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Use and Diversity of Medicinal Plants in Aquaculture Practices

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Abstract*—*Medicinal plants are widely used in Brazilian folk medicine because of their various properties. Their chemical components have attracted the attention of researchers from the field of animal production, particularly aquaculture. This study aimed to analyze the use of medicinal plants in aquaculture practices. The main results showed that medicinal plants have been used in the management of anesthesia, in antibacterial, antifungal, and antiparasitic treatments, and as growth-promoting additives. When the potential of Brazilian flora is considered, little knowledge has been gained about the use of medicinal plants in aquaculture practices, especially when considering the native species, which may represent an important research front in the development of phytopharmaceuticals for the treatment of diseases of cultured aquatic organisms.

Keywords*—*Fish farming, Plant extract, Tambaqui, Tilapia.

I. INTRODUCTION

In 2016, the world aquaculture production, including aquatic plants, was 110.2 million tons (FAO, 2018). In this context of growing aquaculture activities, Brazilian fish farming reported an 8% growth in 2017, with a total production of 691,700 tons of farmed fish (Peixe & Peixe, 2018). Success in fish farming depends on a number of management practices, including water quality control, quarantine of newly acquired batches, and providing quality and balanced food. This ensures fish health and, consequently, disease prevention (Santos et al., 2013).

According to Tavechio et al. (2009),many of the diseases affecting fish farming are caused by infectious agents that can make the activity costly and unprofitable due to high mortality during outbreaks of infection/infestation. Natural products have been the objects of growing attention, representing a potential alternative as antibacterial agents in the culture of aquatic organisms, mainly because of their easy availability, relatively low cost, and proven efficiency against a number of pathogens (Galina, Yin, Ardó, & Jeney, 2009; Nazzaro, Fratianni, De Martino, Coppola, & De Feo, 2013).

Herbal medicines and compounds from plants (phytopharmaceuticals) can be applied as prophylactic or therapeutic measures against bacterial diseases in aquatic organisms, mainly using two methods: through bathing or by incorporating in the feed(Saccol et al., 2013; Sutili et al., 2014). The substances found in essential oils and plant extracts can act directly on bacteria, causing cell lysis, inhibiting the antibacterial activity of other substances, or inhibiting bacterial resistance mechanisms and virulence factors (Stavri, Piddock, & Gibbons, 2007).

Thus, considering the nutritional, immunological, bactericidal, antifungal, anthelmintic, and antiparasitic properties of medicinal plants, among other benefits, this

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study aimed to analyze the use of medicinal plants in aquaculture practices.

II. MATERIALS AND METHODS

This study was conducted from August to September 2019; it is a qualitative and quantitative review of the literature about the use of medicinal plants in aquaculture practices. Data were searched in three databases: Google Scholar, SciELO, and the journal database of the Brazilian Coordination for the Improvement of Higher-Education Personnel (CAPES),using "AND" as the Boolean operator. The keywords or indexing terms were"medicinal plants AND aquaculture,""medicinal plants AND fish farming,""medicinal plants AND tambaqui (*Colossoma macropomum*),"and "medicinal plants AND tilapia (*Oreochromis niloticus*)."The latter two searches included the scientific name of the species most commonly produced in aquaculture freshwater in Brazil.

The inclusion criteria were scientific articles published in scientific journals in the last 10 years only (2009–2019). Duplicate articles or articles not related to the study theme, as well as abstracts in annals of scientificjournals, dissertations, theses, technical newsletters,and other documents were excluded. The data collected from the articles were inserted into Microsoft Office Excel® 2010 spreadsheets for content analysis and data tabulation.

III. RESULTS AND DISCUSSION

The search in the SCIELO database found only one article based on the descriptor "medicinal plants AND aquaculture," one article for "medicinal plants AND fish farming," no results for "medicinal plants AND tambaqui (*Colossoma macropomum*)."and two results for "medicinal plants AND tilapia (*Oreochromis niloticus*)."In CAPES journals, six articles were found for "medicinal plants AND aquaculture,"but only one met the inclusion criteria;ten results were found for "medicinal plants AND fish farming,"but only two were related to the study theme;and two articles each were found for both "medicinal plants AND tambaqui" and "medicinal plants AND tilapia."

In the Google Scholar database, 2,300 articles were found for "medicinal plants AND aquaculture," 2,850 for "medicinal plants AND fish farming," 549 for "medicinal plants AND tambaqui (*Colossoma macropomum*)," and 1,360 for "medicinal plants AND tilapia (*Oreochromis niloticus*)." After a careful analysis of all Google Scholar search results, only 28 items were related to the study theme, and they were selected for content analysis.

