Ciências Biológicas

***Scientia Amazonia*, v. 9, n.3, B1-B25, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

Infectious agents and parasites that affect tambaqui (Colossoma macropomum) and treatments used to control these pathogens: a systematic review

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Abstract

By 2050, production of animal protein will need to have increased enough to feed an estimated 9.5 billion people around the world. Currently, one of the most widely produced proteins on the planet is fish protein. In Brazil, the most common fishery activity is freshwater fish farming, and the most widely farmed native species is tambaqui (*Colossoma macropomum*). Ensuring fish health and welfare is one of the main obstacles to fish farming and the increased fish production needed to meet the demands of population growth. The aim of this systematic review was to identify scientific articles on infectious agents in tambaqui and treatments to control these pathogens published in six databases prior to 09 April 2020. The databases used were ALICE, PUBMED, SCIENCE DIRECT, SCOPUS, WEB OF SCIENCE and SCIELO. The following data were identified: the origin of the fish used in the studies; the region of Brazil that carries out the most research into tambaqui health and welfare; the infectious agents that affect tambaqui; the organs and anatomical systems most affected; and the treatments used to fight these agents.

Keywords: Fish farming, Fish health, Microorganisms, Metazoa

Agentes infecciosos e parasitários que afetam o tambaqui (*Colossoma macropomum*) e tratamentos usados para controlar esses patógenos: uma revisão sistemática. Até 2050, a produção de proteína animal precisará aumentar o suficiente para alimentar cerca de 9,5 bilhões de pessoas em todo o mundo. Atualmente, uma das proteínas mais amplamente produzidas no planeta é a proteína de peixe. No Brasil, a atividade pesqueira mais comum é a piscicultura de água doce e a espécie nativa mais cultivada é o tambaqui (*Colossoma macropomum*). Garantir a saúde e o bem-estar dos peixes é um dos principais obstáculos à piscicultura e ao aumento da produção de peixes, necessários para atender às demandas do crescimento populacional. O objetivo

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Ciências Biológicas

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Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

desta revisão sistemática foi identificar artigos científicos sobre agentes infecciosos em tambaqui e tratamentos para controlar esses patógenos publicados em seis bancos de dados anteriores a nove de abril de 2020. Os bancos de dados utilizados foram ALICE, PUBMED, SCIENCE DIRECT, SCOPUS, WEB OF SCIENCE e SCIELO. Os seguintes dados foram identificados: a origem do peixe utilizado nos estudos; a região do Brasil que mais pesquisa sobre o bem-estar do tambaqui; os agentes infecciosos que afetam o tambaqui; os órgãos e sistemas anatômicos mais afetados; e os tratamentos usados para combater esses agentes patogênicos.

Palavras-chave: Piscicultura, Sanidade de peixes, Microrganismos, Metazoa

1. Introduction

Fish farming is an activity in which fish are reared under controlled conditions. In Brazil, *Colossoma macropomum*, or tambaqui, as it is popularly known, is the native species most frequently chosen by fish farmers (IBGE, 2014). This bony fish is found in tropical waters in South America, namely the Amazon basin (GOULDING, 1980; GOULDING, CARVALHO, 1982) and Orinoco basin (NOVOA et al., 1984; NOVOA, 1990), and has been introduced into other countries, including the Dominican Republic, Jamaica, Panama, Cuba and Honduras (REIS et al., 2003). The species, which can weigh as much as 30 kg, is of great commercial importance in the state of Amazonas, Brazil, because of its taste and its resistance to the temperature changes and low levels of dissolved oxygen in fish tanks (ARAÚJO-LIMA, GOULDING, 1998; SANTOS, SANTOS, 2005).

While fish farms have a few benefits, they depend on a variety of factors to be viable. The fish can be kept in dug-out ponds, net tanks, cages, barrage ponds and *igarapé*[5] canals. In intensive fish farming, high stocking densities are used to increase production. However, these higher densities can have adverse effects on the fish as they result in less space for them to move around in, a greater demand for oxygen in the water and struggles for food, in turn leading to disputes between fish, the emergence of dominant individuals and increased stress (CAVERO et al., 2003). In Brazil, intensive farms account for 70% of fish production (IBGE 2014).

Increased stress can affect fish welfare and suppress the immune response, leaving fish susceptible to pathogens in the fish-farm environment. Infections in the aquaculture industry have been estimated to cause an annual loss of USD 1 to 9 billion worldwide (SHINN et al., 2015). Diseases have a significant impact on fish farming and its sustainability as morbidity and

[5] A streamlet in the Amazon region that runs into a larger river.

