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EPIDEMIOLOGY OF THE ZOONOTIC NEMATODES PARASITING TILAPIES OF THE GENUS *Oreochromis* (Perciformes: Cichlidae) WITH SOCIOECONOMIC IMPORTANCE

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ABSTRACT

This work aimed to review the main epidemiological data on zoonotic nematodes parasitizing tilapia of the genus *Oreochromis* (Perciformes: Cichlidae) with socioeconomic importance. The literature review was conducted in six specialized search engines, and a total of 320 articles were analyzed. After eliminating documents with duplicated information or those that did not refer to zoonotic nematodes in cichlids, 10 bibliographic sources were processed. The analysis showed that the available documentation refers mainly to the genera *Gnathostoma* in America and *Contracaecum* in Africa, while data are scarce in Europe, Asia, and Oceania. This work includes information on prevalence, distribution, and diagnosis, both from natural and artificial environments. In conclusion, data on the epidemiology of zoonotic nematodes that parasitize tilapia of the genus *Oreochromis* are scarce, so attention should be paid to monitoring economically important fish to prevent parasitological problems in the production chain.

Keywords: *Oreochromis*, *Gnathostoma*, *Contracaecum*, aquaculture, fish meat, parasites.

INTRODUCTION

The development of new and improved technologies in the production of fish meat has economically benefited the industry, which had sustained growth during the last two decades. Currently, more than 173 million Mg of fish are produced (Quiazon, 2015). Tilapia, which refers to 70 species belonging to the Cichlidae family, is of great socioeconomic importance worldwide. The taxonomic classification of tilapia is complex due to the constant changes resulting from the hybridization that takes place naturally. However, there are three main genera: *Oreochromis*, *Sarotherodon*, and *Tilapia*, the first being the most relevant since the 32 species it comprises are resistant to diseases, reproduce rapidly, and adapt easily to changes in environment, food, and water quality (Vega-Villasante *et al*., 2010).

Tilapia has been introduced for aquaculture purposes in more than 90 countries around the world (Vega-Villasante *et al.*, 2010); however, some management practices are limited, resulting in the presence and spread of parasites (Shechonge *et al*., 2019). In Mexico, the production of *Oreochromis* spp. is equivalent to 60 % of national production (Domínguez-May *et al*., 2020), so food safety programs have been carried out to ensure the health and sustainable expansion of production chains. However, the information that exists on parasitic transmission from fish to humans is scarce, becoming a latent risk factor in public and veterinary health (Garrido-Olvera *et al*., 2017), which implies a challenge in the search for the integral management approach in the meat production and consumption chain.

Zoonotic nematodes are those helminths that can potentially be transmitted to humans by the consumption of raw or insufficiently cooked meat harboring parasite larvae. Most of the records on fish-transmitted nematode larvae correspond to the genera *Gnathostoma* (Carod-Artal *et al*., 2017) and *Contracaecum* (Ogutu-Ohwayo *et al*., 2016). Thus, the objective of this study was to make a literature review on the epidemiology of zoonotic nematodes parasitizing tilapia of the genus *Oreochromis* with socioeconomic importance.

MATERIALS AND METHODS

The literature review was performed with search engines using the keywords "zoonotic parasite," "foodborne parasites," "*Oreochromis,*" and "tilapia," together with variants that refer to the parasites or the disease they produce, such as *Gnathostoma* spp. (gnathostomiasis) and *Anisakis* spp. (anisakosis). From these words, the inclusion "*Gnathostoma* or gnathostomiasis and *Oreochromis* or tilapia" was structured for each parasitic organism or disease. Six specialized literature search engines were used (ScienceDirect, PubMed, Primo, CONRICyT, LILAES, and AJOL), from which a total of 320 search results were obtained.

Subsequently, articles referring to taxonomic groups of parasites and fish outside the scope of this review and duplicate bibliographic sources were eliminated, and those with epidemiological data on the zoonotic nematode-typhoid binomial were selected. This resulted in a total of 10 bibliographic sources for the information analyzed in this review. Then, information was captured for the presentation of data and the preparation of the geographical distribution map based on the background information available by country, using the open access program RStudio (Boston, MA, USA).

