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Original Article

Alternating tambaqui (*Colossoma macropomum*) and curimbatá (*Prochilodus lineatus*) production as a rotation strategy for the control of *Neoechinorhynchus buttnerae*

Alternância da produção de tambaqui (*Colossoma macropomum*) com curimbatá (*Prochilodus lineatus*) como estratégia de rotação para o controle de *Neoechinorhynchus buttnerae*

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Abstract

Protocols for species alternation in successive aquaculture production cycles are scarce. The present study evaluated rotation between tambaqui (*Colossoma macropomum*) and curimbatá (*Prochilodus lineatus*) as a potential strategy to control the acanthocephalan *Neoechinorhynchus buttnerae* in ponds. Four earthen ponds were used for tambaqui grow-out; one pond with a history of acanthocephalosis was subjected to a species rotation system with curimbatá for 60 days prior to tambaqui stocking, whereas three ponds had no previous history of acanthocephalosis and were not subjected to species rotation. Tambaqui were evaluated at the beginning of the grow-out phase and after 5 and 7 months. In the pond subjected to species rotation, the prevalence was 100% of *N. buttnerae* at both 5 and 7 months (5/5 at each time), with mean intensities of 1,551 ± 677 and 593 ± 359, respectively, and a predominance of immature and adult males. Fish from this pond had lower final weight and specific growth rate (1.405 kg; 1.848% day^{-1}) than fish from other three ponds (1.662 ± 0.003 kg; 1.928 ± 0.001% day^{-1}). Under the conditions evaluated, the 60-day rotation with curimbatá did not prevent subsequent *N. buttnerae* infection in the pond with a previous history of acanthocephalosis.

Keywords: Acanthocephalosis, aquaculture health management, parasite control, crop rotation.

Resumo

Protocolos de alternância de espécies em ciclos sucessivos de produção aquícola são escassos. O presente estudo avaliou a rotação entre tambaqui (*Colossoma macropomum*) e curimbatá (*Prochilodus lineatus*) como estratégia potencial para controle do acantocéfalo *Neoechinorhynchus buttnerae* em viveiros escavados. Foram utilizados quatro viveiros escavados para a engorda do tambaqui: um viveiro com histórico de acantocefalose foi submetido à rotação com curimbatá por 60 dias antes do povoamento com tambaqui, enquanto os outros três viveiros não apresentavam histórico prévio de acantocefalose e não foram submetidos à rotação de espécies. No viveiro submetido à rotação, os tambaquis apresentaram 100% de prevalência de *N. buttnerae* aos 5 e 7 meses (5/5 em cada período de amostragem), com intensidades médias de 1.551 ± 677 e 593 ± 359, respectivamente, e predominância de formas imaturas e machos adultos. Os peixes desse viveiro apresentaram peso final 15,5% menor e taxa de crescimento específico 4,1% menor (1.405 Kg; 1,848% dia^{-1}) do que os peixes dos viveiros nos quais a infecção não foi detectada (1.662 ± 0,003 Kg; 1,928 ± 0,001% dia−1). Nas condições avaliadas, a rotação de 60 dias com curimbatá não evitou a ocorrência subsequente de infecção por *N. buttnerae* no viveiro com histórico prévio de acantocefalose.

Palavras-chave: Acantocefalose, manejo sanitário aquícola, controle parasitário, rotação de cultura.

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Introduction

Rotational systems are widely adopted as sanitary management strategies in animal and plant production, aiming to interrupt pathogen life cycles through the temporary removal of hosts and modification of environmental conditions (Berger, 1977; Barger et al., 1994), thereby reducing environmental pathogen loads. This approach has proven effective in interrupting the life cycle of gastrointestinal helminths by reducing the survival of infective stages in the environment (Sani & Chandrawathani, 1996). For example, *Haemonchus contortus*, an important nematode parasite of goats and sheep, can be controlled through short-term rotational grazing systems, with animals remaining for 2–3 days in each paddock and returning to the original paddock after 30 days, as demonstrated by Barger et al. (1994).