Ciências Biológicas

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ISSN:2238.1910

mortality affect the economic viability of this activity (TAVARES-DIAS, MARTINS, 2017). The greatest losses by weight in farmed tambaqui are a result of infections caused by pathogens such as *Ichthyophthirius multifiliis* (a protozoan ectoparasite that cause white spot disease), *Piscinoodinium pillulare* (a protozoan ectoparasite that causes velvet disease), Monogenea (ectoparasitic flatworms that causes monogeniasis), *Lernea cyprinacea* and *Perulernaea gamitanae* (crustaceans that cause hemorrhage, necrosis and local inflammation), *Neoechinorhyncus buttnerae* (an acanthocephalan that inhabits the digestive tract), *Trichodina sp.* (a protozoan that causes trichodiniasis) and *Henneguya piaractus* (a protozoan that causes inflammation and necrosis of the gills) (TAVARES-DIAS, MARTINS, 2017).

The need for higher stocking densities to increase fish production has made a knowledge of the pathogens that affect fish and the corresponding treatments essential as these can be used as an aide for fish farmers and technicians as well as, to guide future research into the health and welfare of farmed fish.

2. Methodology

Six databases (ALICE, PUBMED, SCIENCE DIRECT, SCOPUS, SCIELO and WEB OF SCIENCE) were searched using the keyword *Colossoma macropomum*. The search identified 2764 articles published before 09 April 2020. The number of articles identified in each database is shown below.

	Alice	Pubmed	science Direct	Scopus	Scielo	web of science
Number of articles identified	546	221	589	575	225	608

2.1 Selection Criteria

2.1.1 Infectious agents and parasites

Of the 2764 articles, 127 were selected because they discussed infectious agents or parasites that affect tambaqui. Duplicated articles or articles unrelated to the topic were excluded, leaving 92 articles to be analyzed (Figure 1).

2.1.2 Treatments

Of the 2764 articles, 120 were selected because they discussed treatments to control infectious agents and parasites that affect tambaqui. Of these, 43 were excluded because they were duplicated or not related to the topic, leaving a total of 77 articles to be analyzed (Figure 1).

2.2 Inclusion Criteria

2.2.1 Infectious agents and parasites

Of the 92 articles selected, complete articles (61) that contained information about tambaqui and discussed infectious agents or parasites that affect this fish were included (Figure 2).

Scientia Amazonia, v. 9, n.3, B1-B25, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910
Ciências Biológicas

2.2.2 Treatments

Of the 77 articles selected, complete articles (63) that contained information about tambaqui and discussed the type of treatment used regardless of whether a diagnosis had been confirmed or not were included (Figure 2).

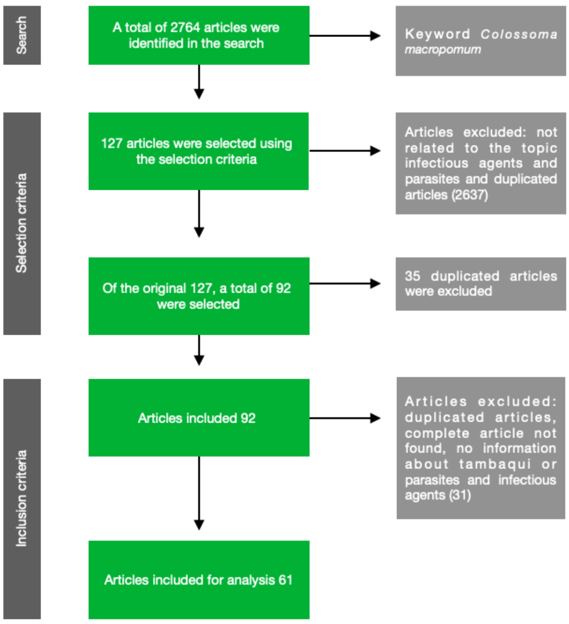

Figure 1. Flowchart showing the selection and inclusion criteria for studies on parasites and infectious agents that affect tambaqui.

2.3 Exclusion Criteria

2.3.1 Treatments and parasites and infectious agents

Duplicated articles and articles that were not related to *Colossoma macropomum* or the parasites and infectious agents that can affect this fish were excluded (Figures 1 and 2).

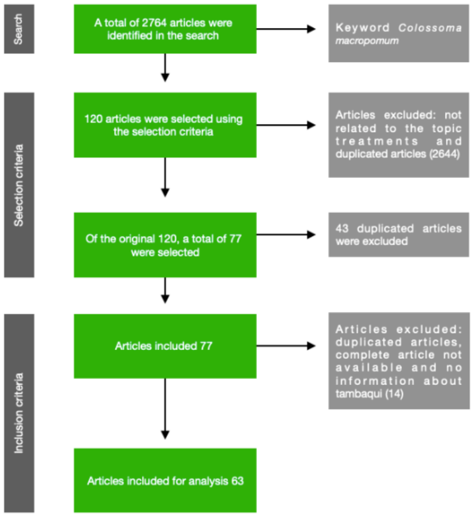

Figure 2. Flowchart showing the selection and inclusion criteria for studies on treatments to combat infectious agents and parasites that affect tambaqui.