The medicinal plants most commonly used in aquaculture practices were pitanga (*Eugenia uniflora* L.), *Hyptidendron canum* (Pohl ex Benth.) Harley, clove basil (*Ocimum gratissimum*L.), mint (*Mentha arvensis* L.),clove (*Eugenia caryophyllus*L.), passion flower (*Passiflora incarnata*L.), aloe vera (*Aloe vera*(L.) Burm. f.), lemon balm(*Lippia*spp.L.)(Verbenaceae), cockspur coral tree (*Erythrina crista-galli*L.), *velame* (*Croton heliotropiifolius*Kunth), country almond(*Terminalia catappa*L.), yellow cinnamon (*Nectandra grandiflora* Ness), and plants from thePiperaceae family.Table 1 shows the use of these medicinal plants in aquaculture practices.

Table 1. List of medicinal plants used in aquaculture and their applications

Medicinal plants	Effect/use in aquaculture	Fish species	Reference
Pitanga (*Eugenia uniflora* L.)	Clinical study	*Oreochromis niloticus*	Fiuza et al. (2011)
Hyptidendron canum (Pohl ex Benth.) Harley	Clinical study	*Oreochromis niloticus*	Fiuza et al. (2015)
Clove basil (*Ocimum gratissimum* L.)	Anesthesia	*Brycon amazonicus*	Ribeiro et al. (2016)
Mint(*Mentha arvensis* L.)	Anesthesia	*Colossoma macropomum*	Façanha & Gomes (2005)
	Anesthesia	*Xiphophorus maculatus*	Hoshiba et al. (2015)
	Anesthesia	*Centropomus parallelus*	Souza et al. (2012)
	Anesthesia	*Piaractus mesopotamicus*	Gonçalves et al. (2008)
Clove (*Eugenia caryophyllus* L.)	Anesthesia	*Piaractus mesopotamicus*	Gonçalves et al. (2008)
	Anesthesia	*Centropomus parallelus*	Souza et al. (2012)

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Passion flower (*Passiflora incarnata* L.)	Nutrition	*Oreochromis niloticus*	Oliveira, Pereira-Da-Silva, & Bueno (2010)
Aloe vera (*Aloe vera* (L.) Burm. f.)	Semen cryopreservation	*Colossoma macropomum*	Melo-Maciel et al. (2015)
Lemon balm (*Lippia* spp.L.)	Nutrition	*Oreochromis niloticus*	Rodrigues-Soares et al. (2018)
	Antibacterial	*Colossoma macropomum*	Oliveira et al. (2018)
Cockspur coral tree (*Erythrina crista-galli* L.)	Anesthesia	*Carassius auratus*	Siqueira, Sousa, Tirloni, & Gebara(2019)
Velame (*Croton heliotropiifolius* Kunth)	Nutrition	*Oreochromis niloticus*	Souza et al. (2018)
Country almond (*Terminalia catappa* L.)	Nutrition	*Oreochromis niloticus*	Santos et al. (2015)
	Antiparasitic	*Colossoma macropomum*	Claudiano et al. (2009)
	Behavior/Performance	*Betta splendens*	Santos et al. (2013)
Yellow cinnamon (*Nectandra grandiflora* Ness)	Antiparasitic	—	Rodrigues et al. (2017)
Piperaceae (spp.)	Anthelmintic	*Colossoma macropomum*	Santos et al. (2018)

Source: The authors themselves (2019).

3.1 Pitanga (*Eugenia uniflora* L.)

The *pitanga* tree (*E. uniflora* L.) has edible fruits that are well known and appreciated in Brazil; the infusion of its leaves has applications in folk medicine mainly as a hypotensive, anti-gout, stomachic, and hypoglycemic agent (Auricchio & Bacchi, 2003). In vitro and in vivo tests have shown that extracts from the leaves of *E. uniflora* L. have several pharmacological properties, such as antidiarrheal, diuretic, anti-inflammatory, and antifungal actions(Almeida, Faria, & Silva, 2012). Fiuza et al. (2011) found that tilapia (*Oreochromis niloticus*) exposed to different *E. uniflora* L. extracts and leaf fractions had a vasodilation effect on gills, and toxic effects, such as detachment and desquamation of the respiratory epithelium and hyperplasia of the interlamellar epithelium cells.These effects were more pronounced in those individuals who received the highest concentrations. This study contributed to establish *Nile tilapia* as a model system for testing active ingredients of plants, such as the vasodilation effect, the effect on cell morphology and on the tissues of the gills, the main respiratory organ of fishes.

