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Stocking density of yellowtail lambari (*Astyanax lacustris*) in earthen ponds for small-scale aquaculture

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ABSTRACT

The yellowtail lambari, *Astyanax lacustris*, is a small-sized species suitable for small-scale aquaculture. Five stocking densities (10, 25, 50, 75, and 100 fish/m^2) were evaluated in three production cycles. Experimental units were 50-m^2 earthen ponds, with minimal water replacement to compensate for infiltration and evaporation. Sixty-day-old fish (5.67 ± 0.10 cm and 2.67 ± 0.16 g) were fed a commercial diet twice daily in 45-day production cycles. Stocking densities influenced lambari growth. Lambari growth at all treatments showed good fit in the logistic model, but lower densities resulted in higher growth rates and larger asymptotic sizes. Among productive performance parameters, daily weight gain and specific growth rate were inversely proportional to stocking density, whereas the number of fish and biomass produced per area were directly proportional. These growth results were associated with reduced water quality and feed intake at higher stocking densities. Fish density did not affect feed conversion ratios (ranging from 1.44 to 1.58) but did influence carcass yield (82.00 to 84.85%). Under the conditions of this study, intermediate stocking densities showed good balance between growth and productivity per area.

Keywords: Growth; Logistic model; Water quality; Feed intake.

Densidade de estocagem do lambari-do-rabo-amarelo (*Astyanax lacustris*) em viveiros escavados para aquicultura em pequena escala

RESUMO

O lambari-do-rabo-amarelo, *Astyanax lacustris*, é uma espécie de pequeno porte adequada para piscicultura em pequena escala. Cinco densidades de estocagem (10, 25, 50, 75 e 100 peixes/m^2) foram avaliadas em três ciclos de produção. As unidades experimentais foram viveiros escavados de 50 m^2, com reposição mínima de água para compensar as perdas por infiltração e evaporação. Peixes de 60 dias de idade (5,67 ± 0,10 cm e 2,67 ± 0,16 g) foram alimentados com dieta comercial duas vezes ao dia em ciclos de produção de 45 dias. As densidades de estocagem influenciaram o crescimento do lambari. O crescimento do lambari em todos os tratamentos apresentou bom ajuste ao modelo logístico, mas as densidades mais baixas resultaram em maiores taxas de crescimento e maiores tamanhos assintóticos. Entre os parâmetros de desempenho produtivo, o ganho em peso diário e a taxa de crescimento específico foram inversamente proporcionais à densidade de estocagem, enquanto o número de peixes e biomassa produzida por área foram diretamente proporcionais. Esses resultados de crescimento foram associados com a redução da qualidade de água e da ingestão alimentar em maiores densidades de estocagem. A densidade dos peixes não afetou a conversão alimentar (variando de 1,44 a 1,58), mas influenciou o rendimento de carcaça (82,00 a 83,85%). Nas condições deste estudo, densidades de estocagem intermediárias apresentaram bom balanço entre crescimento e produtividade por área.

Palavras-chave: Crescimento; Modelo logístico; Qualidade da água; Ingestão alimentar.

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INTRODUCTION

In recent years, global aquaculture has been surpassing extractive fisheries as the primary source of food and income for the population. According to Food and Agriculture Organization (2018), in addition to contributing to global aquaculture, small-scale aquaculture contributes to the development of rural livelihoods through the provision of food and the generation of opportunities for rural communities. In Brazil, a native fish species with potential for fish farming is the yellowtail lambari (*Astyanax lacustris*), which can be a good model of low-trophic level small fish for aquaculture aimed at developing local communities (Fonseca et al., 2017).

Lucena and Soares (2016) reviewed the species of the *Astyanax bimaculatus* subgroup, characterized by the presence of a caudal peduncle spot, comprising fish of the drainages of the Prata and São Francisco rivers, as well as the coastal regions of Brazil and Uruguay. These authors named two valid species: *A. lacustris* (junior synonyms: *Astyanax altiparanae*, *Astyanax jacuhiensis*, and *Astyanax asuncionensis*) and *Astyanax abramis* (junior synonym: *Bertoniolus paraguayensis*). According to the Brazilian Institute of Geography and Statistics (IBGE, 2024a; 2024b), nearly 362 tons of fish commonly referred to as lambari were produced through aquaculture in Brazil in 2023, being present in 10% of the fish farms evaluated in the census. Lambari is a small-sized fish that supplies distinct markets, including traditional rural cuisine and gastronomy, the sport fishing market as live bait, and the aquarium trade as a feeder fish for carnivorous species.