3. Results

After the database search had been carried out and the articles analyzed, those that discussed parasites and infectious agents that affect tambaqui and treatments used to combat them were selected. Figure 4 shows the distribution of scientific articles by region in Brazil. The North had the greatest number of articles on parasites and infectious agents that affect this fish (81%), followed by the Southeast (7%), Northeast (6%), South (4%) and Midwest (2%). This is probably because the North has the greatest tambaqui production in the country: in 2017 alone, the states of Amazonas and Rondônia accounted, respectively, for 28,000 and 77,000 tons of fish native to the region (PEIXE BR 2018).

Most of the articles on infectious agents and parasites were produced in collaborative efforts by several research

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Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

and educational institutions (62%), and 38% were produced by researchers from a single institution. In the case of the articles on treatments against these pathogens, 58% were the fruit of institutional partnerships. Among the institutions and universities that produced articles on the topics researched here, most notable is EMBRAPA Brazilian Agricultural Research Corporation), indicating the organization's commitment to the development of Brazilian fish farming.

The vast majority of the studies on tambaqui involved dug-out ponds (92%), followed by net pens (4%) and wild fish (4%). This can be explained by the type of aquaculture in the North of Brazil. High-density farming is very common in dug-out ponds because of the need to ensure high productivity and meet market demand: in the North, consumption per person is around 33 kg/year (PEDROSA, 2018) compared with an average of 9 kg/year in other regions of Brazil (MARONI, 2018).

A knowledge of which infectious agents and parasites affect tambaqui, which organs and anatomical systems are affected and what treatments are recommended is important to ensure fish health and welfare. Figure 5 shows the percentages of studies on each of the infectious agents and parasites found in tambaqui up to 09 April 2020. The most diagnosed parasites were monogeneans, flatworms frequently found in the gills of fish. Another infectious agent studied was *Aeromonas hydrophila*, a gram-negative bacteria in the family Aeromonadaceae whose habitat is predominantly aquatic (freshwater and saltwater) and which causes ulcerated lesions and hemorrhagic septicemia in freshwater fishes. The clinical signs of infection by this agent are small superficial lesions, local hemorrhage (in the gills and opercula), ulcers, exophthalmos and abdominal distension. Internally, an accumulation of ascitic fluid, anemia and lesions in the liver and kidney can be observed (AUSTIN et al., 1989). Figure 3 shows the organs and anatomical systems most affected by infectious agents and parasites: the gills, followed by the integument, intestine and stomach. Because they pose a large surface area in contact with the environment, gills are most susceptible to pathogenic agents.

Table 1 shows all the infectious agents and parasites discussed in the articles selected for the systematic review after application of the inclusion criteria and the organs and anatomical systems affected.

Of the articles selected, 92% discussed treatment, 2% diagnosis and 2% anesthetics that can help to eliminate pathogens of tambaqui. For example, in one article the effect of different concentrations of eugenol, an anesthetic, on the motility and viability of monogeneans was discussed (BOIJINK et al., 2016). Despite the importance of studies on the control of infectious agents, there are to our knowledge no studies on the diagnosis and treatment of intestinal infections by fungi (PRESTES et al., 2011) and parasites such as acanthocephalans (FARIAS et al., 2018; SANTOS et al., 2018).

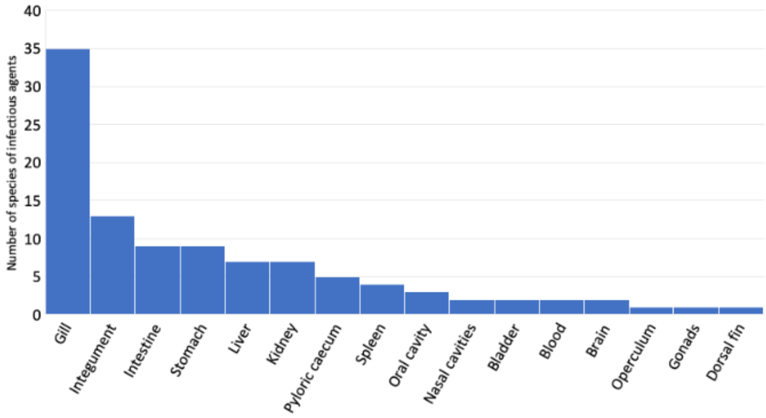

Figure 3. The number of species of infectious agents and parasites that can infect and parasitize tambaqui by anatomical localization.

Table 2 shows treatments to control different infectious agents and parasites tested by researchers and the effectiveness of each treatment. It should be noted that the authors of the studies did not use antibiotic therapy, which is a positive point as indiscriminate use can lead to bacterial resistance, becoming a worldwide public health problem (SANTOS, 2004). Furthermore, these medications can not only contaminate the environment but also be retained in fishes used for human consumption or to produce animal feed.

As shown in Table 2, the majority of the studies related to infectious agents and parasites included in this review discuss the antimicrobial and antiparasitic properties of essential oils of aromatic plants, the most commonly used species being those belonging to the genera *Lippia*, *Piper* and *Mentha*.