In aquaculture, species rotation or alternation may represent a productive and sanitary management strategy in which different species are cultivated in successive production cycles within the same farming unit. This approach may contribute to reducing sanitary pressure by interrupting the life cycle of specific pathogens while also improving environmental quality and optimizing resource use through different patterns of nutrient utilization and interactions with the culture environment (Paclibare et al., 1998; Yuvaraj et al., 2015; Santhi & Deivasigamani, 2017). Species rotation has been extensively studied in shrimp farming, particularly following evidence of host specificity among certain strains of *Vibrio harveyi* (Paclibare et al., 1998). In this context, different species rotation strategies have been evaluated, including the alternation of marine shrimp species such as *Litopenaeus vannamei* and *Penaeus monodon* with tilapia (Paclibare et al., 1998), as well as with species such as *Mugil cephalus* and *Chanos chanos* (Yuvaraj et al., 2015; Santhi & Deivasigamani, 2017) and *Trachinotus blochii* (Joseph et al., 2022). Studies involving rotation between *P. monodon* and *Macrobrachium rosenbergii* have also been conducted (Srinivasan et al., 1997).

For native Brazilian fish species, technical recommendations regarding species rotation are scarce and have been little explored. In recent years, following outbreaks of acanthocephalosis in tambaqui (*Colossoma macropomum*) farming systems, this practice has been recommended by technical assistance as a potential sanitary management strategy. This recommendation was based, in part, on field observations that associated species rotation with a lower occurrence of acanthocephalan infection (Perez Pedroti et al., 2025) and by the host–parasite relationship between *N. buttnerae* and *C. macropomum*. By analogy with the concept of crop rotation, the introduction of a different fish host into the production system was expected to disrupt the life cycle of *N. buttnerae*. However, evidence supporting this practice remains primarily observational, and its application as a targeted rotation strategy for the control of *N. buttnerae* in tambaqui production requires further experimental evaluation.

Tambaqui is an Amazonian fish species with favorable zootechnical characteristics for aquaculture (Hilsdorf et al., 2022). In 2025, native fish farming in Brazil reached 257 thousand tons of production, with tambaqui being the most produced species (Peixe BR, 2026). Tambaqui farming is predominantly carried out in earthen ponds, generally under monoculture systems (Pedroza et al., 2016; Valenti et al., 2021). However, the intensification of production systems and the predominance of monocultures may favor the occurrence and dissemination of diseases. Among the main sanitary problems reported in the farming systems of tambaqui and its hybrids (Silva et al., 2013; Chagas et al., 2015; Dias et al., 2015), intestinal parasitic diseases stand out as important causes of productive losses in northern Brazil.

The endoparasite *Neoechinorhynchus buttnerae* is an important acanthocephalan affecting tambaqui and its hybrids throughout all production stages. This is a dioecious parasite with a heteroxenous life cycle that reproduces in the digestive tract of fish, releasing fertilized eggs into the environment through the feces (Santos et al., 2013). The eggs have three membranes that protect the larvae against adverse environmental conditions until they are consumed by the ostracod arthropod *Cypridopsis vidua*, which acts as an intermediate host (Lourenço et al., 2018). Other ostracod species (*Heterocypris* sp. and *Heterocypris punctata*) have also been reported in ponds where *N. buttnerae* occurs at high prevalence (Perez Pedroti et al., 2025). The development of the immature stages (acanthor larvae, acanthella, and cystacanth) of *N. buttnerae* in the ostracod takes approximately 29 days (Lourenço et al., 2018). Subsequently, infected ostracods are ingested by tambaqui, in which the parasite larvae develop into egg-producing adults, thereby completing this stage of the parasite's life cycle in approximately 28–56 days. Therefore, the complete life cycle of *N. buttnerae* may take up to approximately 3 months (Chagas et al., 2019; Castro et al., 2020). These characteristics of the parasite's life cycle may directly influence the effectiveness of species rotation and the rotation period required to interrupt parasite transmission. In addition, the persistence of its developmental stages and intermediate hosts in the production environment may also limit the effectiveness of species rotation. The presence of eggs surrounded by protective layers is an important factor hindering health management in fish farming ponds, as the larvae in different stages can remain viable inside the egg for several months (Kennedy, 2006).

Similarly, ostracods are a common and widely distributed group of zooplankton in fish farming ponds, making it difficult to reduce their population through conventional management practices. The main pathways for parasite dissemination are direct connections, particularly downstream, between ponds and watercourses, which may transport water contaminated with eggs or intermediate hosts, as well as the movement of infected fish, such as broodstock or fingerlings (Sbettega et al., 2026). The mortality associated with *N. buttnerae* infection is generally low. However, attachment of the parasite proboscis to the intestinal wall triggers an intense inflammatory response, increasing mucus production and impairing digestion (Jerônimo et al., 2017; Matos et al., 2017). High parasite intensities may cause intestinal lumen obstruction and reduced nutrient absorption, resulting in weight loss and impaired productive performance (Chagas et al., 2015; Silva-Gomes et al., 2017; Maciel-Honda et al., 2023). Although acanthocephalosis is not considered a zoonotic disease, it has substantial economic importance for tambaqui farming.