3.2*Hyptidendron canum*(Pohl ex Benth) Harley

Hyptidendron belongs to theLamiaceae family, which consists of herbs, shrubs, and trees, with usually quadrangular branches (Fiuza et al., 2010). *Hyptidendron canum* is native to the Brazilian savannah (*cerrado*) regionsand is frequently used in alternative medicine for the treatment of malaria, with anti-inflammatory, anti-ulcerative, and anti-hepatotoxic actions (Brandão, 1991; Ferri &Ferreira, 1992). Desquamation of the respiratory epithelium, changes in curvature, cell hyperplasia, and vasodilation in the lamellae and in the central vessel of the filaments were the main results that Fiuza et al. (2015) found in the gills of *O. niloticus*submitted to ethanol extract and to hexane, chloroform, and ethyl acetate fractions of *H. canum*. The authors pointed out that *H. canum*caused inflammatory processes and injuries that varied according to the dose administered.

3.3 Clove basil (*Ocimum gratissimum*L.)

Ocimum gratissimum, popularly known as clove basil, belongs to the family Lamiaceae, one of the largest families of angiosperms (Cruz & Bezerra, 2017).In traditional medicine, *O. gratissimum* has several indications, such asan anti-flu bath, and diuretic, febrifugal, anti-bleeding, antifungal, antioxidant, antibacterial, antidiarrheal, hypoglycemic, and anti-inflammatory indications (Lemos et al.2005; Stanley, Ifeanyi, Chinedum, & Chinenye,2014). The use of *O.gratissimum*in aquaculture activities is associated with the presence of eugenol, the main active component present in the plant, which has been studied as a natural anesthetic used in fish farming. Ribeiro et al. (2016) used the essential oil of clove basil as a natural anesthetic in young *matrinxã* (*Brycon amazonicus*), a neotropical fish found in the Amazon

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region, without side effects on the fish; as no death was reported for 30 days, the authors suggested that the essential oil of *O. gratissimum* did not pose any risk for handlers at a concentration of 20–60 mg.L^{-1} fora 10-min exposure, , thus allowing its use in *matrinxã* anesthesia.

3.4 Mint (*Mentha arvensis* L.)

The*Mentha*genus comprises approximately 25 different species of mints and related plants that belong to the Lamiaceae family (Watanabe, Nosse, Garcia, & Pinheiro Povh, 2006). Mint (*Mentha arvensis* L.) is an aromatic plant, with menthol as the substance found in the largest amounts in the composition of its essential oil (Paulus et al. 2007; Arrigoni-Blank, 2011). Menthol is a natural anesthetic, which has been used for different species grown in Brazil, proving to be efficient and safe in fish anesthesia procedures, mainly in the following species:tambaqui (*Colossoma macropomum*) (Façanha & Gomes, 2005); platys (*Xiphophorus maculatus*) (Hoshiba et al. 2015); *robalo-peva* (*Centropomus parallelus*), and*pacu* (*Piaractus mesopotamicus*) (Gonçalves, Santos, Fernandes, & Takahaski,2008).

3.5 Clove (*Eugenia caryophyllus* L.)

The clove plant belongs to the Myrtaceae family, which has approximately 3,000 species of tropical and subtropical trees and shrubs. Its scientific name varies with its classification; it was recently classified as *Syzygium aromaticum*(L.) Merr.et Perry, despite several previous citations, as follows: *Eugenia caryophyllus* (Sprengel) Bullock et Harrison, *Caryophyllus aromaticus* L, *E. caryophyllata* Tumb, and *E. aromatica* (L) Baill (Maeda, Bovi, Bovi, & Lago, 1990). Eugenol, the main component of the plant, has anti-inflammatory, healing, and analgesic effects, and it is effective in reducing bacteria present in the mouth (Silvestri et al., 2010). The use of cloves in aquaculture is related to the need to anesthetize cultivated organisms for performing management practices, such as biometrics, reproduction, and transport.The use of cloves has been recommended for *robalo-peva* (Souza et al., 2012) and *pacu* (Gonçalves et al., 2008) juveniles, proving to be safe and efficient for the animals handled.

3.6 Passion flower(*Passiflora incarnata* L.)

Passion flower, of the *Passiflora incarnata*species, has the potential to reduce stress.Its activity is related to the presence of pyronic derivatives, harman alkaloids, and flavonoids, to which sedative and anxiolytic effects are attributed (Dhawan, Kumar, & Sharma,2003). In a study conducted by Oliveira et al. (2010), the authors suggested that passion flower extract could be included in the diet of young tilapia, without prejudice to food consumption and growth. They also reported that the extract changed the morphometry of hepatocytes, suggesting the activity of flavonoids on carbohydrate metabolism, which contributed to increased glycogen levels in liver, particularly in the group that received 100 mg.kg^{-1} of the extract.