Species of *Lippia* are found in the states of Minas Gerais, Bahia and Goiás (Espinhaço Mountains) in two Brazilian biomes: *cerrado* (savannah-like grasslands) and *caatinga* (an area with xerophilous spiny trees and shrubs) (OLIVEIRA et al., 2007; GOMES et al.,2011). Some studies have shown the antimicrobial and antiparasitic properties of extracts of *Lippia* sp., and the essential oil of *L. alba* has been shown to be effective against *Candida albicans* serotype B, *Candida albicans*, *Candida guilliermondii*, *Candida parapsilosis*, *Cryptococcus neoformans*, *Trichophytum rubrum*, *Fonsecaea pedrosoi*, *Staphylococcus aureus*, *Staphylococcus aureus* (MRSA), *Lactobacillus casei*, *Streptococcus mutans*, *Acinetobacter baumanni*, *Bacillus subtilis*, *Escherichia coli*,

Scientia Amazonia, v. 9, n.3, B1-B25, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

Staphylococcus intermedis, *Leishmania chagasi* and *Trypanosoma cruzi*. The essential oil of *L. origanoides* is effective against *Candida albicans* serotype B, *Candida albicans*, *Candida guilliermondii*, *Candida parapsilosis*, *Cryptococcus neoformans*, *Trichophytum rubrum*, *Fonsecaea pedrosoi*, *Staphylococcus aureus* MRSA, *Lactobacillus casei*, *Streptococcus mutans*, *Leishmania chagasi*, *Trypanosoma cruzi*, *Salmonella enteritidis*, *Salmonella typhimurium*, *Escherichia coli*, *Bifidobacterium breve* and *Lactobacillus acidophilus*. The essential oil of *L. sidoides* is active against *Microsporum canis*, *Candida albicans*, *Candida tropicalis*, promastigote forms of *Leishmania chagasi*, *Dermacentor nitens*, *Rhipicephalus microplus*, *Haemonchus contortus*, *Syphacia obvelata*, *Aspiculuris tetraptera* and promastigote and amastigote forms of *Leishmania chagasi* (SOARES, TAVARES-DIAS, 2013)

A wide variety of species from the family Piperaceae are found in the Amazon forest, and some have significant antiparasitic potential. The essential oil of *Piper hispidinervum*, for example, can cause 100% lethality in acanthocephalans in 15 minutes at certain concentrations (SANTOS et al., 2018).

Mentha sp. is widely used as an antiparasitic, antifungal and antibacterial agent. *Mentha crispa*, which is known in the region as *hortelã-da-folha-miúda* (small-leafed mint), *hortelã-rasteira* (creeping mint) and *hortelã-panela* (pot mint) and is distributed throughout Brazil (ALMEIDA, 1993), is used in folk medicine to prepare teas and in orthodox medicines such as Giamebil plus®, a phytotherapic drug with anti-amoeba and anti-giardia activities used in the treatment of human parasitosis (DIMECH et al., 2006). *Mentha piperita* exhibits antimicrobial activity against yeast and fungal strains (*Candida albicans* and *Saccharomyces* spp., *Penicillium digitatum*, *Mucor* spp., *Aspergillus niger*, *Aspergillus flavus*, *Fusarium oxysporum*) and bacterial strains (*Pseudomonas fluorescens*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Escherichia coli*) (TYAGI, MALIK, 2011) and yielded satisfactory results against infectious agents and parasites of tambaqui according to the same authors, as shown in Table 2.

In addition to essential oils, substances that are toxic to fishes and widely used in agriculture and fish farming, such as Lufenuron© a benzoylurea insecticide that interferes with the synthesis of chitin in insects during molting, were identified in the review. At concentrations of from 0.7 to 0.9 mg/L, this insecticide can harm fish, causing hemorrhage in the eyes and gills, among other toxic effects (SOARES et al., 2016).

The herbicide Paraquat can damage organs such as the gills, kidneys and liver depending on temperature and concentration and can interfere with the immune response and blood parameters; the herbicide Triazine can

***Scientia Amazonia*, v. 9, n.3, B1-B25, 2020**
Revista on-line http://www.scientia-amazonia.org
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also affect the kidneys (SALAZAR-LUGO et al. 2011; SALAZAR-LUGO et al. 2009).

Studies on the diagnosis and treatment of diseases caused by these pathogens are very important for rapid treatment of these infections as they allow preventive measures to be taken and more appropriate treatment to be adopted, avoiding the use of off-label drugs; however, there is a dearth of articles on this subject.

The articles identified in this review varied in the information they contained about fish weight and length; the species of the infectious agent; the organs and anatomical systems where the infectious agent was found; the source of the fish; and the geographic coordinates of the locations where collections were performed. This information is important when developing suitable diagnostic methods and treatment for each phase of the production cycle: fry nursing, farming and fattening.