The yellowtail lambari, *A. lacustris*, is a species with omnivorous feeding habits and fast growth. According to Porto-Foresti et al. (2010), reproduction can occur naturally or through hormonal induction, larviculture is carried out in earthen ponds, and larvae initially feed on zooplankton but quickly adapt to commercial feed during growth. Silva et al. (2011) concluded that there is no standardized lambari rearing model, which creates uncertainty for producers. In seven fish farms evaluated, these authors observed different grow-out systems: a single-stage rearing (from larvae to commercial size), a multi-stage rearing, a rearing together with broodstock, and a polyculture with other species. In addition, stocking densities in ponds ranged from 10 to 98 fish/m^2, with fish measuring 1 to 3 cm at stocking and 5 to 12 cm at harvest, over a grow-out period of two to four months. Fonseca et al. (2017) also reported diversification of lambari farming systems in southeastern Brazil and stated that simple strategies are required to improve productivity, given the conditions of rural producers.

Despite efforts to determine optimal conditions for yellowtail lambari rearing, research on stocking density remains scarce, particularly during the grow-out phase in semi-intensive earthen ponds. Some studies on lambari productive performance in cages or elevated tanks used densities ranging from 350 to 750 fish/m^3 (Hayashi et al., 2004; Henriques et al., 2022; Sussel et al., 2014). Additionally, one study evaluated stocking densities in experimental cages with 31, 62, 93 or 124 fish/m^3 (Vilela & Hayashi, 2001). However, the results from intensive system studies cannot be applied or directly compared to those from semi-intensive systems in earthen ponds.

According to Abd El-Hack et al. (2022), defining the stocking density of farmed fish is crucial for the sustainable development of aquaculture, ensuring the optimal use of the productive potential of both species and farming systems. Baldwin (2011) noted that the effects of density on the stress response, growth rate, and health of farmed fish are highly dependent on the physiological requirements and behavior of each species. Stress can lead to reduced energy intake and increased physiological energy utilization, resulting in a negative energy balance.

Given the potential of yellowtail lambari for small-scale aquaculture and the need for good management practices, this study aimed to evaluate growth and productive performance of this species at different stocking densities during the grow-out phase in semi-intensive earthen ponds.

MATERIALS AND METHODS

Experimental design

The present study evaluated the stocking density of yellowtail lambari in earthen ponds in a semi-intensive system. The experiment, including fish rearing, biometric measurements, and water quality analyses, was conducted at the aquaculture experimental area of APTA Regional de Pariquera-Açu, SP, Brazil. Body composition and carcass yield analyses were performed at Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Registro *Campus*, SP, Brazil. All fish handling procedures were conducted in accordance with the guidelines approved by the Animal Experimentation Ethics Committee of the Instituto de Pesca (Protocol no. 13/2018, January 14, 2019).

A randomized block design was used in the study, with five treatments (stocking densities) and three blocks (production cycles). Five stocking densities were tested: 10, 25, 50, 75, and 100 fish/m^2. The 45-day production cycles were carried out during the summer: January 30 to March 16, 2020 (cycle 1); February 10 to March 29, 2021 (cycle 2); and February 2 to March 21, 2022 (cycle 3). The five stocking densities were randomly assigned among the six available earthen ponds in each cycle, leaving one pond empty per cycle. The block statistical model, considering the production cycles as temporal blocks, was chosen due to limited availability of experimental units.

Biological material

Juvenile yellowtail lambari (*A. lacustris*) were obtained from APTA Regional de Pariquera-Açu. Breeders received a single dose of carp pituitary extract (5 $mg \cdot kg^{-1}$), diluted in saline solution (0.5 $mg \cdot mL^{-1}$), and were mated at a female-to-male ratio of 1:2, identified by a smooth anal fin in females and a rough anal fin in males. Spawning and fertilization occurred semi-naturally in circular tanks, using a plastic screen to prevent egg predation. On the third day after hatching, larvae were transferred to outdoor fertilized earthen ponds, in which they initially fed on wild zooplankton and received commercial food from the fifth day onward, according to each developmental stage. At approximately 60 days post-hatching, juveniles were selected for use in the experiment.

Experimental units

The experimental units consisted of six earthen ponds, of which five were randomly used in production cycles over time. Each 50-m^2 pond had an average depth of 1.5 m and received an independent water inlet to compensate for infiltration and evaporation, without water exchange. The pond area was covered with anti-bird netting to prevent fish predation. The experimental ponds were prepared before fish stocking by drying them for at least 15 days, followed by limestone application to maintain alkalinity and pH, pond filling with water, and initial fertilization with urea and single superphosphate to stimulate phytoplankton production and to increase water turbidity.