The selection of species for rotation may be strategically guided by biological characteristics that could further contribute to disrupting parasite transmission beyond the effect of temporarily removing the susceptible host. In the present study, we proposed replacing tambaqui with curimbatá (*Prochilodus lineatus*) as a potential strategy to interrupt the life cycle of *N. buttnerae* by temporarily removing its host fish from the production system. Considering its feeding habit, characterized by the ingestion of organic matter from pond sediments (Kalous et al., 2012), together with the bioturbation promoted by bottom-foraging activity (Lima et al., 2026), curimbatá could consume *N. buttnerae* eggs remaining in pond sediments or prey on ostracods. In addition to these biological characteristics, curimbatá has commercial relevance in Brazilian aquaculture and export markets (Valenti et al., 2021; Peixe BR, 2026), which could provide an additional productive benefit from its use in rotational systems. The 60-day rotation period was selected on the basis of the typical nursery period of curimbatá and the aim of evaluating a strategy that could be practically incorporated into tambaqui production schedules, particularly given the feasibility of integrating curimbatá into multitrophic farming systems with tambaqui (Lima et al., 2026).

Therefore, the main aim of the present study was to evaluate the rotation of tambaqui with curimbatá for 60 days as a potential sanitary management strategy for controlling of *N. buttnerae* in ponds. We hypothesized that temporarily replacing tambaqui with curimbatá could contribute to interrupting *N. buttnerae* transmission during the subsequent tambaqui production cycle. Additionally, we descriptively compared the productive performance of tambaqui from the pond in which infection was detected with that of fish from ponds in which infection was not detected.

Material and Methods

Experimental design and fish production

The study was conducted at the Aquaculture Experimental Center of the Brazilian Agricultural Research Corporation (Embrapa), located in Palmas, Tocantins, Brazil (10°8′1.33″S, 48°19′9.86″W). Four earthen ponds (A–D), each with an area of 600 m^2 and a depth of 1.3 m, were used in the study. The pond was considered the experimental unit. Pond A was selected for species rotation because of its previous history of *N. buttnerae* infection and was therefore not randomly assigned to this condition. The three additional ponds (B–D) had no previous history of acanthocephalan infection and were not subjected to species rotation. Since only one pond with a previous history of infection was available for species rotation, the study did not include replication at the pond level for this condition. Therefore, the effects of species rotation could not be distinguished from potential differences associated with the previous infection history of pond A.

Before each production cycle, the ponds were drained, disinfected with quicklime (200 g m^{-2}), limed with agricultural limestone (200 g m^{-2}), and fertilized with urea (5 g m^{-2}), single superphosphate (3 g m^{-2}), and rice bran (10 g m^{-2}). Subsequently, the ponds were filled with water from a local reservoir. The pond subjected to the species rotation (pond A) had a previous history of tambaqui nursery production in which acanthocephalan infection had been detected, exhibiting a 100% prevalence and a mean intensity of 263 ± 142 parasites per fish. After the preparation procedures described above, the pond was stocked with curimbatá fingerlings (3.2 ± 2.1 g), which were cultured for 60 days until they reached a final weight of 15.5 ± 8.7 g.

During the curimbatá nursery phase, the fish were fed *ad libitum* four times daily with commercial extruded feed (1–2.6 mm pellet size and 45% crude protein). At the end of this period, pond A was prepared again for tambaqui grow-out. Simultaneously, tambaqui growth was conducted in three additional ponds (B–D) with no previous history of acanthocephalan infection, which were subjected to the same preparation procedures described above.