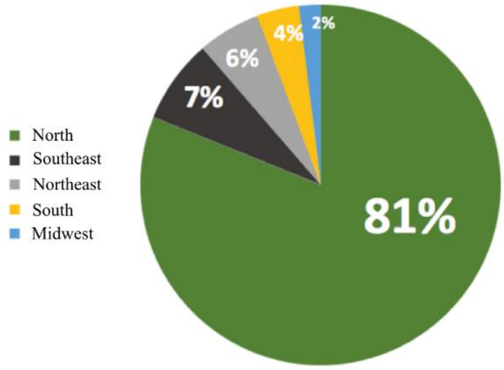

Figure 4. Scientific literature on infectious agents and parasites in tambaqui by region in Brazil.

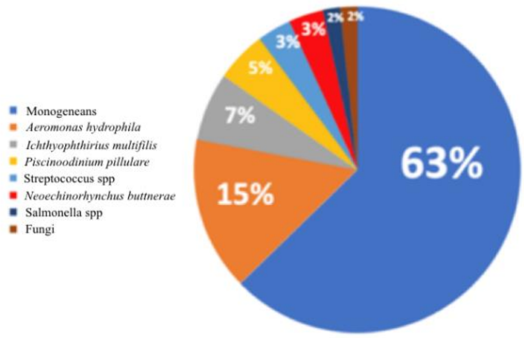

Figure 5. Proportion of studies on infectious agents and parasites in tambaqui.

Table 1. Species of infectious agents and parasites found in different organs and anatomical systems of tambaqui according to the literature (Fig.3)

Location	Species and classification	Source
Gills	**Mites** *Acarina gen. sp.* **Gram-negative bacteria** *Aeromonas hydrophila* *Bacilus cereus* *Edwardsiella tarda* *Escherichia coli* *Plesiomonas shigelloides* *Pseudomonas fluorescens* *Salmonella arizonae* *Serratia sp.*	FISHER et al. 2003 ROCHA et al. 2018 VIDEIRA et al. 2016 JERÔNIMO et al. 2015 PEREIRA et al. 2012 TAVARES-DIAS et al. 2015 GONÇALVES et al. 2018 MARTINS and ROMER, 1996 SANTOS et al. 2013 SOBERON et al. 2014 TAVARES-DIAS et al. 2009 GARCIA and BOIJINK 2017 RAMOS et al. 2016 BENETTON and MALTA 1999

	Crustaceans *Argulus multicolor* *Braga patagonica* *Dolops carvalhoi* *Ergasilus turucuyus* *Gamidactylus jaraquensis* *Lernaea cyprinacea* *Perulernaea gamitanae* **Fungi** *Branchiomyces* **Monogeneans** *Anacanthorus spathulatus* *Ancyrocephalinae* *Linguadactyloides brinkimanni* *Mymarothecium boegeri* *Mymarothecium iiapensis* *Mymarothecium viatorum* *Notozothecium janauachensis* **Parasites** Metacercariae of Cladorchiidae **Protozoans** *Chilodonella hexasticha* *Cryptobia sp.* *Henneguya sp.* *Ichthyobodo sp.* *Ichthyophthirius multifiliis* *Myxobolus colossomatis* *Piscinoodinium pillulare* *Tetrahymena sp.* *Trichodina sp.* **Leeches** *Glossiphoniidae gen. sp.*	KRITSKY et al. 1979 PAMPLONA-BASILIO et al. 2001 TAVARES-DIAS et al. 2014 SOUZA et al. 2015 GODOI et al. 2012 DIAS et al. 2015 VARGAS et al. 2015 TAVARES-DIAS et al. 2011 MOREY et al. 2019 FUJIMOTO et al. 2019
Fin	**Crustaceans** *Braga patagônica*	GONÇALVES et al. 2018
Operculum	**Crustaceans** *Perulernaea gamitanae* **Protozoans** *Myxobolus matosi*	JERÔNIMO et al. 2015 TAVARES-DIAS et al. 2009 CAPODIFOGLIO et al. 2019
Nasal cavities	**Crustaceans** *Gamidactylus jaraquensis* *Perulernaea gamitanae*	FISHER et al. 2003 JERÔNIMO et al. 2015 TAVARES-DIAS et al. 2015 TAVARES-DIAS et al. 2009
Oral cavity	**Crustaceans** *Argulus multicolor*	FISHER et al. 2003 JERÔNIMO et al. 2015

