 20 extracts, 27 natural compounds, and three oleoresins from various families such as Verbenaceae, Fabaceae, Rutaceae, Lamiaceae, Bixaceae, Piperaceae, Euphorbiaceae, Dryopteridaceae, Alliaceae, Poaceae, Lythraceae, Caricaceae, and Zingiberaceae.Therapeutic baths for fish against monopisthocotylans and polyopisthocotylans have used 93 plant species (69 extracts, 20 essential oils, 19 natural compounds, two oleoresins, two nanoemulsions with oleoresins, one hydrolate and one fixed oil) of different families (e.g., Fabaceae, Euphorbiaceae, Asteraceae, Piperaceae, Poaceae, Pinaceae, Lamiaceae, Lythraceae, Apocynaceae, Myrtaceae, Dryopteridaceae, Verbenaceae, Bixaceae, Zingiberaceae, Pinaceae, Meliaceae, Apocynaceae, Lauraceae, Dioscoreaceae, Alliaceae, and others). Accordingly, as expected, the number of controlled experimental studies has increased to provide scientific evidence of the anti- monopisthocotylans and polyopisthocotylans activity of medicinal plant extracts, essential oils, and phytochemicals, both *in vitro* and *in vivo*, particularly in studies on therapeutic baths in species of interest for fish aquaculture (Tab. 2 and 3). These results indicate an increase in attention to the use of phytotherapeutics anti-monopisthocotylans and polyopisthocotylans, thereby preventing diseases. Given the satisfactory results of phytotherapics these terapeuthics agents are a promising option for controlling and treating infections by

**Table 2.** Medicinal plants and phytochemicals compounds *in vitro* screened with potential anti-monopisthocotylans and polyopisthocotylans in fish species.

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| *Pterodon emarginatus* essential oil nanoemulsion | *β*-elemene, b-caryophyllene and a-humulene | 400 and 600 mg/L | 100% - 15 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Valentim et al. (2018a) |
| *Copaifera officinalis* oleoesin nanoemulsion | *β*-caryophyllene | 200 and 300 mg/L | 100% - 15 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Valentim et al. (2018b) |
| *Copaifera duckei* oleoresin | *β*- bisabolene (30.9%) and trans-α- ergamotene (21.9%) | 100 mg/L | 100% - 4 h | *Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Costa et al. (2017) |
| *Copaifera reticulata* oleoresin | γ-macrocarpene 14.2%), α-bergamotene (13.6%), *β* -selinene (13.4%) and *β* -caryophyllene (11.7%) | 1000 mg/L | 97.0% - 15 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Malheiros et al. (2020) |
| *Ficus insipida* latex | – | 1000 µL/L | 100% - 2 h | *Notozothecium janauachensis, Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Gonzales et al. (2019) |
| *Rosmarinus officinalis* extract | 1,8-cineole, α-pinene, β-pinene, Camphor and camphene) | 150 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| *Rosmarinus officinalis* extract | 1,8-cineole, α-pinene, β-pinene, camphor and camphene) | 4 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| *Rosmarinus officinalis* extract | 1,8-cineole | 20 g/100 mL | 100% - 7-53 min | *Neobenedenia girellae* | Ingelbrecht et al. (2020) |
| *Rosmarinus officinalis* extract | 1,8-cineole | 20 g/100 mL | 100% - 42 min | *Zeuxapta seriolae* | Ingelbrecht et al. (2020) |
| *Bixa orellana* extract | Bixin (49.0%) | 500 µg/mL | 90.0% - 4 h | *Anacanthorus spathulatus* | Andrade et al. (2016) |
| *Piper aduncum* extract | 412.7 µg/mL | 200 mg/L | 100% - 4 h | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Queiroz et al. (2022) |
| *Astragalus membranaceus* extract | – | 1000 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| *Dryopteris setosa* extract | – | 1000 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| *Glycyrrhiza uralensis* extract | – | 1000 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| *Salvia miltiorrhiza* extract | – | 1000 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| *Zingiber officinale* extract | – | 250 mg/L/mL | 100% - 5 min | *Dactylogyrus* sp. | Van et al. (2021) |
| *Punica granatum* extract | – | 500 mg/L/mL | 100% - 3 min | *Dactylogyrus* sp. | Van et al. (2021) |
| *Punica granatum* extract | – | 1000 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |

**Table 2.** (continued).

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| *Carica papaya* seed extract | Capric acid (71.2%), oleic acid (71.2%), tetradecanoic acid (61.3%) and linoleic acid, methyl ester (63.4%) | 2 mL/L | 100% - 1 h | *Cichlidogyrus tilapiae* | Radwan et al. (2023) |
| *Vernonia amygdalina* extract | – | 40 mg/L | 46.5% –3.9 h | *Diplozoon* spp., and capsalids, *Dactylogyrus* spp. and *Gyrodactylus* spp. | Jetithor et al. (2025) |
| *Pseudolarix amabilis* extract | (+)-catechin | 100 mg/L | 100% - 48 h | *Dactylogyrus intermedius* | Ji et al. (2025) |
| *Allium cepa* extract | – | 10 mg/mL | 100% - 6 min | *Gyrodactylus elegans* | Yildiz and Bekcan (2020) |
| *Allium cepa* extract | Alkaloids, flavonoids, tannins, saponins, cardiac glycosides, terpenoids and resin | 0.5 g/mL | 100% - 25 min | *Dactylogyrus* spp. | Reda et al. (2024) |
| *Allium sativum* extract | Allicin | 1 g/100 mL | 100% - 3 min | *Neobenedenia girellae* | Ingelbrecht et al. (2020) |
| *Allium sativum* extract | Allicin | 1 g/100 mL | 100% - 40 min | *Zeuxapta seriolae* | Ingelbrecht et al. (2020) |
| *Allium sativum* extract | – | 10 mg/mL | 100% - 6 min | *Gyrodactylus elegans* | Yildiz and Bekcan (2020) |
| *Jatropha gossypiifolia* extract | Phenolic compounds (59.4%) and lipids (21.9%) | 2000 mg/L | 100% - 45 min | *Anacanthorus spathulatus, Mymarothecium viatorum* and *Anacanthorus penilabiatus* | Cornejo-Rigaud et al. (2025) |
| *Jatropha curcas* extract | Phenolic compounds (66.6%) and lipids (29.25) | 1500- 2000 mg/L | 100% - 10 min | *Anacanthorus spathulatus, Mymarothecium viatorum* and *Anacanthorus penilabiatus* | Cornejo-Rigaud et al. (2025) |
| *Allium sativum* extract | Alkaloids, flavonoids, tannins, saponins, cardiac glycosides, terpenoids and resin | 0.5 g/mL | 100% - 5 min | *Dactylogyrus* spp. | Reda et al. (2024) |
| *Ocimum gratissimum* essential oil | Eugenol (42.3%) and 1,8-cineole (20.4%) | 320 mg/L | 100% - 2 h | *Cichlidogyrus tilapiae* | Meneses et al. (2018) |
| *Ocimum gratissimum* essential oil | Eugenol (95.0%) | 10 mg/L | 50.0% - 1 h | *Gyrodactylus* sp. | Bandeira Jr et al. (2017) |
| *Hesperozygis ringens* essential oil | Pulegone (97.0%) | 10 mg/L | 40.0% -1 h | *Gyrodactylus* sp. | Bandeira Jr et al. (2017) |
| *Melaleuca alternifolia* essential oil | Terpinen-4-ol (39.8%) and γ-terpinene (14.6%) | 400 mg/L | 100% - 4 h | *Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Costa et al. (2017) |
| *Melaleuca alternifolia* essential oil | terpinen-4-ol | 1 μL/mL | 100% - 2 min | *Dactylogyrus* sp. | Yilmaz and Yildiz (2023) |
| *Melaleuca alternifolia* essential oil | Oleic acid (13.95), α-terpinene (11.30%), γ-terpinene (10.76%), terpinen-4-ol | 40 mg/L | 100% - 8 h | *Dactylogyrus* spp. | Rahman et al. (2024) |