The four ponds were stocked with tambaqui juveniles (29.0 ± 4.0 g) at a density of 0.4 fish m^{-2}. The tambaqui grow-out phase lasted seven months, during which time the fish were fed twice daily (08:00 and 16:00 h) with commercial extruded feed (Archer Daniels Midland Company, Brazil). Fish weighing between 30 and 230 g, 230 and 410 g, and 410 and 700 g were fed a diet containing 32% crude protein at feeding rates of 4.5%, 3%, and 2% of body weight per day, respectively. Fish weighing between 700 and 1,130 g and above 1,130 g received feed containing 28% crude protein at feeding rates of 2% and 1.5% of body weight per day, respectively (Oliveira et al., 2013). Throughout the experimental period, water was added only to compensate for evaporation and seepage losses.

Water quality and sediment analysis

Water temperature, dissolved oxygen, and pH were measured three times per week using a YSI Professional Plus multiparameter probe (Yellow Springs Instruments Company, Yellow Springs, USA). Each pond was sampled monthly for the analysis of turbidity, chlorophyll-*a* concentration, dissolved solids, and total suspended solids. For variables measured more than once per month, measurements were first averaged within each month. Monthly values were then averaged over the grow-out period to obtain a single value for each water quality variable in each pond. Water analyses followed the methodology described by APHA (2017), except for turbidity, which was measured using a turbidimeter (Hach 2100Q, Loveland, CO, USA).

At the beginning of the tambaqui grow-out phase, soil samples were collected from each pond using three cores (10–15 cm depth), which were pooled into a composite sample. The samples were dried in a forced-air oven at 45 °C for 72 h. Carbon and total nitrogen were determined by high-temperature combustion using a CHNS elemental analyzer (Vario MACRO Cube, Elementar, Germany). Phosphorus was determined after wet digestion with a nitric–perchloric acid mixture (3:1) using the molybdate–vanadate spectrophotometric method (Silva, 2009).

Zootechnical parameters

Monthly, 30 tambaquis were randomly sampled and weighed in each pond to monitor zootechnical performance and adjust feeding rates, after which the fish were returned to their respective ponds. Uneaten feed remained floating on the water surface, and the observed amount was negligible. Therefore, the amount of feed supplied was considered representative of actual feed intake and was used to calculate the apparent feed conversion ratio (FCR) and specific growth rate (SGR) as follows: apparent FCR = total feed supplied/total weight gain; and SGR = 100 × [(ln final weight − ln initial weight)/days of experiment]. At the end of the experimental period, the ponds were drained, and all the fish were weighed in batches of five individuals to determine total production. Productivity was subsequently calculated as the ratio between the final biomass and pond area, whereas survival was calculated as the ratio between the final and initial number of fish × 100.

Parasitic analysis

Before stocking (initial time point), 10 tambaquis were sampled in total for parasitological analysis. At 5 and 7 months after the beginning of the grow-out phase, 5 tambaquis were subsequently sampled from each of the four ponds. The fish were anesthetized with eugenol and euthanized by cerebral concussion prior to necropsy and collection of biological material for parasitological analysis. The study complied with official Brazilian guidelines for the care and use of animals for scientific and educational purposes (Concea-CEUA protocol 76/2022). The gastrointestinal tract was collected and fixed in 4% buffered formalin (Eiras et al., 2006). The intestines were dissected under a stereomicroscope, and the acanthocephalans were quantified and classified according to their developmental stages as larvae (L), immature individuals (I), adult males (M), and adult females (F). Developmental stages were identified on the basis of the following criteria: (a) cystacanth larvae were visibly smaller than immature or adult parasites; (b) individuals with undetermined sex were classified as immature; and (c) female parasites were larger than males and could also be distinguished on the basis of their visible morphological characteristics under stereomicroscopy. Male parasites present a copulatory bursa and penis at the posterior end, whereas females are larger and present a posterior vagina and a genital orifice (gonopore) at the posterior end (Núñez & Drago, 2017). Female characteristics were clearly distinguishable, particularly on the basis of body size, whereas adult males could not be reliably distinguished from immature individuals. Therefore, these two groups were combined for analysis. Parasitological indices were calculated according to Bush et al. (1997). Prevalence was expressed as the number of infected hosts relative to the number of examined hosts, followed by the corresponding percentage [P = number of infected hosts/number of examined hosts × 100].

Mean intensity (MI) was calculated as the total number of parasites recovered divided by the number of infected hosts. The range of intensity was defined as the minimum and maximum numbers of parasites recorded in infected hosts, while total abundance was defined as the total number of parasites counted, followed by the relative percentage of each parasite developmental stage in parentheses. Considering the small number of hosts evaluated at each time point (n = 5) and the high variability of the parasitological data, the first and third quartiles (Q1 and Q3) and the interquartile range (IQR) were presented (Rózsa et al., 2000).