RESULTS AND DISCUSSION

Prevalence and distribution

Human activities have a direct impact on the incidence and spread of parasites that can be transmitted zoonotically. The main activities associated with zoonotic transmission of nematodes are the culinary habit of consuming raw or undercooked meat, tourism, migratory flows (Williams *et al*., 2020), and, of course, the introduction of different fish species for zootechnical purposes. The global distribution of zoonotic transmission nematodes (Figure 1) indicates the presence of *Gnathostoma* spp. in the Americas and *Contracaecum* spp. in Africa, involved in the tilapia production and consumption chain. It is important to consider that nematodiasis associated with the consumption of raw or undercooked meat of cichlid fish (species other than tilapia) is also reported in the Americas and in Mexico (DOF, 2009). In particular, gnathostomiasis, which is associated with the consumption of raw tilapia meat as the second intermediate host of *Gnathostoma spinigeru*, *G. turgidum,* and *G. binucleatum* (Diaz-Camacho *et al*., 2002; Mosqueda-Cabrera *et al*., 2009), is the subject of epidemiological surveillance (DOF, 2009).

Gnathostoma spp. are distributed in the states of Campeche, Chiapas, Guerrero, Jalisco, Nayarit, Oaxaca, Tabasco, and Veracruz; an outbreak of gnathostomiasis was even recorded due to the introduction of cichlids (species different from tilapia) in the Miguel Alemán dam in the state of Oaxaca (Martínez-Cruz *et al*., 1989). *G. binucleatum* has been recorded in *Oreochromis aureus*, *O. mossambicus*, and *O. niloticus* in the Temascal dam

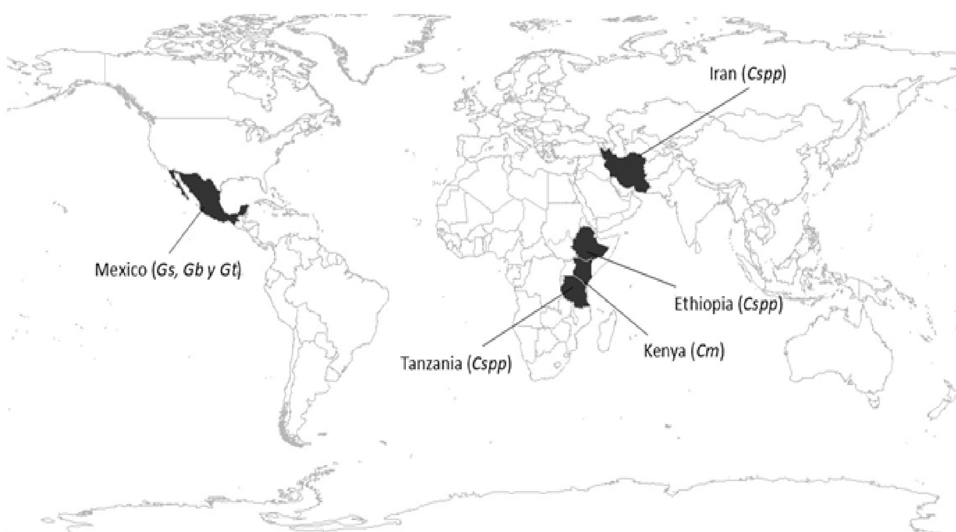

Figure 1. Distribution of nematodes with zoonotic potential associated with the production and consumption of raw or undercooked tilapia meat. Nematodes are identified as *Gnathostoma spinigerum* (*Gs*), *G. binucleatum* (*Gb*), *G. turgidum* (*Gt*), *Contracaecum* spp. (*Cspp*), and *C. multipapillatum* (*Cm*).

in Oaxaca, with a prevalence of 1.2, 1.7, and 2.1 %, respectively (Salgado-Maldonado *et al*., 2005). In Veracruz, *G. binucleatum* was found with a prevalence of 26 % in *O. massambicus* and 7 % in *O. niloticus* (León-Règagnon *et al*., 2005).

The presence of *Contracaecum* spp. has been documented in Kenya, Tanzania, and Ethiopia (Yimer, 2000; Adugna, 2020; Chibwana *et al*., 2020). *Oreochromis niloticus* and *Tilapia galileae* from Lake Nasser in Egypt have been documented with a prevalence of 35.6 and 0.14 %, respectively (Motamedi *et al*., 2019), while in Lake Turkana in Kenya, the nematode was found with a prevalence of 15.9 to 18.2 % in *Tilapia zillii* (Otachi *et al*., 2015). *O. amphimelas* from the Nyumba ya Mungu dam in Tanzania was documented with a prevalence of 47.3 % in commercially sized fish (20 to 30 cm in length); the prevalence in males was 46.7 %, and in females, 33.3 % (Chibwana *et al*., 2020). However, in the Gojam zone of Ethiopia, a prevalence of 58.8 % was reported for *Contracaecum* spp. in tilapia production farms (Adugna, 2020).