**Table 2.** (continued).

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| | (9.09%),1,8-cineole (8.95%) and p-cymene (8.11%) | | | | |
| *Mentha piperita* essential oil | Menthol (35.2%) menthone and (21.4%) | 400 mg/L | 100% - 4 h | *Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Costa et al. (2017) |
| *Mentha piperita* essential oil | Menthol (30.5%), menthyl acetate (14.5%), pulegone (14.2%) and menthone (12.9%). | 700 mg/L | 100% - 9 min | *Neobenedenia melleni* | Silva et al. (2024) |
| *Mentha piperita* essential oil | Menthol | 1 µL/mL | 100% - 15 min | *Dactylogyrus* sp. | Yilmaz and Yildiz (2023) |
| *Lippia alba* essential oil | Carvone (58.2%) | 100 mg/L | 100% - 3 h and 12 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Lippia alba* essential oil | Carvone (61.7% | 550 mg/L | 100% - 1 h | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Tavares-Dias et al. (2021a) |
| *Lippia origanoides* essential oil | Carvacrol (49.7%) and p-Cymeno (13.3%) | 320 mg/L | 100% - 20 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis*, *Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Soares et al. (2017a) |
| *Lippia origanoides* essential oil | p-cymene (37.0%) | 60 mg/L | 100% - 9 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Lippia origanoides* essential oil | Carvacrol (49.7%) and γ-terpinene (11.6%) | 700 mg/L | 100% - 1 min | *Neobenedenia melleni* | Silva et al. (2024) |
| *Lippia sidoides* essential oil | Thymol (64.5%) | 320 mg/L | 100% - 10 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis* and *Mymarothecium boegeri* | Soares et al. (2017b) |
| *Lippia sidoides* essential oil | Thymol (75.4%) | 700 mg/L | 100% - 4 min | *Neobenedenia melleni* | Silva et al. (2024) |
| *Lippia sidoides* essential oil | Thymol (72.2%) | 40 mg/L | 100% - 8 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Lippia alba* + *Lippia origanoides* essential oil | – | 60 mg/L | 100% -12 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Lippia alba* + *Lippia sidoides* essential oil | – | 60 mg/L | 100% - 20 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Lippia origanoides* + *Lippia sidoides* essential oil | – | 80 mg/L | 100% -8 min | *Dactylogyrus minutus* and *Dactylogyrus extensus* | Brasil et al. (2019) |
| *Cymbopogon citratus* essential oil | Geranial (45.7%) and neral (33.9%) | 500 mg/mL | 100% - 4 min | *Anacanthorus spathulatus*, *Mymarothecium boegeri* | Gonzales et al. (2020) |

**Table 2.** (continued).

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| | | | | and *Notozothecium janauachensis* | |
| *Cymbopogon martinii* essential oil | – | 24 mg/L | 100% - 4 h | *Gyrodactylus kobayashii* | Zhou et al. (2022) |
| *Cymbopogon nardus* essential oil | | 13.7 mg/L | 100% - 30 min | *Anacanthorus spathulatus*, *Mymarothecium boegeri* and *Notozothecium janauachensis* | Luz et al. (2025) |
| *Minthostachys mollis* essential oil | Pulegone (36.8%) and menthone (13.4%) | 800 mg/L | 100% - 5 min | *Anacanthorus spathulatus, Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Gonzales et al. (2022) |
| *Origanum vulgare* essential oil | Sabinene (25.7%, γ-Terpinene (11.5%) and L-4-terpineo (11.4%) | 1000 mg/L | 100% - 8 min | *Anacanthorus spathulatus*, *Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Gonzales et al. (2022) |
| *Salvia rosmarinus* essential oil | α-pinene (25.5%) and eucalyptol (24.2%) | 1500 mg/L | 100% - 8 min | *Anacanthorus spathulatus, Anacanthorus penilabiatus* and *Mymarothecium viatorum* | Gonzales et al. (2022) |
| *Alpinia zerumbet* essential oil | Terpinen – 4-ol (27.7%) and eucalyptol (19.2%) | 600 mg/L | 100% - 3h | *Anacanthorus spathulatus*, *Mymarothecium boegeri* and *Notozothecium janauachensis* | Luz et al. (2021) |
| *Piper callosum* essential oil | Safrole (53.8%) and α-pinene (12.2%) | 600 mg/L | 100% - 5 min | *Anacanthorus spathulatus*, *Notozothecium janauachensis, Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Alves et al. (2021) |
| *Piper hispidum* essential oil | g- terpinene (30.9%) and α- terpinene (14.0%) | 600 mg/L | 100% - 20 min | *Notozothecium janauachensis*, *Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Alves et al. (2021) |
| *Piper marginatum* essential oil | 3,4- methylenedioxy-propiophenone (20.8%) | 200 mg/L | 100% - 1 h | *Notozothecium janauachensis*, *Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Alves et al. (2021) |
| *Lippia grata* essential oil | Carvacrol (48.12%) and p-cymene (24.4%) | 700 mg/L | 100% - 30 min | *Notozothecium janauachensis*, *Mymarothecium boegeri* and *Linguadactyloides brinkmanni* | Barriga et al. (2020) |
| *Curcuma longa* essential oil | – | 30 mg/L | 91.5% - 8 h | *Gyrodactylus kobayashii* | Zhou et al. (2022) |