For stocking in the experimental units, juveniles were previously selected by size using plastic screens to reduce heterogeneity. The experiment was conducted with juveniles having an initial length of 5.67 ± 0.10 cm and an initial weight of 2.67 ± 0.16 g (mean ± standard deviation), until they reached commercial size.

Fish count for stocking in the experiments was estimated. Three samples of 100 fish each were weighed to determine average individual weight, with the average weight of each sample (total weight/100) summed and divided by three. Then, the biomass (average weight × number of fish) to be stocked in each pond was calculated according to the predetermined stocking densities for the 50-m^2 ponds: 10 fish/m^2 = 500 fish; 25 fish/m^2 = 1,250 fish; 50 fish/m^2 = 2,500 fish; 75 fish/m^2 = 3,750 fish; and 100 fish/m^2 = 5,000 fish. A total of 13,000 lambari juveniles were used per production cycle. Fish biomass was weighed using a bucket containing 10 L of water and a digital scale (5 g precision).

Fish were fed extruded commercial feed of 2.6 mm and 36% crude protein (according to the manufacturer's specifications). Feeding was carried out until apparent satiation twice daily (morning and afternoon), except on Sundays.

Biometrics, sample collection, and chemical analysis

Biometric measurements were performed at the beginning and at 15, 30, and 45 days of the experiment, in all production cycles. Thirty fish from each experimental unit were evaluated for weight (digital scale, 0.01-g precision) and total length (measuring board, 0.1-cm precision). The feed supply was monitored daily. At the end of each cycle, the number of fish in each experimental unit was estimated by weighing the total biomass, following the same procedure used during stocking, but using a hanging scale and a fish weighing bag.

Samples for proximate body composition analysis consisted of a pool of 100 fish from the initial batch and a pool of 50 fish from each experimental unit at the end of production cycles. Additionally, 50 fish per experimental unit were collected for the evaluation of carcass yields.

Water quality analysis in the ponds was performed weekly in the morning (8:00 a.m.): minimum and maximum temperature (mercury thermometer), water transparency (Secchi disk), dissolved oxygen and oxygen saturation (portable digital meter), pH (digital meter), and alkalinity (titration method). Additionally, water samples were collected and frozen for subsequent analysis of total ammonia, nitrite, and nitrate (spectrophotometry). Non-ionized ammonia was estimated based on tables of temperature and pH (Arana, 2010).

Calculations and statistical analysis

The parameters of productive performance, body composition, carcass yield, and water quality were initially tested for assumptions and subsequently subjected to analysis of variance (ANOVA) following a randomized block design with five treatments (stocking densities) and three blocks (production cycles). For variables that showed a significant effect of treatments, means were compared using the Tukey's test ($p < 0.05$).

For productive performance, average weight (g) and length (cm) were evaluated at 15, 35, and 45 days of the production cycle. Feed intake (Eq. 1) was calculated for the following intervals: 1–15, 16–30, and 31–45 days. At the end of the study, the number of fish (Eq. 2), biomass (Eq. 3), and condition factor (Eq. 4) were evaluated. Other parameters were calculated for the entire production cycle: daily weight gain (Eq. 5), specific growth rate (Eq. 6), and feed conversion rate (Eq. 7).

$$\text{Feed intake (\% live weight day}^{-1}) = 100 \times \{[\textit{consumption} \times \textit{days}^{-1}] \times [(\textit{final weight} + \textit{initial weight}) \times 2^{-1}]^{-1}\} \quad (1)$$

$$\text{Number of fish (fish/m}^2) = \textit{final number of fish} \times \textit{area}^{-1} \quad (2)$$

$$\text{Biomass (kg/m}^2) = (\textit{final average weight} \times \textit{final number of fish}) \times \textit{area}^{-1} \quad (3)$$

$$\text{Condition factor} = (\textit{weight} \times \textit{length}^{-3}) \times 100 \quad (4)$$

$$\text{Daily weight gain (g day}^{-1}) = \textit{weight gain} \times \textit{days}^{-1} \quad (5)$$

$$\text{Specific growth rate (\% day}^{-1}) = [(\ln \textit{final weight} - \ln \textit{initial weight}) \times \textit{days}^{-1}] \times 100 \quad (6)$$

$$\text{Feed conversion rate} = \textit{feed supplied} \times \textit{weight gain}^{-1} \quad (7)$$

Body proximate composition (%) was evaluated in fish at the end of production cycles, and included dry matter, crude protein, ash, and lipids, according to the methods described by the Association of Official Analytical Chemists (1999). Fish were also evaluated for carcass yield 1 (gutted fish without scales) and carcass yield 2 (gutted fish without scales, head, and fins) using Eq. 8.

$$\text{Carcass yield (\%)} = (\text{processed weight} \times \text{whole weight}^{-1}) \times 100 \quad (8)$$

Water quality parameters were evaluated in each treatment dividing the cycle into two periods: from day 1 to 21 (first three-week period) and from day 22 to 45 (second three-week period).