In Europe, the consumption of fish meat is recorded at 24.33 kg per capita per year, placing the inhabitants of the continent as one of the populations at highest risk. *Gnathostoma* spp. has been reported in England, where its presence has been documented in humans who acquired the infection in Botswana, a landlocked country in southern Africa (Herman *et al*., 2009). Asia is the continent with the highest aquaculture and fishery production worldwide, where China is one of the main tilapia producers. However, the only reports of *Contracaecum* spp. are from Iran (Table 1) (Motamedi *et al*., 2019).

Unfortunately, in different geographic areas, the monitoring of fish-borne zoonotic agents is low profile. The incidence of clinical cases associated with the consumption of raw tilapia meat from aquaculture systems is absent, largely due to the sanitary

Table 1. Summary of the prevalence and location of zoonotic nematode larvae in tilapias of socioeconomic value.

Country	Parasites	Prevalence (%)	Host	Anatomical distribution	Reference
Mexico	*Gnathostoma spinigerum*, *G. binucleatum*, *G. turgidum*	1.2–80	*Oreochromis niloticus*, *O. mossambicus*, *O. aureus*	Muscle	Diaz-Camacho *et al*. (2002); León-Règagnon *et al*. (2005); Mosqueda-Cabrera *et al*. (2009); Salgado-Maldonado *et al*. (2005)
Ethiopia	*Contracaecum* spp.	5.5–27.4	*Oreochromis niloticus*, *Tilapia zillii*	Gills, mesentery, heart	Gulelat *et al*. (2013)
Kenya	*Contracaecum multipapillatum*	-51.8–19.6	*Oreochromis leucostictus*, *Tilapia zillii*	Gills, mesentery, heart, intestine, liver	Otachi *et al*. (2014a, 2014b, 2015)
Tanzania	*Contracaecum* spp.	55.6	*Oreochromis aureus*	Mesentery	Chibwana *et al*. (2020)
Iran	*Contracaecum* spp.	0.1–35.6	*Oreochromis niloticus*, *Tilapia galileae*	Mesentery	Motamedi *et al*. (2019)

control system of each fish farm as well as the sanitary inspections carried out by the meat distribution companies. Despite the high risk of infection due to the consumption of fish over which there is no sanitary control and which are often consumed in "artisanal" culinary dishes based on raw or insufficiently cooked meat, the epidemiological report of the clinical case is ambiguous because it considers the clinical manifestation as "food poisoning." Few are the cases that conclude with a laboratory diagnosis (Acosta-Pérez *et al*., 2022); at least in Mexico, epidemiological surveillance of other zoonoses, such as taeniasis and cysticercosis, transmitted by pork consumption, have continuous monitoring and well-defined diagnostic strategies (Hernández-Ramírez *et al*., 2023).

Life Cycles

Nematodes of the genus *Gnathostoma* belong to the Gnathostomidae family. Their life cycle begins with dioecious adults lodged in the intestine of the definitive host (dogs, cats, pigs). The female oviposits eggs, which are released with the feces, which must be deposited in a freshwater environment so that the larvae of the first stage of development (L1) are released and consumed by a copepod (Crustacea), which acts as the first intermediate host where the L2 larvae develop (Diaz-Camacho *et al*., 2002). Secondary intermediate hosts such as tilapia become infected by ingesting L2 larvae lodged in the copepods. Subsequently, the L3 stage develops in muscle tissue.

Consumption of raw fish meat constitutes the source of infection for three different types of hosts. First, for transport or paratenic hosts (piscivorous birds). Secondly, for the definitive host (carnivorous mammal), which may consume the infected fish or the transport host. In the third case, humans become an accidental host, where L3, the etiological agent of gnathostomiasis, will migrate to the brain, eyes, viscera, or skin (Figure 2) (Martínez-Cruz *et al*., 1989; Leroy *et al*., 2017), but will not reach the adult stage.

Contracaecum is a nematode of the family Anisakidae that uses fish as intermediate hosts in its life cycle (Figure 3). The eggs hatch in the marine environment with the feces of the definitive host; in the water and inside the egg, the larval stages L1 and L2 develop. The egg hatches, and the L2s are ingested by a copepod, which is the first intermediate host where L3s develop. When infected copepods are ingested by fish, these become transport hosts. L3 can be transmitted several times from fish to fish until they are ingested by a piscivorous bird or marine mammal. Humans or other organisms with ichthyophagous habits become accidental hosts by the ingestion of raw or undercooked fish meat (Shamsi, 2019). In humans, L3s do not develop in adults, but parasite antigens provoke anaphylactic reactions.