**Table 2.** (continued).

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| *Curcuma longa* essential oil | α-phellandrene (10.2%) and 1,8-cineole (7.0%) | 13.7 mg/L | 100% - 30 min | *Anacanthorus spathulatus*, *Mymarothecium boegeri* and *Notozothecium janauachensis* | Luz et al. (2025) |
| *Zingiber officinale* essential oil | Limonene (8.0%), Geranial (7.1%) and camphene (4.6%) | 30.9 mg/L | 100% - 2 h and 15 min | *Anacanthorus spathulatus*, *Mymarothecium boegeri* and *Notozothecium janauachensis* | Luz et al. (2025) |
| *Citrus limon* essential oil | Limonene | 1µL/mL | 100% - 10 min | *Dactylogyrus* sp. | Yilmaz and Yildiz (2023) |
| 1,8-cineole | – | 1 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| α-pinene | – | 90 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| β- pinene | – | 90 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| Camphor | – | 180 g/L | 100% - 1 h | *Dactylogyrus minutus* | Zoral et al. (2017) |
| Arctigenin | – | 8 mg/L | 100% - 33 min | *Gyrodactylus kobayashii* | Tu et al. (2018) |
| Timor C | – | 100 mg/L | 100% - 1h | *Gyrodactylus turnbulii* | Zorin et al. (2019) |
| α-terpinene | – | 55.4 mg/L | 60.0% - 5 h | *Cichlidogyrus tilapiae*, *Cichlidogyrus dossoui*, *Cichlidogyrus sclerosus* and *Scutogyrus longicornis* | Morales-Serna et al. (2019) |
| (+)-limonene oxide | – | 55.4 mg/L | 90.0% - 5 h | *Cichlidogyrus tilapiae*, *Cichlidogyrus dossoui*, *Cichlidogyrus sclerosus* and *Scutogyrus longicornis* | Morales-Serna et al. (2019) |
| Curdione | – | 12.0 mg/L | 87.0% - 48 h | *Gyrodactylus kobayashii* | Zhang et al. (2020) |
| 10-gingerol | – | 1000 mg/L | 53.3% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Curcumin | – | 1000 mg/L | 60.0% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Curcumin | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| Plumbagin | – | 2 mg/L | 100% - 45 min | *Gyrodactylus kobayashii* | Tu et al. (2021) |
| Emodin | – | 1000 mg/L | 20.0% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Kuwanon-G | – | 125 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Kuwanon-O | – | 125 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Sophoraflavanone-G | – | 125 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Cynatratoside-C | – | 125 mg/L | 100% - 8 h | *Neobenedenia girellae* | Liu et al. (2021) |
| Ononin | – | 0.5 mg/L | 100% - 48 h | *Dactylogyrus intermedius* | Yang et al. (2022) |
| Dioscin | – | 0.6 mg/L | 100% - 24 h | *Gyrodactylus kobayashii* | Zhou et al. (2021) |
| (+)-catechin | – | 20 mg/L | 98.2% - 48 h | *Dactylogyrus intermedius* | Ji et al. (2025) |
| Azadirachtin | – | 25 mg/L | 100% - 4 h | *Dactylogyrus* sp. | Sharma et al. (2025) |
| Isoimperatorin | – | 1.0-2.0 mg/L | 100% - 2 h | *Gyrodactylus kobayashii* | Liu et al. (2022) |
| Cedrol | – | 0.2 mM | 100% - 1 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| (+) - trans-chrysanthemic acid | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| Coumarin | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |

**Table 2.** (continued).

| Plants or bioactive compounds | Majority components | Concentrations | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|
| Eucalyptol | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| Garlicin 80% | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| Pyrethrins 50% | – | 1 mM | 100% - 24 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |
| 1R - Camphor | – | 2 mM | 100% - 1 h | *Sparicotyle chrysophrii* | Mladineo et al. (2021) |

– Not analyzed.

**Table 3.** Medicinal plants and phytochemicals compounds tested in therapeutic baths for different fish species with anti-monopisthocotylans activity.

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Copaifera duckei oleoresin | β- bisabolene (30.9%) and trans-α-ergamotene (21.9%) | *Piaractus mesopotamicus* | 50 mg/L | 45.0% - 20 min for 7 days | Anacanthorus penilabiatus and Mymarothecium viatorum | Costa et al. (2017) |
| Copaifera reticulata oleoresin | γ-macrocarpene 14.2%), α-bergamotene (13.6%), β-selinene (13.4%) and β-caryophyllene (11.7%) | *Colossoma macropomum* | 100 mg/L | 48.5% - 1 h for 3 days | Anacanthorus spathulatus, Mymarothecium boegeri and Notozothecium janauachensis | Malheiros et al. (2022) |
| Carapa guianensis fixed oil | Oleic acid (53.4%) and palmitic acid (28.7%) | *Colossoma macropomum* | 500 mg/L | 91.4% - 1 h for 5 days | spathulatus, Mymarothecium boegeri and Notozothecium janauachensis | Malheiros et al. (2023) |
| Allium sativum oil | – | *Arapaimas gigas* | 5.0 mg/L | 42.5% - 96 h | Dawestrema cycloancistrium | Oliveira-Lima et al. (2025) |
| Mentha x villosa hydrolate | – | *Colossoma macropomum* | 20 mg/L | 84.5% - 1 h | – | Jatobá et al. (2023) |
| Mentha x villosa hydrolate | – | *Oreochromis aureus* | 20 mg/L | 79.0% - 1 h | – | Jatobá et al. (2023) |
| Mentha x villosa hydrolate | – | *Oreochromis mossambicus* | 20 mg/L | 85.5% - 1 h | – | Jatobá et al. (2023) |
| Mentha x villosa hydrolate | – | *Oreochromis hornorum* | 20 mg/L | 73.5% - 1 h | – | Jatobá et al. (2023) |
| Cortex meliae extract | – | *Carassius auratus* | 155.6 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2017) |
| Radix zanthoxyli extract | – | *Carassius auratus* | 214.5 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2017) |
| Semen aesculi extract | – | *Carassius auratus* | 68.0 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2017) |
| Macleaya cordata extract | – | *Carassius auratus* | 8.6 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2017) |
| Rosmarinus officinalis extract | 1,8-cineole, α-pinene, β-pinene, camphor and camphene | *Cyprinus carpio* | 0.8 g/L | 77.7% - 30 min | Dactylogyrus minutus | Zoral et al. (2017) |

**Table 3.** (continued).

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Rosmarinus officinalis extract | 1,8-cineole, α-pinene, β-pinene, camphor and camphene | *Cyprinus carpio* | 50 g/L | 97.4% - 30 min | Dactylogyrus minutus | Zoral et al. (2017) |
| Bixa orellana seed extract | Bixin (49%) | *Colossoma macropomum* | 250 µg/mL | 100% –2 h for 2 days | Anacanthorus spathulatus | Andrade et al. (2016) |
| Evodia rutaecarpa extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Cnidium monnieri extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Sophora flavescens extract | – | *Carassius auratus* | 300 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Areca catechu extract | – | *Carassius auratus* | 150 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Citrus reticulate extract | – | *Carassius auratus* | 400 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Mentha haplocalyx extract | – | *Carassius auratus* | 400 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Punica granatum extract | – | *Carassius auratus* | 600 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Agrimonia pilosa extract | – | *Carassius auratus* | 600 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Omphalia lapidescens extract | – | *Carassius auratus* | 800 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Quisqualis indica extract | – | *Carassius auratus* | 800 mg/L | 94.7% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Dryopteris crassirhizoma extract | – | *Carassius auratus* | 200 mg/L | 89.0% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Pharbitis nil extract | – | *Carassius auratus* | 200 mg/L | 54.4% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Stemona sessilifolia extract | – | *Carassius auratus* | 700 mg/L | 43.4% - 48 h | Gyrodactylus kobayashii | Lian et al. (2020) |
| Curcuma zedoaria extract | – | *Carassius auratus* | 30 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Peucedanum praeruptorum extract | – | *Carassius auratus* | 30 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Spatholobus suberectus extract | – | *Carassius auratus* | 35 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Homalomena oculta extract | – | *Carassius auratus* | 50 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Paris polyphylla extract | – | *Carassius auratus* | 60 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Paris polyphylla extract | Dioscin, gracillin and Polyphyllin I, II, VI and VII | *Carassius auratus* | 30 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Alisma plantago extract | – | *Carassius auratus* | 70 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Cinnamomum cassia extract | – | *Carassius auratus* | 80 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Cinnamomum cassia extract | – | *Carassius auratus* | 200 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Bletilla striata extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Glycyrrhiza uralensis extract | – | *Carassius auratus* | 100 mg/L | 96.0% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| | – | | 100 mg/L | 95.0% - 48 h | | |