Statistical analysis

Given the absence of replication for pond A, comparisons between pond A and ponds B–D were performed descriptively. Pond-level values for water quality, sediment characteristics, and productive performance are presented individually or, where appropriate, as mean ± standard deviation for ponds B–D. Parasitological data were also analyzed descriptively because infection was detected only in pond A.

Results

Water quality parameters during the tambaqui grow-out period were described for pond A and ponds B–D (Table 1).

Table 1. Water quality parameters recorded during the tambaqui *Colossoma macropomum* grow-out period in pond A and ponds B–D. Values for ponds B–D are also presented as mean ± standard deviation (SD).

Pond	Temperature (°C)	Dissolved Oxygen (mg L^{-1})	Transparency (cm)	pH	Turbidity (NTU)	Chlorophyll *a* (µg L^{-1})	Dissolved solids (mg L^{-1})	Suspended solids (mg L^{-1})
A	**28.55**	**6.22**	**54.25**	**8.68**	**54.22**	**21.50**	**99.50**	**20.81**
B	28.80	5.38	55.00	8.43	63.86	33.54	103.00	31.44
C	29.04	4.94	91.63	8.57	23.30	12.78	121.75	10.38
D	29.10	5.91	116.13	8.96	12.98	7.78	85.76	6.71
B–D mean ± SD	**28.98 ± 0.16**	**5.41 ± 0.48**	**87.58 ± 30.76**	**8.65 ± 0.27**	**33.38 ± 26.89**	**18.04 ± 13.66**	**103.50 ± 18.00**	**16.18 ± 13.34**

Tambaquis sampled before the grow-out phase (initial time point) had no acanthocephalans in the intestinal tract. Similarly, no acanthocephalans were observed at the end of the production cycle in the fish from ponds B–D. In contrast, the prevalence of *N. buttnerae* was 100% (5/5 at each sampling time; exact binomial 95% confidence interval was 47.8–100%) for tambaquis from pond A, which had undergone a 60-day species rotation with curimbatá, at both 5 and 7 months of growth (Table 2). The mean intensity was 1,551 ± 677 parasites per infected fish at 5 months and 593 ± 359 parasites per infected fish at 7 months.

Mean intensity and total abundance were higher at 5 months than at 7 months. The combined group of immature individuals and adult males predominated throughout the infection period (Table 2). The proportion of larvae was higher at five months of growth, whereas the proportion of adult females increased at the end of the production cycle.

Tambaqui produced in pond A had lower final weights and specific growth rates than those produced in ponds B–D (Table 3). Final weight was 1.405 kg in pond A and 1.662 ± 0.003 kg in ponds B–D, corresponding to an approximately 15.5% lower final weight in pond A. Feed conversion ratio, productivity, and survival were 1.64, 0.39 kg m^{-2}, and 69%, respectively, in pond A, compared with 1.67 ± 0.12, 0.43 ± 0.03 kg m^{-2}, and 66 ± 4%, respectively, in ponds B–D (Table 3).

Table 2. Parasitological indices and developmental-stage distribution of *Neoechinorhynchus buttnerae* in tambaqui *Colossoma macropomum* sampled from pond A at 5 and 7 months of grow-out. MI, mean intensity; SD, standard deviation; Q2, second quartile or median; Q1, first quartile; Q3, third quartile; IIQ, interquartile range = Q3 – Q1; IR, intensity range; TA, total abundance, followed by the relative percentage of each parasite developmental stage in parentheses. Prevalence is presented as the number of infected fish/number of examined fish, followed by the percentage in parentheses. For a prevalence of 5/5 (100%), the exact binomial 95% confidence interval was 47.8–100%.