Definitive hosts

Parasitic prevalence is rarely described in all hosts involved in the food web where tilapia participate, causing the diagnosis to occur fortuitously. In definitive hosts that are infected by ichthyophagous habits, parasitological evaluation is systematized and

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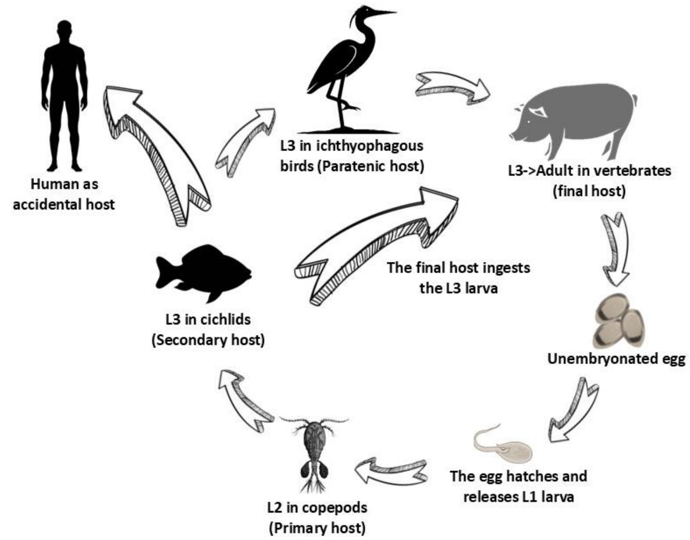

Figure 2. Life cycle of *Gnathostoma* spp. Humans become infected by eating raw or undercooked fish meat (tilapia, for example), where viable L3 larvae are found. Adapted from Moore *et al*. (2003).

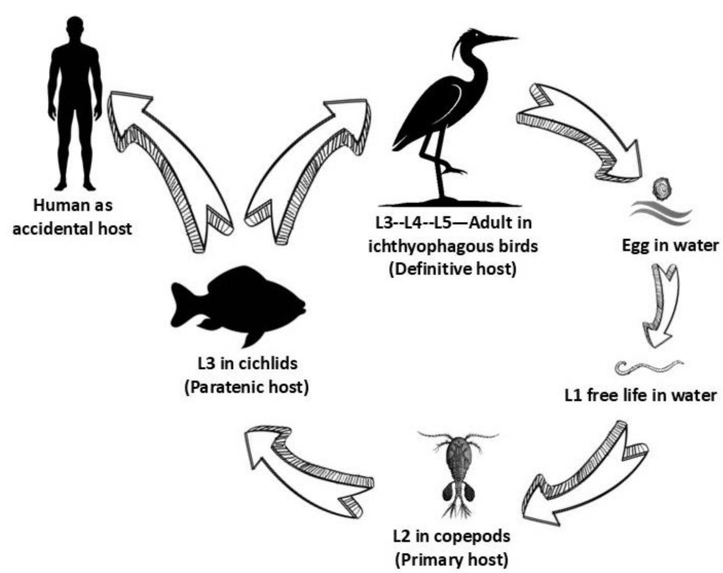

Figure 3. Life cycle of *Contracaecum* spp. L1, L2, and L3 refer to the larval stages in the different hosts involved in the life cycle. Adapted from Valles-Vega *et al*. (2017).

is usually associated with fauna living near water bodies (Pérez-Ponce de León *et al*., 2018).

In the life cycle of *Gnathostoma* spp., a wide variety of naturally infected definitive hosts have been identified, including herons (*Egretta alba* and *E. thula*), the white American pelican (*Pelecanus erythrorhynchos*), the blue heron (*Ardea herodias*), neotropical cormorant (*Phalacrocorax olivaceous*), the brown pelican (*Pelecanus occidentalis*), opossum (*Didelphis virginiana*) (Diaz-Camacho *et al*., 2002), turtles (*Kinosternon integrum*), and the amphibian leopard frog (*Lithobates zweifeli*) (Mosqueda-Cabrera *et al*., 2009). In addition, experimental infections by *Gnathostoma binucleatum* have been reported viable in dogs, evidencing that some domestic animals can act as definitive hosts (Álvarez-Guerrero *et al*., 2018). Likewise, humans are potential accidental hosts, where *Gnathostoma* spp. larvae do not develop into adults. Nevertheless, parasitic infections can lead to relevant conditions (Herman, 2009).