**Table 3.** (continued).

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Vladimiria souliei extract | | *Carassius auratus* | | | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Cynanchum glaucescens extract | – | *Carassius auratus* | 80 mg/L | 90.0% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Capsicum annuum extract | – | *Carassius auratus* | 200 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Lindera aggregata extract | – | *Carassius auratus* | 300 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Pinus massoniana extract | – | *Carassius auratus* | 400 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Rumex japonicus extract | – | *Carassius auratus* | 400 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Daucus carota extract | – | *Carassius auratus* | 600 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Picrasma quassioides extract | – | *Carassius auratus* | 600 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Rheum franzenbachii extract | – | *Carassius auratus* | 700 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Pseudolarix amabilis extract | – | *Carassius auratus* | 800 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Melia toosendan extract | – | *Carassius auratus* | 1000 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Dryopteris crassirhizoma extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Artemisia annua extract | – | *Carassius auratus* | 1000 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Torreya grandis extract | – | *Carassius auratus* | 1000 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Hydnocarpus antihelmintica extract | – | *Carassius auratus* | 600 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Dioscorea collettii extract | – | *Carassius auratus* | 15 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Dioscorea nipponica extract | – | *Carassius auratus* | 35 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Dioscorea spongiosa extract | – | *Carassius auratus* | 250 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Dioscorea bulbifera extract | – | *Carassius auratus* | 800 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Dioscorea zingiberensis extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Dioscorea zingiberensis extract | | *Carassius auratus* | 250 mg/L | 95.6% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Solanum nigrum extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Cynanchum otophyllum extract | – | *Carassius auratus* | 800 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Cynanchum bungei extract | – | *Carassius auratus* | 1000 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Cynanchum stauntonii extract | – | *Carassius auratus* | 100 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Cynanchum stauntonii extract | | *Carassius auratus* | 250 mg/L | 90.2% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Tupistra chinensis extract | – | *Carassius auratus* | 800 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Smilax china extract | – | *Carassius auratus* | 900 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |

**Table 3.** (continued).

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Solanum americanum extract | – | *Carassius auratus* | 1000 mg/L | 98.1% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Reineckea carnea extract | – | *Carassius auratus* | 1000 mg/L | 97.8% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Smilax glabra extract | – | *Carassius auratus* | 250 mg/L | 92.4% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Angelica dahurica extract | Isoimperatorin | *Carassius auratus* | 2.0-5.0 mg/L | 94.4% - 48 h | Gyrodactylus kobayashii | Liu et al. (2022) |
| Piper aduncum extract | – | *Colossoma macropomum* | 60 mg/L | 99.21% - 12 h for 2 days | Anacanthorus spathulatus, Notozothecium janauachensis and Mymarothecium boegeri | Queiroz et al. (2022) |
| Spatholobi caulis extract | Ononin | *Carassius auratus* | 150 mg/L | 100% - 48 h | Dactylogyrus intermedius | Yang et al. (2022) |
| Azadirachta indica extract | Meliantriol (20.8%), nimbidinin (20.7%), azadiradione (20.4%) and quercetin (20.0%) | *Oreochromis niloticus* | 3 g/L | 92.4% - 7 days | Dactylogyrus sp. | Radwan et al. (2024) |
| Allium cepa extract | Alkaloids, flavonoids, tannins, saponins, cardiac glycosides, terpenoids and resin | *Oreochromis niloticus* | 0.07 g/L | 90.5% - 72 h | Dactylogyrus spp. | Reda et al. (2024) |
| Allium sativum extract | Alkaloids, flavonoids, tannins, saponins, cardiac glycosides, terpenoids and resin | *Oreochromis niloticus* | 0.08 g/L | 100% - 72 h | Dactylogyrus spp. | Reda et al. (2024) |
| Jatropha gossypiifolia extract | Phenolic compounds (59.4%) and lipids (21.9%) | *Piaractus brachypomus* | 100 mg/L | 100% - 20 min for 3 days | Anacanthorus spathulatus, Mymarothecium viatorum and Anacanthorus penilabiatus | Cornejo-Rigaud et al. (2025) |
| Jatropha curcas extract | Phenolic compounds (66.6%) and lipids (29.25) | *Piaractus brachypomus* | 100 mg/L | 100% - 20 min for 3 days | Anacanthorus spathulatus, Mymarothecium viatorum and Anacanthorus penilabiatus | Cornejo-Rigaud et al. (2025) |
| Lippia grata essential oil | Carvacrol (48.12%) and pcymene (24.39%) | *Colossoma macropomum* | 700 mg/L | 95.1% - 30 min for 3 days | Notozothecium janauachensis, Mymarothecium boegeri and Linguadactyloides brinkmanni | Barriga et al. (2021) |
| Ocimum gratissimum essential oil | Eugenol (42.3%) and 1,8-cineole (20.4%) | *Oreochromis niloticus* | 320 mg/L | 87.7%- 5 min for 3 days | Cichlidogyrus tilapiae | Meneses et al. (2018) |
| Mentha piperita essential oil | – | *Oreochromis niloticus* | 35 mg/L | 0% - 1h | – | Anjos and Isaac (2020) |
| Mentha piperita essential oil | Menthol | *Cyprinus carpio* | 2.5 µL/mL | 28.3% - 5 min (single) | Dactylogyrus sp. | Yilmaz and Yildiz (2023) |
| | Limonene | | 0.7 µL/mL | | Dactylogyrus sp. | |