3.7 Aloe vera (*Aloe vera*(L.)Burm. f.)

*Aloe vera*belongs to the Aloaceae family,which includes approximately 15 genera and 800 species. It is a herbaceous plant that grows on any type of soil, but it is better adapted to light and sandy soils and does not require much water (Freitas, Rodrigues, & Gaspi,2014). It is very common in Brazil, where it is popularly used in wound healing, in the treatment of burns, conjunctivitis, rheumatic pain, and other uses (Guerra, Araújo, & Oliveira,2008; Araújo, Lemos, Menezes, Fernandes, & Kenrtopf,2015). The use of *Aloe vera* in fish farming was studied by Melo-Maciel et al. (2015) in tambaqui semen cryopreservation, and the authors concluded that *A. vera*as a crude extract did not improve sperm production during the cryopreservation process.

3.8 Lemon balm(*Lippia*spp.Linn.)

The*Lippia*genus (Verbenaceae) includes approximately 200 species of herbs, shrubs, and small trees mainly found in Central America and in the tropical regions of Africa, North America, South America, and Australia (Reis et al. 2014; Gomes, Nogueira, & Moraes,2011). The species of this genus are widely used in folk medicine because they have anti-inflammatory, antifungal, antiseptic, antihypertensive, anxiolytic, anti-*Leishmania*, antiviral, and digestive properties, among other applications (Soares & Tavares-Dias, 2013; Costa, Souza, Brito, & Fontenelle,2017). Rodrigues-Soares et al. (2018) added *Lippia alba*essential oil to the feed of tilapia (*O. niloticus*) in order to analyze the hemato-immunological parameters. The authors concluded that the essential oil did not contribute to anti-inflammatory activities; however, an increase in the number of neutrophils was observed. In a study by Oliveira et al. (2018), the authors used*L. origanoides*essential oil to control infections by *Aeromonas hydrophila* in tambaqui (*C. macropomum*) juvenilesand found a survival rate of 79.2% after a therapeutic bath with 10 mg.L^{-1} of essential oil; the changes in hematological and biochemical parameters were not significant.

3.9 Cockspur coral tree (*Erythrina crista-galli* L.)

The *Erythrina*genus (Fabaceae) contains more than 100 species distributed in the tropical and subtropical areas of the Americas, Africa and Australia (Kone, Solange, & Dosso,2011). This tree is found in very humid areas, in secondary open formations, from Maranhão to Rio Grande do Sul (Gratieri-Sossella & Nienow, 2008).

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Pharmacological investigations have demonstrated that *E.crista-galli* seed extracts have sedative, hypertensive, laxative, and diuretic properties (Maier, Rödi, Deus-Neumann, & Zenk,1999). Additionally, its bark is used to treat many diseases associated with rheumatism and hepatitis (Hashimoto, 1996). Siqueira et al. (2019) conducted a study to evaluate the anxiolytic effect of *E. crista-galli* extract in goldfish (*Carassius auratus*)juveniles, and the authors observed that the extract did not present fish toxicity or mortality.However, it did cause undesirable changes in blood physiological parameters when used in doses above100 $mg.L^{-1}$.Thus, the authors reported that the anxiolytic action was not beneficial to the fish species analyzed.

3.10*Velame*(*Croton heliotropiifolius* Kunth)

Croton is the second largest genus of Euphorbiaceae, with approximately 1,200 species predominantly distributed across the American continent (Berry, Hipp, Wurdack, Van, & Riina,2005). Brazil has the largest number of species, approximately 350, distributed across the most diverse ecosystems, especially the savannah (*cerrado*), the semiarid plateau (*caatinga*), and rupestrian fields (Berry et al. 2005). This genus' species have demonstrated anti-inflammatory (Ramos et al., 2013), gastroprotective (Coelho-De-Souza et al., 2013), and woundhealing (Cavalcanti et al., 2012) properties. Souza et al. (2018) evaluated the nutritional effect of adding extracts of *Croton heliotropiifolius* to the diet of young tilapia. The authors found that the inclusion of *velame* extract reduced the average weight gain and the total blood sugar and protein concentrations, whereas the specific growth and survival rates had a small improvement with the addition of 2.0% of crude *velame* extract to the diet.