Grow-out time	Parasitological indices	Acanthocephalans	Larvae	Immatures + Adult males	Adult females
5 months	Prevalence	5/5 (100%)	–	–	–
	MI ± SD	1,551.0 ± 676.87	484.0 ± 458.86	1,062.6 ± 330.92	4.4 ± 6.80
	Median	1,338	374	1,129	1
	Q1 - Q3	1,235–1,639	250–436	1,088–1,203	0–5
	IIQ	404	186	115	5
	IR	882–2,661	90–1,270	507–1,386	0–16
	TA (%)	7,755	2,420 (31.2%)	5,313 (68.5%)	22 (0.3%)
7 months	Prevalence	5/5 (100%)	–	–	–
	MI ± SD	593.0 ± 359.1	19.4 ± 34.1	540.6 ± 338.8	33.0 ± 14.0
	Median	502	1	465	28
	Q1 - Q3	443–750	(0–17)	389–726	23–40
	IIQ	307	17	337	17
	IR	157–1,113	0–79	117–1,006	20–54
	TA (%)	2,965	97 (3.3%)	2,703 (91.2%)	165 (5.6%)

Table 3. Zootechnical performance of tambaqui *Colossoma macropomum* during a 7-month grow-out period in ponds with and without previous history of *Neoechinorhynchus buttnerae* infection. Pond A had a previous history of *N. buttnerae* infection and was subjected to the 60-day species rotation with curimbatá before tambaqui stocking. Ponds B–D had no previous history of acanthocephalan infection and were not subjected to species rotation. Values for ponds B–D are also presented as mean ± standard deviation (SD). FCR, feed conversion ratio; SGR, specific growth rate.

Pond	Final weight (kg)	FCR	SGR (% day^{-1})	Productivity (kg m^{-2})	Survival (%)
A	1.405	1.64	1.848	0.39	69
B	1.665	1.54	1.929	0.42	66
C	1.664	1.75	1.928	0.47	70
D	1.659	1.73	1.927	0.41	62
B–D mean ± SD	**1.663 ± 0.003**	**1.67 ± 0.12**	**1.928 ± 0.001**	**0.43 ± 0.03**	**66 ± 4**

Discussion

Under the evaluated conditions, the 60-day alternation of tambaqui and curimbatá did not prevent infection by *N. buttnerae*. Fish from pond A showed lower final weight and specific growth rate than fish from ponds B–D, while smaller differences were observed for the remaining productive parameters. Interpretation of these findings is limited by (i) the lack of replication at the pond level for species rotation under a previous history of infection and (ii) the absence of a control condition consisting of ponds with a previous history of infection maintained without species rotation. Therefore, these limitations should be considered when interpreting the results and drawing conclusions regarding the effectiveness of species rotation. However, conducting this type of experiment under production conditions is challenging, which may explain the scarcity of similar studies in the literature. In particular, obtaining a sufficient number of infected and uninfected ponds with comparable production characteristics is difficult.

In general, water quality parameters remained within the ranges recommended for fish production according to Boyd (2020), suggesting favorable environmental conditions for fish growth. The analyzed sediment variables showed similar values among ponds, suggesting comparable conditions for the evaluated sediment characteristics.

The mean intensity of *N. buttnerae* observed in the present study was markedly greater than the values previously reported for tambaqui farming in Brazil, with the exception of the values reported in Rondônia (Table 4). However, the fish evaluated in the present study were considerably larger than those assessed in previous reports, potentially reflecting a longer exposure period to infective stages and progressive parasite accumulation throughout the grow-out cycle. Given the approximately three-month duration of the life cycle of *N. buttnerae*, the fifth month of natural exposure (approximately 20 weeks) would have allowed sufficient time for the completion of at least one parasite life cycle and the potential establishment of a subsequent cycle of infection. Similarly, by the seventh month of natural exposure (approximately 28 weeks), the parasites would have had sufficient time to complete multiple life cycles and for superimposed infections to occur, potentially contributing to the high parasite intensities observed in the present study.

Table 4. Reported parasite intensity of *Neoechinorhynchus buttnerae* in tambaqui farming systems in Brazil. Ni = not informed.

Study	Fish weight (g)	Range of intensity(-) / Mean intensity(±)	Production system	State
Malta et al. (2001)	131-636	31–406	Dam	Amazonas
Matos et al. (2017)	57	81–708	Pond	Amazonas
Lourenço et al. (2017)	149	107–921	Pond	Amazonas
Matos et al. (2017)	57.7	81-708	Pond	Amazonas
Silva-Gomes et al. (2017)	399	15–720	Pond	Amazonas
Aguiar et al. (2018)	102.69	95-310	Pond	Amazonas
Pereira & Morey (2018)	360	188–388	Dam	Roraima
Chagas et al. (2019)	462	54–931	Ni	Amazonas
Chagas et al. (2019)	645	81–1,219	Ni	Amazonas
Maciel-Honda et al. (2023)	206	51.4 ± 45.7	Pond	Tocantins
Perez Pedroti et al. (2025)	173.3-3,626	14-2,977	Pond	Rondônia
Present study	1,405	882–2,661	Pond	Tocantins

Superimposed infections could also explain the presence of all developmental stages of *N. buttnerae* in the tambaqui intestinal tract, including larvae, immature stages, and adult males and females. Although parasite intensity and abundance are generally expected to increase with host age and size, as well as with the duration of infection, parasite establishment may be constrained by biological limitations within the host.