**Table 3.** (continued).

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Citrus limon essential oil | | *Cyprinus carpio* | | 30.9% - 5 min (single) | | Yilmaz and Yildiz (2023) |
| Melaleuca alternifólia essential oil | – | *Carassius auratus* | 40 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Melaleuca alternifolia essential oil | Terpinen-4-ol | *Cyprinus carpio* | 0.3 µL/mL | 35.3%% - 2 min (single) | Dactylogyrus sp. | Yilmaz and Yildiz (2023) |
| Cymbopogon citratus essential oil | Geranial (45.7%) and neral (33.9%) | *Colossoma macropomum* | 60 mg/L | 47.1% - 20 min for 3 days | Anacanthorus spathulatus, Mymarothecium boegeri and Notozothecium janauachensis | Gonzales et al. (2020) |
| Cymbopogon martinii essential oil | – | *Carassius auratus* | 10 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Alpinia zerumbet essential oil | Terpinen – 4-ol (27.7%) and eucalyptol (19.2%) | *Colossoma macropomum* | 300 mg/L | 94.0% - 30 min for 6 days | Anacanthorus spathulatus, Mymarothecium boegeri and Notozothecium janauachensis | Luz et al. (2021) |
| Curcula longa essential oil | – | *Carassius auratus* | 12 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Curcuma zedoaria essential oil | – | *Carassius auratus* | 15 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Pogostemon cablin essential oil | – | *Carassius auratus* | 10 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Ruta graveolens essential oil | – | *Carassius auratus* | 25 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Melia azedarace essential oil | – | *Carassius auratus* | 40 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Cinnamomum cassia essential oil | – | *Carassius auratus* | 14 mg/L | 95.0% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Eucalyptus globulus essential oil | | *Carassius auratus* | 100 mg/L | 90.1% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2022) |
| Piper marginatum essential oil | 3,4-methylenedioxy-propiophenone (20.8%) | *Colossoma macropomum* | 100 mg/L | 42.8% - 20 min for 6 days | Notozothecium janauachensis, Mymarothecium boegeri and Linguadactyloides brinkmanni | Alves et al. (2024a) |
| Piper hispidum essential oil | γ- terpinene (30.9%) and α- terpinene (14.0%) | *Colossoma macropomum* | 100 mg/L | 78.6% - 1 h for 3 days | Notozothecium janauachensis, Mymarothecium boegeri and Linguadactyloides brinkmanni | Alves et al. (2024b) |
| Piper callosum essential oil | Safrole (53.8%) and α- pinene (12.2%) | *Colossoma macropomum* | 100 mg/L | 83.6% - 20 min for 6 days | Anacanthorus spathulatus, Notozothecium janauachensis, Mymarothecium boegeri and Linguadactyloides brinkmanni | Alves et al. (2025) |
| Arctigenin | – | *Carassius auratus* | 6 mg/L | 100% - 3 h | Gyrodactylus kobayashii | Tu et al. (2018) |

**Table 3.** (continued).

| Plants or bioactive compounds | Majority component | Host fish species | Concentration | Efficacy-Exposure | Species of parasite | References |
|---|---|---|---|---|---|---|
| Curdone | | *Carassius auratus* | 3 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhang et al. (2020) |
| Dioscin | – | *Carassius auratus* | 0.5 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Dioscin | – | *Carassius auratus* | 0.6 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Zhou et al. (2021) |
| Gracillin | – | *Carassius auratus* | 0.2 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Polyphyllin I | – | *Carassius auratus* | 0.2 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Polyphyllin II | – | *Carassius auratus* | 0.2 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Polyphyllin VI | – | *Carassius auratus* | 1.9 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Polyphyllin VII | – | *Carassius auratus* | 2.7 mg/L | 100% - 48 h | Gyrodactylus kobayashii | Zhou et al. (2020) |
| Plumbagin | – | *Carassius auratus* | 4.0 mg/L | 100% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Thymoquinone | – | *Carassius auratus* | 0.75 mg/L | 100% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Psoralen | – | *Carassius auratus* | 4 mg/L | 100% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Osthole | – | *Carassius auratus* | 4 mg/L | 100% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Quercetin | – | *Carassius auratus* | 16 mg/L | 91.7% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Betulin | – | *Carassius auratus* | 8 mg/L | 81.5% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Berberine | – | *Carassius auratus* | 16 mg/L | 80.0% - 48 h | Gyrodactylus kobayashi | Tu et al. (2021) |
| Isoimperatorin | – | *Carassius auratus* | 1 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Liu et al. (2022) |
| Ononin | – | *Carassius auratus* | 1 mg/L | 100% - 24 h | Dactylogyrus intermedius | Yang et al. (2022) |
| Thymoquinone | – | *Carassius auratus* | 3 mg/L | 100% - 24 h | Gyrodactylus kobayashii | Tu et al. (2025) |

– Not analyzed.

monopisthocotylans and polyopisthocotylans in aquaculture fish. However, these results must be validated in large-scale aquaculture systems.

The low yield of essential oils and the low purity of phytotherapy extracts make it difficult to identify their majority phytochemical compounds. This could explain the few commercial phytotherapeutics against monopisthocotylans and polyopisthocotylans, as well as the lack of studies in the field validating experimental results in aquaculture tanks using fish for consumption. These studies require large quantities of essential oils and fish, leading to high costs. Consequently, many studies have only been carried out *in vitro* screening with phytotherapeutic agents in models with different monopisthocotylans and polyopisthocotylans species of interest in aquaculture because these experiments are quicker and more economical than therapeutic baths, which require a greater number of fish and demand their sacrifice. Often, these studies terminate at this prescreen. Despite the difficulties associated with phytotherapeutic baths for *in vivo* validation of *in vitro* screening, the number of these studies *in vivo* was greater than the number of studies on *in vitro* (see Tab. 2 and 3). Validation of phythotherapics using different steps is crucial for their acceptance by scientists and fish farmers, ensuring thus the safety and consistency in their therapeutic use in fish aquaculture (Fig. 2).

Curcumenol, one of the majority sesquiterpene component isolated from the essential oil of *Curcuma zedoaria*, did not show *in vitro* efficacy against *G. kobayashii*, unlike curdione (Zhang et al., 2020). However, Zhu et al. (2020) hypothesized that unpurified herbal drugs are used less regularly because their ingredients are less effective. These drugs are also not