Ciências Biológicas

***Scientia Amazonia*, v. 9, n.3, B1-B25, 2020**
Revista on-line http://www.scientia-amazonia.org
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	Braga patagonica *Perulernaea gamitanae*	TAVARES-DIAS et al. 2015 GONÇALVES et al. 2018 TAVARES-DIAS et al. 2014 BENETTON and MALTA 1999 TAVARES-DIAS et al. 2011
Pyloric cae-cum	**Acanthocephalans** *Neoechinorhynchus buttnerae* **Nematodes** *Procamallanus (S.) inopinatus* *Spectatus spectatus* **Parasites** Metacercariae of Cladorchiidae **Protozoans** *Mixobolus colossomatis*	GONÇALVES et al. 2018 CAPODIFOGLIO et al. 2019
Intestine	**Nematodes** *Contracaecum sp.* *Cucullanus colossomi* **Crustaceans** *Lernaea cyprinacea* **Parasites** Metacercariae of Cladorchiidae **Protozoa** *Myxobolus sp.* **Acanthocephalans** *Neoechinorhynchus buttnerae* **Nematodes** *Procamallanus inopinatus* *Spectatus spectatus* *Spirocamallanus sp.*	FISCHER et al. 2003 ROCHA et al. 2018 JERÔNIMO et al. 2015 AGUIAR et al. 2018 TAVARES-DIAS et al. 2015 GONÇALVES et al. 2018 CHAGAS et al. 2016 SANTOS et al. 2013 COSTA et al. 2018 MALTA et al. 2001 SANTOS et al. 2017 AQUINO-PEREIRA et al. 2014 ROCHA et al. 2018 DE MATOS et al. 2017 JERÔNIMO et al. 2017 CHAGAS et al. 2015 DIAS et al. 2015 PEREIRA and MOREY 2018 LOURENÇO et al. 2018 SILVA-GOMES et al. 2017 FUJIMOTO et al. 2019
Gallbladder	**Nematodes** *Contracaecum sp.* **Protozoa** *Ellipsomyxa sp.*	VIDEIRA et al. 2016 GONÇALVES et al. 2018
Liver	**Gram-negative bacteria** *Edwardsiella tarda* *Plesiomonas shigelloides* *Pseudomonas fluorescens* *Salmonella arizonae* **Protozoans** *Calyptospora sp.* *Mixobolus sp.*	VIDEIRA et al. 2016 JERÔNIMO et al. 2015 RAMOS et al. 2016

Scientia Amazonia, v. 9, n.3, B1-B25, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

	Thelohanellus sp.	
Kidneys	**Gram-negative bacteria** *Aeromonas hydrophila* *Edwardsiella tarda* *Flavobacterium columnare* *Pseudomonas fluorescens* *Salmonella arizonae* **Protozoans** *Myxobolus sp.* *Thelohanellus sp.*	JERÔNIMO et al. 2015 PILARSKI et al. 2008 RAMOS et al. 2016
Spleen	**Gram-negative bacteria** *Edwardsiella tarda* *Plesiomona shigelloides* *Pseudomona fluorescens* **Protozoans** *Mixobolus sp.*	JERÔNIMO et al. 2015 RAMOS et al. 2016
Stomach	**Acanthocephalans** *Neoechinorhynchus buttnerae* **Gram-positive bacteria** *Bacilus cereus* **Gram-negative bacteria** *Edwardsiella tarda* *Plesiomonas shigelloides* *Pseudomonas fluorescens* *Salmonella arizonae* *Salmonella enterica* *Serratia sp.* **Nematodes** *Procamallanus (S.) inopinatus* **Protozoans** *Mixobolus longissimus*	GONÇALVES et al. 2018 RAMOS et al. 2016 CAPODIFOGLIO et al. 2019
Blood	**Protozoans** *Mixobolus sp.* *Trypanosoma sp.*	JERÔNIMO et al. 2015 RODRIGUES et al. 2017 MACIEL et al. 2011
Integument	**Gram-negative bacteria** *Flavobacterium columnare* **Crustaceans** *Argulus chicomendesi* *Braga patagonica* *Dolops carvalhoi* *Lernaea cyprinacea* **Monogeneans** *Anacanthorus spathulatus*	JERÔNIMO et al. 2015 TAVARES-DIAS et al. 2015 SANTOS et al. 2013 PILARSKI et al. 2008 DIAS et al. 2015 FUJIMOTO et al. 2019

Ciências Biológicas

***Scientia Amazonia*, v. 9, n.3, B1-B25, 2020**
Revista on-line http://www.scientia-amazonia.org
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	Protozoans *Apiosoma sp.* *Henneguya sp.* *Ichthyobodo sp.* *Ichthyophthirius multifiliis* *Myxobolus sp.* *Piscinoodinium pillulare* *Trichodina sp.*	
Gonads	**Protozoan]** *Calyptospora sp.*	
Brain	**Gram-positive bacteria** *Streptococcus sp.* **Gram-negative bacteria** *Aeromonas hydrophila*	MAJOLO et al. 2014 MARTINS et al. 2015 MARTINS et al. 2014