In Mexico, *Contracaecum microcephalum* has only been recorded in Mexico City on the birds *Nycticorax nycticorax*, *Pelecanus erythrorhynchus,* and *Anhinga anhinga*; in the State of Guerrero, *Pelecanus erythrorhynchus* has been identified, while *C. caballeroi* has only been recorded once on *Anhinga anhinga* in the Chapultepec Zoo (Fagerholm and Overstreet, 2009).

Diagnosis in tilapia

The diagnosis of parasites in cichlid fish is carried out by necropsy; in this procedure, different parasitic stages are recovered, including L3 larvae that can infect humans and other accidental hosts. The parasites recovered are processed by staining to show morphological structures that allow their identification by means of taxonomic keys (Sepulveda and Kinsella, 2013). In addition, Mexican regulations indicate the candling procedure for parasite identification (DOF, 2009). Likewise, microscopic analysis of larvae in muscle includes the observation of sectioned meat or organs between two glass plates using low magnification objectives (Diaz-Camacho *et al*., 2002). However, it is becoming increasingly relevant that observations are complemented with molecular diagnostic techniques. This is indispensable for the confirmation and identification of etiological agents in fish as well as in human clinical cases. For example, for the identification of nematodes of the genus *Contracaecum*, the amplification of the ITS2 regions, including the 5.8S rRNA gene (Motamedi *et al*., 2019), and the ITS1 region (Otachi *et al*., 2015), has been documented.

Tilapia as a transmitter of zoonotic nematodes and their impact on human health

The consumption of culinary dishes that include raw tilapia meat, such as sushi or sashimi, is a risk factor for the transmission of nematodes with zoonotic potential (Leroy *et al*., 2017). Some adulterations in marketing, such as species substitution in the meat industry, increase the risk for consumers. Previously, the presence of larvae of the nematode *Gnathostoma* spp. was reported, in addition to sporozoites of *Cryptosporidium parvum* and adults of the cestode *Diphyllobothrium latum* in tilapia, which is sold as a substitute for snapper fish (Williams *et al*., 2020), which is a traditional fish in the sushi trade, an internationally popular culinary preparation of Japanese gastronomy, based on rice and raw fish meat (Vicente-Pardo, 2016).

Frequently, human clinical diagnosis of nematodes is based on epidemiology, blood chemistry (hypereosinophilia and positive serological test), and isolation of larvae in skin biopsies (Leroy *et al*., 2017). For example, in England, two clinical cases of human gnathostomiasis were followed up, where at 2- and 5-weeks post-infection, intermittent abdominal discomfort was reported, along with pain in body mobility, spleen swelling, pruritus in the right axilla and groin, a subcutaneous lump at the level of the thorax, larval mobility, swelling, and pain and itching in the knee. Regarding eosinophilia, 0.69 × 109 and 0.9 × 109 L1 cells were recorded, respectively in each case (Herman, 2009).

The clinical manifestations caused by *Gnathostoma* spp. may include skin damage caused by the migratory larvae (Martínez-Cruz *et al*., 1989; Diaz-Camacho *et al.*, 2002), as well as visceral disease, including hepatic, pulmonary, and gastrointestinal conditions, less frequently urogenital, and in the most severe cases, cerebral and ocular involvement (Carod-Artal *et al*., 2017) that can induce radiculomyelitis with paraplegia, myeloradiculoencephalitis, and subarachnoid or cerebral hemorrhage (Leroy *et al*., 2017).

Clearly, the next step after diagnosis is the therapeutic treatment of nematodiases, for which different anthelmintics such as diethylcarbamazine, ivermectin, albendazole, and praziquantel have been used, in some cases combined with dexamethasone (Herman *et al*., 2009; Leroy *et al*., 2017). However, the information analyzed indicates that there is no standardized treatment. Thus, the characterization and reporting of the parasitosis show areas of opportunity in the study of zoonotic diseases caused by the consumption of raw or insufficiently cooked tilapia meat.

CONCLUSIONS

Tilapia species act as a host and reservoir for parasites with zoonotic potential that can lead to sanitary problems in cichlid populations and public health. Considering that tilapia is a fish resistant to changes in diet and environment, it is often preferred over other species in aquaculture; however, it is also considered an invasive species that limits the growth of native populations (Mendoza-Alfaro and Koleff-Osorio, 2014). Human infections originate from the consumption of raw or undercooked tilapia meat that harbors viable larvae, which try to complete their life cycle, causing clinical problems. Thus, zoonotic parasites pose the need to develop and implement epidemiological surveillance programs within a comprehensive and unifying “one health” approach to balance and optimize the health of people, animals, and ecosystems.

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