An asymptotic pattern, for example, was observed in the establishment of *Pomphorhynchus laevis* in experimentally infected *Oncorhynchus mykiss* (Brown, 1986). When fish from the two size groups were exposed to increasing numbers of infected intermediate hosts, the number of parasites that successfully established in the intestine increased with exposure but eventually approached a limit that depended on fish size, rather than increasing proportionally with the number of parasites to which the fish were exposed. In addition, parasite loss during infection has been proposed as a factor contributing to this pattern (Crompton & Whitfield, 1968; Brown, 1986). Consistent with this possibility, in the present study, the decreases in mean intensity and total parasite abundance at 7 months compared with those at 5 months may reflect biological constraints on the establishment and maintenance of the parasite population within the intestinal tract, potentially associated with parasite loss and density-dependent processes.

At 7 months, the reduction in parasite burden was accompanied by a marked decrease in the proportion of larvae. The lower proportion of larvae may reflect the maturation dynamics of the parasite population and limitations in the host's carrying capacity. According to Brown (1986) superimposed infections are possible when pre-established parasites are small (e.g., larvae) and present at densities below the carrying capacity of the host. However, as established parasites increase in size and maturity (e.g., immature and adult individuals), they may increasingly constrain the establishment of new infections, potentially reflecting competition for available space within the intestinal tract.

With respect to acanthocephalan sex ratios, previous studies have shown that as population size increases, parasite loss may result in a greater proportion of males than females (Kennedy, 1972; Crompton & Whitfield, 1968; Hassanine & Al-Jahdali, 2008). For example, experimental infection of *Carassius auratus* with *P. laevis* clearly resulted in a predominance of females during the first two weeks of infection. Thereafter, a proportional loss of females was observed, resulting in a predominance of males (Kennedy, 1972). However, in the present study, the proportion of females increased at 7 months compared with preceding sampling period. This observation does not allow definitive conclusions regarding the sex ratio or sexual pattern of *N. buttnerae* because adult males were grouped with immature parasites. Nevertheless, the increased proportion of adult females at 7 months could be associated with the presence of reproductive maturation, potentially contributing to egg release and the maintenance of parasite transmission within the production system.

Under the conditions evaluated, alternated culture with curimbatá did not prevent the subsequent occurrence of *N. buttnerae* infection. The detritivorous feeding habit of curimbatá, combined with the bioturbation promoted during bottom foraging activity (Lima et al., 2026), suggests that curimbatás could consume *N. buttnerae* eggs remaining in pond sediments or prey on ostracods, which act as intermediate hosts. However, under the experimental conditions and rotation period evaluated, these mechanisms did not prevent subsequent infection, because *N. buttnerae* was recorded in tambaqui after the two-month curimbatá production period. Considering that this pond was subjected to disinfection procedures on two occasions, before curimbatá rearing and again prior to tambaqui growth, the subsequent occurrence of infection suggests that the procedures applied were insufficient to eliminate all the components involved in parasite transmission. One possible explanation is the persistence of *N. buttnerae* in the pond environment despite the disinfection procedures, potentially reflecting their resistance to abrupt changes in pH caused by quicklime application. The three protective envelopes surrounding the eggs (Kennedy, 2006; Gonçalves et al., 2021; Serra et al., 2022) may contribute to the persistence of infective stages in pond sediments, representing an important challenge for the sanitary management of acanthocephalosis in ponds, particularly in systems with high organic matter accumulation, limited sediment removal, and incomplete drying between production cycles. Additionally, although bioturbation was initially considered potentially beneficial for reducing infection stages, it is also possible that sediment disturbance promoted by curimbatá activity could increase the availability of parasite eggs and intermediate hosts within the production environment.