Table 2. Infectious agents, parasites and the corresponding treatments

Agent	Treatment	Effective-ness	Source
Monogeneans	Aspersion with or immersion in benzocaine or eugenol	Good	BOIJINK et al. 2016
	Essential oil of clove basil (*Ocimum gratissimum*)	Very good	BOIJINK et al. 2016
	Immersion in eugenol	Good	BOIJINK et al. 2015
	Essential oil of *Mentha piperita*	Good	RIBEIRO et al. 2018
	Essential oil of *Lippia alba*	Very good	SOARES et al. 2016
	Essential oil of *Lippia sidoides*	Very good	SOARES et al. 2017
	Essential oil of *Lippia origanoides*	Good	SOARES et al. 2017
	Essential oil of *Lippia alba*	Good	OLIVEIRA et al. 2014
	Essential oil of *Lippia alba*	Good	SOARES et al. 2016
	Mebendazole	Good	ARAÚJO et al. 2006
	Immersion in eugenol	Good	MIRANDA et al. 2009
	Cat's claw flour (*Uncaria tomentosa*)	Good	SANTOS et al. 2012 s
	Banana tree residue (*Musa* sp.)	Good	COSTA et al. 2018
	Salt (NaCl)	No effect	CHAGAS et al. 2012
	Noni (*Morinda citrifolia*) pulp flour in feed	No effect	ROSAS et al. 2012
	Nanoemulsion of oil of *Copaifera officinalis* resin	Very good	VALENTIM et al. 2018
	Acetone extract of *Bixa orellana*	Very good	ANDRADE et al. 2016
	Mebendazole in feed	Very good	ARAÚJO and CHAGAS, 2006
	Banana leaf flour (*Musa* sp.)	Good	GARCIA et al. 2016
	Essential oil of *Lippia sidoides*	Good	SOARES et al. 2014
	Garlic (*Allium sativum*)	Good	INOUE et al. 2016
	Bixa orellana seed extract	Very good	ANDRADE et al. 2018
	Essential oil of clove basil (*Ocimum gratissimum*)	Good	CHAGAS et al. 2012
	Garlic vine (*Adenocalymma alliaceum*) and clove basil (*Ocimum gratissimum*)	Very good	

Scientia Amazonia, v. 9, n.3, B1-B25, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

	Mebendazole in feed	Good	BOIJINK et al. 2011
	Nanoemulsion of essential oil of *Pterodon emarginatus*	Very good	CHAGAS et al. 2016
	Garlic (*Allium sativum*) in feed	Good	VALENTIM et al. 2017
	Essential oil of clove basil (*Ocimum gratissimum*)	Very good	
	Praziquantel	Good	RIBEIRO et al. 2009
	Copper sulfate	Poor	MIRANDA et al. 2010
	Immersion in mebendazole solution	Good	MACIEL et al. 2011
	Neguvon	Good	TAVARES-DIAS et al. 2011
	Homeopatila 100	No effect	CARVALHO et al. 2008
			CARVALHO et al. 2010
			PINHEIRO et al. 2014
			GONZALES et al. 2019
	Ficus insipida latex	Further studies needed	
Aeromonas hydrophila	Essential oil of *Mentha piperita*	Good	SILVA et al. 2017
	Ethanol and aqueous extract of *Lippia alba* and *Lippia origanoides*	Good	FERREIRA et al. 2016
		Good	OLIVEIRA et al. 2015
	Essential oil of *Lippia* sp.	Good	NASCIMENTO et al. 2013
	Essential oil of *Lippia origanoides*	Further studies needed	DIAS et al. 2018
	Essential oils of *Piper aduncum*, *Piper hispidinervum*, *Piper callosum* and *Curcuma longa*		CHAGAS et al. 2020
			RIBEIRO et al. 2016
			OLIVEIRA et al. 2015
	Bacillus cereus supplement	Good	OLIVEIRA et al. 2018
	Essential oil of *Mentha piperita*	Good	MAJOLO et al. 2019
	Essential oil of *Lippia origanoides*	Good	
	Essential oil of *Lippia origanoides*	Good	
	Essential oils from five brazilian Piper species	Further studies needed	
Anacanthorus spatulatus	Essential oil of *Mentha piperita*	Good	SOARES et al. 2016
	Essential oil of *Lippia alba*	Very good	SOARES et al. 2017
	Essential oil of *Lippia sidoides*	Very good	SOARES et al. 2017
	Essential oil of *Lippia origanoides*	Good	SOARES et al. 2016
	Essential oil of *Lippia alba*	Good	ARAÚJO et al. 2006
	Mebendazole	Good	CHAGAS et al. 2012
	Salt (NaCl)	No effect	