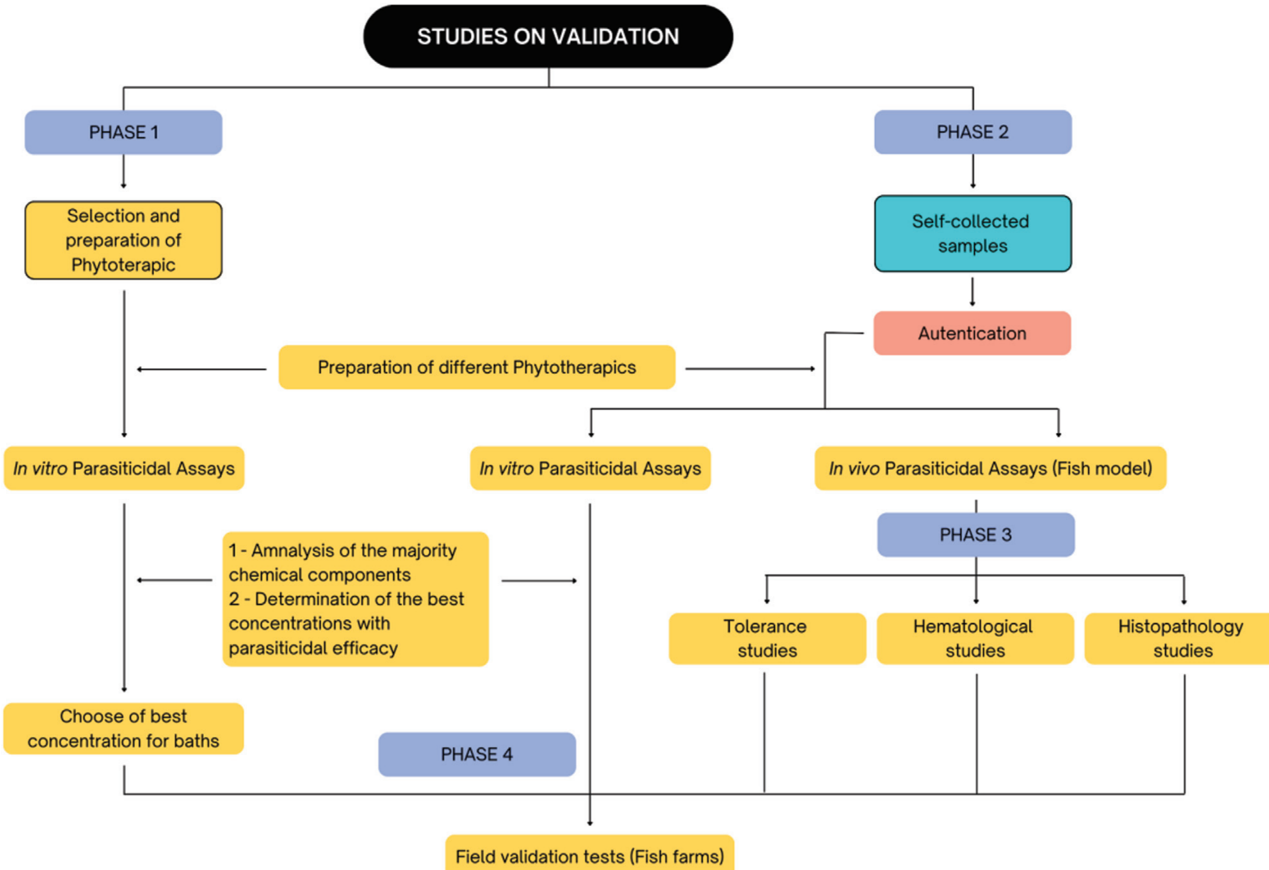


**Fig. 2.** Schematic representation of the steps related to validation studies with phytotherapics anti- monopisthocotylans and polyopisthocotylans in fish.

suitable for economic or environmental protection due to their high cost, numerous adverse effects, and low efficacy resulting from the interaction of various chemical components. However, there is no cost estimation for the use of unpurified herbal drugs. Previous review studies and published data up to 2016 reported that several essential oils tested in *vitro* and *in vivo* had therapeutic efficacy against monopisthocotylans and polyopisthocotylans in fish (Tavares-Dias, 2018). The present study shows that various extracts, essential oils and their majority components had effectiveness (*in vitro* and *in vivo*) against against monopisthocotylans and polyopisthocotylans in fish (Tab. 2 and 3).

Despite the enormous benefits of phytotherapeutics compared to chemotherapeutics in fish aquaculture, there are limitations in controlling and treating against monopisthocotylans and polyopisthocotylans that should be highlighted. These limitations are related to the low solubility of essential oils in water and the toxicity and antiparasitic effects of the solvents used. However, these limitations have already been widely demonstrated and discussed in previous studies (Steverding et al., 2005; Zhou et al., 2017; Tavares-Dias, 2018; Malheiros et al., 2020; Zhang et al., 2020; Zhou et al., 2020; Zhou et al., 2021; Tavares-Dias et al., 2021b; Zhou et al., 2022; Malheiros et al., 2023; Yilmaz and Yildiz, 2023), as well as the tolerance of host fish to phytotherapeutic products. Concentrations of oils or herbal extracts with efficacy against monopisthocotylans and polyopisthocotylans obtained in *in vitro* screening are often not tolerated by host fish for application in therapeutic baths (Tavares-Dias, 2018; The discrepancies between *in vitro* results and those obtained with therapeutic baths may be because the biological responses of host fish differ from those observed *in vitro* given the intricate biological interactions that occur in the gills and on the body surfaces of host fish (Yilmaz and Yildiz, 2023). Notably, Lian et al. (2020) demonstrated that, of the 14 herbal extracts tested for the control and treatment of infections by *G. kobayashi* in *C. auratus*, 50% had a tolerance higher than the *in vitro* anti-*G. kobayashi*-effective concentration. We demonstrated the potential of using silk fibroin solutions as solvents for essential oils and enhancing their anthelmintic effectiveness (Tavares-Dias et al., 2021b). Studies have also suggested that a nanoemulsion containing *Copaifera reticulata* oleoresin is more effective in controlling and treating against dactogyrideans in *C. macropomum* than oleoresin alone because it is better tolerated by the host fish and causes fewer changes in blood parameters (Malheiros et al., 2020, 2022). This indicates that nanoformulations could also reduce toxicity and increase tolerance to phytotherapeutic agents in fish.

Nanotechnology is an emerging technology that has gained significant attention because it addresses challenges in controlling diseases and opens up novel dimensions in drug discovery research. Considering nanoparticles as novel drug carriers and given their substantial specific surface area and strong adhesion capacity, they can overcome the shortcomings of many antiparasitic phytotherapics with low bioavailability, solubility, cellular permeability, and nonspecific distribution (Malheiros et al., 2020, 2022; Ranasinghe et al., 2023; Kumari et al., 2024). However, phytotherapies using nanotechnology have not yet been widely used in fish veterinary medicine as anti-monopisthocotylans and polyopisthocotylans agents (Tab. 2 and 3), especially compared to silver nanoparticles (Kumari et al., 2024). Currently, in light of the urgent need to develop new anti-monopisthocotylans and polyopisthocotylans compounds, a computer-guided drug repositioning approach is a promising alternative. While this approach can be useful for selecting new candidate drugs for experimental testing against monopisthocotylans and polyopisthocotylans, it does not guarantee success due to the complexity of biological interactions. It is still crucial to conduct in vivo trials with various compounds to validate this method (Caña-Bozada et al., 2024). Furthermore, the biogenic synthesis of metal nanoparticles (NPs), also known as green nanotechnology (Green nanoparticle synthesis), has paved the way for the discovery of a broad spectrum of innovative therapies in fish aquaculture. Nevertheless, green nanoparticle synthesis methods, which involve using various natural biological agents ranging from microorganisms to plant-derived materials, must be adopted to enhance therapeutic efficacy (Elgendy et al., 2024; Kumari et al., 2025). Additionally, further studies are required to evaluate the in vivo toxicity and anti-parasitic efficacy of NPs in fish (Kumari et al., 2025), as well as the use of herbal-derived compounds.

The toxicity of herbal products can potentially establish a pathological state when introduced to or interacting with fish, as determined by toxicological evaluations. These tests provide data on lethal concentrations, clinical signs (Tavares-Dias, 2018; Reda et al., 2024), and adverse effects on the physiology and histology of animals. Several studies have shown varied changes (increases or decreases) in biochemical, erythrocyte, and leukocyte parameters in various fish species after therapeutic baths with different essential oils, oleoresins, herbal extracts, and majority components of medicinal plants for the control and treatment of infections by monopisthocotylans and polyopisthocotylans, as well as severe damage to gill filaments (e.g. hyperplasia, hypertrophy, detachment and lifting of the epithelium, fusion and secondary lamella congestion, partial lamellar fusion, edema, aneurysms, etc.) from exposed host fish ranging from mild to moderate (Soares et al., 2017a, b; Meneses et al., 2018; Andrade et al., 2016; Anjos and Isaac, 2020; Gonzales et al., 2020; Yildiz and Bekcan, 2020; Zhou et al., 2021; Queiroz et al., 2022; Zhou et al., 2022; 2023; Reda et al., 2024; Alves et al., 2004a,b; Alves et al., 2025; Cornejo-Rigaud et al., 2025). Therefore, this reinforces the need for detailed evaluations of the possible toxic effects of herbal-derived products and the factors responsible for them, because effectiveness and safety are important considerations for fish in intensive aquaculture. Moreover, field studies are necessary to assess the anti-monopisthocotylans and polyopisthocotylans efficacy of essential oils, extracts, and herbal active compounds under natural conditions to validate significant experimental results.