In contrast to the results observed in the present study, the use of secondary species in crop rotation systems has shown promising results in shrimp farming. Species such as *M. cephalus* and *C. chanos* have been cultivated between production cycles of *L. vannamei* (Yuvaraj et al., 2015). In that study, one pond was subjected to a six-month fish production cycle followed by a 4.5-month shrimp cycle, whereas the control pond was subjected to two consecutive shrimp production cycles. The longer duration of species alternation compared with the 60-day curimbatá production period adopted in the present study may have contributed to the differences in sanitary outcomes between the studies. The 60-day period adopted in the present study was selected based on the typical nursery period of curimbatá, with the goal of evaluating a rotation strategy that could be practically incorporated into tambaqui production systems. However, considering the environmental persistence of *N. buttnerae* eggs and the time required for parasite development within the intermediate host, a longer rotation period may be necessary to effectively interrupt parasite transmission.

With respect to productive performance, fish from pond A, where *N. buttnerae* infection was detected, had lower final weight and specific growth rate than fish from ponds B–D, where infection was not detected. This pattern is consistent with the findings of previous studies reporting negative effects of *N. buttnerae* infection on tambaqui growth performance (Silva-Gomes et al., 2017; Maciel-Honda et al., 2023). However, given the experimental design of the present study, the observed differences cannot be attributed specifically to parasite infection. Feed conversion ratio, productivity, and survival showed relatively similar values between pond A and ponds B–D. Previous studies have generally reported low or absent mortality in tambaquis affected by *N. buttnerae* infection, indicating that infected fish may remain active and continue feeding despite intestinal parasitism (Silva-Gomes et al., 2017; Maciel-Honda et al., 2023). In the present study, no mortality was directly attributed to acanthocephalosis, although relatively low survival rates (60–70%) were recorded because of bird predation during the first three months of culture, affecting all ponds.

The similar feed conversion ratios observed in pond A and ponds B–D suggest that the lower growth observed in pond A was not accompanied by a marked difference in feed conversion. However, intestinal damage caused by parasite attachment may impair nutrient utilization and growth efficiency (Matos et al., 2017). The lower specific growth rate observed in the pond in which *N. buttnerae* infection was detected is consistent with this possibility, although the experimental design does not allow this response to be attributed specifically to parasite infection. Previous studies suggest that parasitic infection may redirect energy toward immunological defense (Dezfuli et al., 2016; Biller & Chagas, 2022), potentially reducing the energy available for somatic growth.

Although the final weight of the fish from the pond in which *N. buttnerae* infection was detected was approximately 15.5% lower, this difference corresponded to a 10% lower productivity than that in the ponds in which no infection was detected. Nevertheless, a 10% difference in productivity may be relevant in a production system. However, this difference should be interpreted with caution considering the high variability among ponds, bird predation during the first months of culture, and the absence of replication for the pond condition in which infection was detected.

The lack of effective sanitary protocols for the control of *N. buttnerae* remains a major challenge for tambaqui farming in Brazil. In this context, preventive and biosecurity-based strategies are particularly important, given the economic relevance of tambaqui production for aquaculture in the Amazon region. Although the 60-day species rotation with curimbatá evaluated in the present study did not prevent the subsequent occurrence of *N. buttnerae* infection, the results provide information for the development and evaluation of future preventive approaches for the management of acanthocephalosis in tambaqui production systems. Future studies should evaluate longer rotation periods with curimbatá and alternative species with commercial relevance to better assess the applicability of rotational systems for sanitary management.

Conclusions

Under the conditions evaluated, *N. buttnerae* infection was detected in tambaqui after a 60-day species rotation with curimbatá in the pond with a previous history of acanthocephalosis, indicating that the rotation strategy adopted did not prevent subsequent infection. The final individual weight and specific growth rate of the fish from this pond were lower than those of the fish from the ponds in which no infection was detected.

Given the absence of replication for the pond subjected to species rotation and the absence of a comparable infected pond without rotation, these findings should be considered preliminary and do not allow definitive conclusions regarding the effectiveness of species rotation for the control of *N. buttnerae*.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

The study complied with official Brazilian guidelines for the care and use of animals for scientific and educational purposes (Concea-CEUA protocol 76/2022), and with the National Management System for Genetic Heritage and Associated Traditional Knowledge (AB47B85).

Conflict of interest

The authors declare they have no conflict of interest.

Author contributions

Patricia Oliveira Maciel-Honda: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, writing - original draft, writing - review & editing. Adriana Ferreira Lima: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, writing - original draft, writing - review & editing.

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