	Nanoemulsion of oil of *Copaifera officinalis* resin	Very good	VALENTIM et al. 2018
	Acetone extract of *Bixa orellana*	Very good	ANDRADE et al. 2016
	Mebendazole in feed	Very good	ARAÚJO and CHAGAS, 2006
	Garlic (*Allium sativum*)	Good	INOUE et al. 2015
	Bixa orellana seed extract	Very good	ANDRADE et al. 2018
	Mebendazole in feed	Good	CHAGAS et al. 2016
	Nanoemulsion of essential oil of *Pterodon emarginatus*	Very good	VALENTIM et al. 2017
	Garlic (*Allium sativum*) in feed	Good	RIBEIRO et al. 2009
	Copper sulfate	Poor	TAVARES-DIAS et al. 2011
	Immersion in mebendazole solution	Good	CARVALHO et al. 2008
	Homeopatila 100	No effect	PINHEIRO et al. 2014
	Levamisole	Good	NOGUEIRA et al. 2019
	Albendazole	Poor	ALVES et al. 2019
Ichthyophthirius multifiliis	Essential oil of *Lippia alba*	Very good	SOARES et al. 2016
	Essential oil of *Lippia sidoides*	Very good	SOARES et al. 2017
	Essential oil of *Lippia origanoides*	Good	SOARES et al. 2017
	Essential oil of *Lippia alba*	Good	SOARES et al. 2016
	Homeopatila 100	No effect	PINHEIRO et al. 2014
	Endemic plant in the state of Sergipe	Good	FRANÇA et al. 2015
Linguadactyloides brinkimani	Homeopatila 100	No effect	PINHEIRO et al. 2014
	Albendazole	Poor	ALVES et al. 2019
Mymarothecium boegeri	Essential oil of *Mentha piperita*	Good	RIBEIRO et al. 2018
	Essential oil of *Lippia alba*	Very good	SOARES et al. 2016
	Essential oil of *Lippia sidoides*	Very good	SOARES et al. 2017
	Essential oil of *Lippia origanoides*	Good	SOARES et al. 2017
	Essential oil of *Lippia alba*	Good	SOARES et al. 2016
	Salt (NaCl)	No effect	CHAGAS et al. 2012
	Nanoemulsion of oil of *Copaifera officinalis* resin	Very good	VALENTIM et al. 2018
	Mebendazole in feed	Good	CHAGAS et al. 2016
	Nanoemulsion of essential oil of *Pterodon emarginatus*	Very good	VALENTIM et al. 2017
	Homeopatila 100	No effect	PINHEIRO et al. 2014
	Levamisole	Good	NOGUEIRA et al. 2019
	Albendazole	Poor	ALVES et al. 2019

***Scientia Amazonia*, v. 9, n.3, B1-B25, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

Neoechinorhynchus buttnerae	Praziquantel Essential oils of *Piper hispidinervum*, *Piper hispidum*, *Piper marginatum* and *Piper callosum* Avermectins, praziquantel and levamisole	Good Very good Further studies needed	FARIAS et al. 2018 SANTOS et al. 2018 OLIVEIRA et al. 2019
Notozothecium janauachensis	Essential oil of *Mentha piperita* Essential oil of *Lippia alba* Essential oil of *Lippia sidoides* Essential oil of *Lippia origanoides* Essential oil of *Lippia alba* Salt (NaCl) Nanoemulsion of oil of *Copaifera officinalis* resin Mebendazole in feed Mebendazole in feed Nanoemulsion of essential oil of *Pterodon emarginatus* Homeopatila 100 Levamisole Albendazole	Good Very good Very good Good Good No effect Very good Very good Good Very good No effect Good Poor	RIBEIRO et al. 2018 SOARES et al. 2016 SOARES et al. 2017 SOARES et al. 2017 SOARES et al. 2016 CHAGAS et al. 2012 VALENTIM et al. 2018 ARAÚJO and CHAGAS,2006 CHAGAS et al. 2016 VALENTIM et al. 2017 PINHEIRO et al. 2014 NOGUEIRA et al. 2019 ALVES et al. 2019
Piscinoodinium pillulare	Homeopatila 100 Essential oil of *Mentha piperita* Essential oil of *Mentha piperita*	No effect Good Good	PINHEIRO et al. 2014 FERREIRA et al. 2018 FERREIRA et al. 2019
Salmonella typhimurium	Ozone	No effect	LUIZ et al. 2017
Streptococus agalactiae	Probiotics: *Bacillus subtilis* and *Saccharomyces cerevisiae*	Good	PAIXÃO et al. 2017
Streptococcus sp.	Essential oils of *Piper aduncum*, *Piper hispidinervum*, *Piper callosum* and *Curcuma longa*	Further studies needed	NASCIMENTO et al. 2013
Fungi	Epoxyconazole, pyraclostrobin and a mixture of these	Poor	PRESTES et al. 2011

Effectiveness: Very good (100% effective, non-toxic); Good (effective and non-toxic); Poor (toxic and harmful); Further studies needed (inconclusive); No effect (did not exhibit any activity).

Scientia Amazonia, v. 9, n.3, B1-B25, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

4. Conclusion

This systematic review has identified the infectious agents and parasites that most commonly affect tambaqui and the treatment alternatives for them. The review showed that the literature does not provide sufficient information to allow a more complete analysis, which would not only help to ensure adequate diagnosis and treatment but also allow the development of new, faster diagnostic methods and treatment alternatives, consequently ensuring the health and welfare of fish consumed by the population.

5. Acknowledgement

To CAPES for the concession of master's degree scholarships. MCS is the recipient of a CNPq productivity fellowship (ref. 303032/2016–2 and 307237/2019-2)

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