3.11 Country almond (*Terminalia catappa* L.)

The country almond (*Terminalia catappa*) belongs to the Combretaceae family.It is an ornamental plant found in several tropical countries, widely used in urban forestry, and present in coastal areas to provide shade (Francis, 1989). Its origin is the coastal areas of eastern India, Indochina, Malaysia, northern Australia, Oceania, Philippines, and Taiwan (Francis, 1989). Studies have demonstrated its bactericidal and fungicidal effects (Costa, Bevilaqua, Morais, & Vieira,2008), and its anti-*Helicobacter pylori*and anti-ulcer (Pinheiro Silva et al., 2015), anti-diabetic (Nagappa, Thakurdesai, Venkat Rao, & Singh,2003), and anti-inflammatory (Fan et al., 2004) properties. *T. catappa* leaves were tested as a growth-promoting additive for *N. tilapia* (*Oreochromins niloticus*)juveniles, and the results did not showany positive effects on performance.However, when administered at high levels, it reduced mortality (Santos et al., 2015). In a study conducted by Claudiano et al. (2009), an aqueous extract of dry leaves of *T. catappa* presented improved efficiency at the dose of 120 $ml.L^{-1}$ and effectively controlled monogenetic parasites and the protozoan *Piscinoodinium pillulare* in *tambaqui* (*C. macropomum*) juveniles; however, it had no effect against the protozoan *Ichthyophthirius multifiliis*. Santos et al. (2013) evaluated the performance and behavior of *Betta splendens* fish growing at different concentrations of *T. catappa* aqueous extract, and concluded that the extract had no effect on fish performance,whereasfish behavior was influenced by the concentration—that is, higher concentrations caused the fish to be calmer.

3.12 Yellow cinnamon(*Nectandra grandiflora* Ness)

The yellow cinnamon (*Nectandra grandiflora* Ness) (Lauraceae) is an endemic species of Brazil, predominantly found in the Atlantic rainforest and *cerrado* biomes (Lorenzi & Brasileira,2002). Regarding the properties of this medicinal plant, Ribeiro (2002) and Ribeiro et al. (2005) analyzed the antioxidant activity of an ethanol extract of *N. grandiflora* leaves the extract inhibited the oxidation of β-carotene, analgesic (da Silva-Filhoet al., 2004), antibacterial (Ferrazet al., 2018), and anxiolytic (Garlet et al., 2019) actions. Rodrigues et al. (2017) reported an in vitro analysis in which the essential oil of *N. grandiflora*exhibited an antiparasitic effect against *I. multifiliis*, a fish parasite that causes considerable losses in aquaculture. They also suggested that in vivo studies should be conducted to develop a product for the control of *I.multifillis.*

3.13 Species of the Piperaceae family

The *Piper*genus belongs to the Piperaceae family, which was described in the 18th century by Linnaeus. It hasapproximately 12 genera, of which *Piper* and *Peperomia* are the most important ones in the Brazilian flora (Medeiros & Guimarães, 2007). Thisfamily's pharmacological potential is related to its antitumor (Duh, Wu, & Wuang,1990), insecticide (Mamood, Hidayatulfathi, Budin, Ahmad Rohi, & Zulfakar,2017), anesthetic (López et al., 2016), anesthetic, and antimycobacterial (Cunico et al., 2015)properties. Santos et al. (2018) found that essential oils from four species of plants of the family Piperaceae—*Piper hispidinervum, P. hispidum, P. marginatum,* and*P. callosum*—showed anthelmintic efficacy against the acanthocephalon parasite *Neoechinorhynchusbuttnerae*in *tambaqui* (*C. macropomum*) juveniles, and that parasite mortality occurred at the highest concentrations andtimes of exposure to the essential oils. The authors concluded the

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essential oils were an alternative source for direct use or for the development of anthelmintic herbal medicines, requiring advanced studies for in vivo treatment.

IV. CONCLUSION

This study on the use of medicinal plants in aquaculture practices demonstrated the diversity of plants used. However, when analyzing the biodiversity of the Brazilian flora across its most diverse biomes, the production of knowledge in this area still presents few results, particularly considering that the tests were conducted with *Nile tilapia*, the main exotic species grown in Brazilian aquaculture.

The potential of the Brazilian flora for the production of phytopharmaceuticals that can be used in aquaculture still needs further investigation, mainly regarding its use with cultivated native species. While fish farming activities have increased in Brazil, many cases of diseases related to the presence of parasites, endoparasites, bacteria, fungi, and viruses have been reported because of the intensive systems used in fish farming practices. Fish sanitary diagnoses are usually expensive, particularly for small fish farmers. Thus, the use of medicinal plants, especially those producing essential oils and mentioned in this study, has presented great potential for the treatment of aquaculture diseases. Further studies evaluating their use are required to reduce the costs involved in the treatment of these diseases.

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