As monopisthocotylans and polyopisthocotylans pose a significant threat to the viability of fish aquaculture, diseases caused by they are a major global concern. Thus, due to their high efficacy, safety, and low environmental risk, medicinal plants and phytochemicals used to control and treat such infections have received a lot more attention nowadays. However, to our knowledge, few studies have been carried out in this field. For example, field treatment studies on a commercial ornamental fish farm with *Poecilia reticulata* infected with *Gyrodactylus turnbulii* demonstrated decreased parasitic prevalence and intensity following a single application of 10 or 15 mg/L of Timor C, a plant-based commercial insecticide (Zorin et al., 2019). Tu et al. (2025), who conducted large-scale treatments with thymoquinone (0.1 or 0.2 mg/L) for *C. auratus* infected with *G. kobayashi*, found 100% efficacy. Nevertheless, large-scale fish studies are necessary to validate treatments against monopisthocotylans and polyopisthocotylans with plant-derived compounds. These studies have been more frequent with ornamental fish because food fish are larger and require larger tanks and larger quantities of products for these validation tests.

In summary, as expected, medicinal plant-derived compounds and phytochemicals offer various advantages, such as safety, low toxicity, and a minimal environmental footprint. Thus, they provide new alternatives for the treatment of finfish parasitic diseases, including monopisthocotylans and polyopisthocotylans species. Traditionally, these unmodified herbal products have played a crucial role in drug discovery for fish aquaculture. However, in the distant future, they will be surpassed by their analogues, which will exhibit enhanced parasiticide efficacy and lower toxicity to host fish than unmodified phytochemical compounds (Tu et al., 2025).

## 5 Action of chemical compounds derived from medicinal plants on fish parasites

Although the exact action mechanism of phytotherapeutics on fish parasites has not yet been clearly explained due to several impediments, some discussions have emerged. Fu et al. (2019) reported that *I. multifiliis* exposed to gingerol, a majority components of *Z. officinale*, exhibited colloidal protoplasm and ruptured plasmatic membrane with spilled cytoplasm and disintegrated plasma membranes. Ultrastructural changes were also observed, including cytoplasmic vacuolation, damaged cilia and kinetosomes and mitochondrial atrophy, as well as several organelle fragments in the cytoplasm. In general, it has been suggested that the effects of parasiticides, due to the synergistic action of chemical compounds, are usually caused by changes in the permeability of the tegument membrane (as well as damage to the cuticle and intestinal walls of helminths), reduction in the number of ribosomes, swelling, vacuolization, and cytoplasmic leakage, as well as pronounced gaps between the parasite wall and plasma membrane, cytoplasmic shrinkage and plasmolysis, causing disorganization of the parasite's internal structure (Fig. S3). Ribosomes are critical organelles in protein production in all cells. Their primary function is to promote translation, and alterations in ribosomal proteins can lead to abnormal cell proliferation. These alterations target mitochondrial function, secretory pathways, and cellular functions dependent on mitochondrial energy production, leading to the death of parasites exposed to phytotherapeutic agents (Faria and Silva, 2021; Huang et al., 2022; Yuan et al., 2025; Ng, 2024). Additionally, nematicidal activity similar to *A. simplex* has been attributed to the anti-acetylcholinesterase activity of carvacrol, a phytochemical component predominantly found in various medicinal plants (López et al., 2018; Les et al., 2024). Metacercariae of *C. phalacrocoracis* exposed to *V. alternifolia* extracts exhibited changes such as the disappearance of transverse striations, dislocation of suckers, and marked desquamation of the oral sucker and disappearance of sensory papillae. The tegument surface surrounding the sucker showed distinct stretching and detachment of the tegument on the hind body. Metacercariae exposed to *M. piperita* extract showed a marked disappearance of transverse ridges' striations and dislocation of the two suckers. They also exhibited edematous swelling and numerous blebs on the tegument surface. The oral sucker exhibited disfigurement of the collar-like ring, as well as ejections of blebs around the margins of the ventral sucker fold. Numerous blebs were also observed on the hind body tegument (Mahdy et al., 2022).

The tegument of monopisthocotylans and polyopisthocotylans is the primary surface of these helminths; it is an essential structure for survival, providing protection and helping to maintain homeostasis. The tegument of these parasites has been considered the main sites for energy transduction, supplying ATP to deeper tissues of these parasites by utilizing oxygen from the adjacent environment (Zhang et al., 2020). Thus, this structure, which is usually covered by thin wrinkles, is crucial for the survival of the parasites. Consequently, exposure to *B. orellana* seed extract caused *A. spathulatus* to absorb the extract, resulting in a swollen body and slow movements (Andrade et al., 2016). Exposure to *M. alternifolia*, *M. piperita* essential oils, or *Copaifera duckei* oleoresin also caused swelling, lysis, and death in *A. penilabiatus* and *M. viatorum* (Costa et al., 2017), as well as on *A. penilabiatus, A. spathulatus* and *M. viatorum* after exposure to *Jatropha gossypiifolia* or *Jatropha curcas* extract (Cornejo-Rigaud et al., 2025). After exposure of *A. spathulatus*, *M. boegeri*, *N. janauachensis*, and *G. kobayashii* to essential oils of *Cymbopogon citratus*, *Alpinia zerumbet*, *P. callosum, P. marginatum, P. hispidum*, *Copaifera reticulata* oleoresin, plumbagin, curdione, arctigenin, dioscin or isoimperatorin, analyses by scanning electron microscope (SEM) had also demonstrated everything from deep wrinkles to substantial damage, such as ruptures and shrinkage of the tegument layers, as well as wrinkling and/or perforation of the tegument surface (Tavares-Dias, 2018; Tu et al., 2018; Zhang et al., 2020; Gonzales et al., 2020; Malheiros et al., 2020; Alves et al., 2021; Luz et al., 2021; Zhou et al., 2021; Tu et al., 2021; Liu et al., 2022; Alves et al., 2024a,b). A significant decrease in ATP content has also been reported with *in vitro* and *in vivo* exposure of *G. kobayashii* to curdione (majority constituent of *C. zedoaria*), leading to a rapid decline in motility. This insufficient energy production, which plays a vital role in the tegument's function, including gas exchange, seems to be related to the monopisthocotylans and polyopisthocotylans' tegument damages, leading to their death. Therefore, the effects of phytotherapics in these parasites are likely associated with altered membrane permeability, which is necessary for energy generation. It is known that the biological properties of some compounds are associated with reduced membrane potential and depleted ATP pools (Zhang et al., 2020). Moreover, other factors are involved in the action of phytotherapics on monopisthocotylans and polyopisthocotylans. For instance, the presence of oxygen compounds seems to be partially involved in the previously reported damages (Fig. S4).

A full understanding of the mode of action of phytochemicals and phytotherapics with parasiticidal and anti-monopisthocotylans and polyopisthocotylans activities is crucial for developing adequate management strategies to control and treat parasitic diseases in fish aquaculture. This could enhance our ability to improve the health of fish populations by making these antiparasitic treatments more effective and available. This would be achieved by filling knowledge gaps and pursuing new approaches. Detailed information on the action mechanisms of these substances on fish parasites is imperative for the potential clinical application of medicinal plant-derived products. Nevertheless, as these investigations are complex and require assessing every stage of the parasite life cycle to understand their therapeutic potential, these studies have largely been neglected. For example, the life cycles of parasitic helminths, except monopisthocotylans and polyopisthocotylans, are complex and have several stages: eggs, larvae, and adult worms. Most reported screens are in vitro studies using biological models of a few helminth parasite species that are commonly found in fish relevant to aquaculture. However, many controlled experimental studies have been carried out to validate and measure the parasiticide efficacy of medicinal plant extracts, essential oils, and phytochemicals for use in fish aquaculture.

Into parasites in general, the action mode of phytotherapics and phytochemicals on parasites is through secondary metabolites, which often modulate a corresponding molecular target in their cells, such as proteins, biomembranes, or nucleic acids. This disrupts membrane permeability, provokes neurotoxic activity, and affects antioxidant activity (Fig. S4). In helminth parasites, these metabolites may affect gene expression, interfere with cell signaling pathways, and disrupt calcium pumps and ATPases. They can also damage neurons, alter membrane permeability, and affect mitochondrial function, leading to paralysis and death (Ahmad et al., 2023).

## 6 Conclusions and future perspectives

Parasitic infestations are a significant concern in aquaculture management, affecting the health and productivity of fish, as well as the livelihoods of fish farmers worldwide. Parasite infections can cause anorexia, loss of body condition, decreased health and welfare, anemia, and other direct and indirect impacts, resulting in substantial economic losses for fish farming owners. This requires effective, environmentally friendly therapeutic medicines for disease management. A variety of medicinal plant species have extracts, essential oils, and phytochemicals that show great potential as parasiticides and antihelminthics. However, the number of isolated phytochemicals is yet limited, demonstrating the need for further assessment studies and trials in order to obtain new anthelmintics and parasiticides for fish aquaculture. Chemotherapeutants are unsatisfactory, and phytotherapy is a potentially enormous source of natural medicines. Therefore, studies identifying phytochemicals are a crucial step in discovering new anthelmintics and new parasiticides because the use of phytotherapics has gradually grown through a systematic process and is now widely accepted in fish aquaculture. Notably, the use of plant-derived compounds from these natural products in the control of parasites in fish diets has been poorly studied, as has the recovery time following exposure to extracts, essential oils, and phytochemicals. Moreover, there are almost no studies on reinfection by monopisthocotylans and polyopisthocotylans in the short or long term after treatment with phytotherapics, although these are highly relevant for evaluating the duration of such treatments. Although the cost of phytotherapy medicines used in fish aquaculture has not been estimated, the development of resistance to traditional chemotherapeutants has led to an ongoing search for alternative drug sources based on medicinal plants. Thus, diverse extracts, essential oils, and bioactive phytochemicals have been used as nutraceuticals, adjuvants, and parasiticides in fish aquaculture because these natural practices can reduce parasite burdens and increase fish health, welfare, and survival rates, thereby increasing production, productivity, and economic gains. Hence, phytotherapy offers a promising alternative, with more than 250,000 medicinal plants, of which less than 0.003% are used in aquaculture. Moreover, only approximately 40% (~ 3,500) of the essential oils derived from these plants are known, indicating their enormous potential. It is estimated that there are at least 250,000 essential oils and 5,000,000 majority constituents derived from these essential oils (on average, each essential oil has 20 majority constituents). In addition, there are tens of thousands more from possibilities for use of different extracts. Thus, medicinal plants and their phytochemicals may be a good strategy for boosting fish immune systems and helping them develop resistance to a range of parasite species, as well as parasiticides, including those with activity against monopisthocotylans and polyopisthocotylans. Commercially available plant-based medicines could serve as treatments for aquaculture fish, but only if they have been proven to be effective and safe. Few products are readily available for parasiticide treatments in fish aquaculture, considering the diversity of medicinal plants and their derivatives. Therefore, our results suggest that various medicinal plant products and their phytochemicals may be utilized to control and treat parasite infections in fish aquaculture. Adequate management of parasitic diseases is essential to maintaining the constant growth of this key industry, whether at the regional or global level, and to avoid disease outbreaks. Moreover, phytotherapy holds tremendous potential for discovering new structures for synthesizing and optimizing drugs against parasitic diseases in fish. Since research on the use of compatible medicinal plants and phytochemicals with synergistic effects on parasites is still relatively limited, such effects could be an exciting approach for fish aquaculture. However, any veterinary phytotherapy should demonstrate its potential biological activity against the indicated disease and thus be highly effective. Every country should regulate commercial veterinary phytotherapy products and have quality control and quality assurance in place, such as national quality specifications and standards for each herbal product, good manufacturing practices, labeling, manufacturing licenses, imports, and merchandise. Phytotherapeutic products intended for veterinary use should follow the same regulatory procedures as human and veterinary medications, ensuring they meet the necessary safety, efficacy, and quality criteria. Considering that nanotechnology has helped overcome technical challenges such as the solubility and stability of bioactives, it could contribute significantly to the development of parasiticide treatments for fish aquaculture. Phytotherapies with nanoemulsions promote the efficient application of essential oils for parasitic control and increase antiparasiticide activity, including efficacy against monopisthocotylans and polyopisthocotylans. Therefore, the future of chemotherapeutic treatments in aquaculture remains elusive. However, we believe that they will gradually be discouraged due to their detrimental effects and gradually be substituted by phytotherapeutics for the management, control, and treatment of parasitic diseases, including monogeniosis. Although we presented current data and discussed the action mechanisms of phytotherapics on parasites, further studies and broader discussion are needed to improve our knowledge. Lastly, the cost of phytotherapy in fish aquaculture is unknown; however, it is inexpensive compared to conventional treatments and cost-effective due to its low environmental impact. As research advances regarding the global use of phytotherapics and adequate handling practices in fish aquaculture expand, parallel advances are being made in biosecurity and the incorporation of these natural products into more sustainable diets and management plans for the control and treatment of parasitic diseases. This crucial food production industry must prepare to reshape its future vision in regarding the use of chemotherapeutants.

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## Conflicts of interest

All authors confirm that they have read and approved the content of the submitted article. They also declare that there are no conflicts of interest among the authors or regarding the journal's publication ethics.

## Data availability statement

No new data/codes were created or analyzed in this study.

**Supplementary material**

**Figure S1.** Direct and indirect benefices with use of phytotherapeutics in parasitic disease's management in fish aquaculture (Adapted from Jeyavani et al., 2022).

**Figure S2.** Chemical structures of some molecules derived from medicinal plants with potential parasiticidal and anthelminthic activity in fish.

**Figure S3.** Simplified schematic representation for action mechanism of phytotherapics on fish parasites (Adapted from Ranasingle et al., 2023). ROS: Reactive oxygen species.

**Figure S4.** Action mechanism of essential oils on monopisthocotylans and polyopisthocotylans with their antioxidative role (a) and free radical scavenging (b) which to formation of oxygenated compounds. Adapted from Miri (2025).

The Supplementary Material is available at https://www.alr-journal.org/10.1051/alr/2025021/olm.

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