Regression analysis was also performed on data related to number of fish, biomass, daily weight gain, specific growth rate, dissolved oxygen, and oxygen saturation, with the aim of identifying the direct relationships between these parameters and the stocking densities tested.

To verify the growth behavior of the animals, the logistic model was adjusted for weight and length as functions of the days of experiment at each stocking density. The equation used was Eq. 9

$$y = A\,(1 + Be^{-kt})^{-1} \quad (9)$$

A: the asymptotic size at which the growth of the animal slows down; k: the growth rate constant. Therefore, the higher the value of k, the earlier the animal reaches its growth plateau. B: a constant in the equation; t: the time in days.

RESULTS

Growth and feed consumption

The average weight and length of yellowtail lambari, *A. lacustris*, reared at five stocking densities differed significantly at 15, 30, and 45 days of grow-out in earthen ponds ($p < 0.05$, Table 1). In general, the length of fish reared at 10, 25, and 50 fish/m² was greater than that of fish reared at 100 fish/m². Regarding weight, lambari reared at 10 and 25 fish/m² were heavier than those at 100 fish/m². There was a reduction in feed intake throughout the experimental period at all tested stocking densities (Table 1). In the first 15-day period, feed intake ranged from 4 to 6% of live weight per day; during the second period, it declined to 3–4%; and in the third period, it further decreased to 1–2%. During the first two periods, fish stocked at 10, 25, and 50 fish per m² exhibited higher feed intake ($p < 0.05$, Table 1). At the end of the grow-out period, there was no significant difference ($p > 0.05$, Table 1).

Table 1. Growth and feed intake of lambari at five stocking densities during 45-day productive cycle*.

		Stocking density (fish/m²)					*Pooled SEM*	*p*-value *Block*	*p*-value *Trat.*
		10	25	50	75	100			
Length (cm)	Initial	5.67	5.67	5.67	5.67	5.67	1.342	...	...
	15 days	7.34[a]	7.15[ab]	7.06[ab]	6.79[bc]	6.60[c]	0.496	< 0.001	< 0.001
	30 days	8.39[a]	8.15[ab]	7.72[ab]	7.47[bc]	6.98[c]	0.326	0.503	0.001
	45 days	8.63[a]	8.42[ab]	8.23[ab]	7.88[bc]	7.38[c]	0.359	0.138	0.002
Weight (g)	Initial	2.67	2.67	2.67	2.67	2.67	0.208	...	...
	15 days	6.61[a]	6.22[a]	5.60[ab]	4.84[bc]	4.41[c]	1.027	0.002	< 0.001
	30 days	10.58[a]	9.49[ab]	8.01[abc]	7.01[bc]	5.64[c]	1.467	0.072	1.000
	45 days	11.10[a]	10.15[ab]	9.09[abc]	7.51[bc]	6.49[c]	1.299	0.286	0.002
Feed intake (% live weight·day⁻¹)	1–15 days	5.93[a]	5.50[ab]	5.02[abc]	4.54[bc]	3.85[c]	0.800	0.042	0.004
	16–30 days	3.76[a]	3.82[a]	3.46[ab]	2.87[b]	2.66[b]	0.677	0.004	0.004
	31–45 days	1.73	1.70	2.05	1.48	1.43	0.442	0.932	0.398

*Means followed by different letters, within the same row, indicate significant difference ($p < 0.05$). Means are average values of three production cycles (N = 3); SEM: standard error of mean.

Growth curves showed a good fit to the logistic model for lambari at all densities. Logistic model parameters are presented in Table 2. Lower stocking densities resulted in faster growth rates (parameter k) and greater asymptotic size (parameter A), that is, the weight or length reached before the slowdown in growth (inflection of the curve). Since all curves showed similar patterns, only the intermediate density of 50 fish/m^2 is presented in Fig. 1 to illustrate the logistic model.

Table 2. Parameters of the logistic model estimated for lambari growth in weight and length during 45-day cycle at five stocking densities*.

	Density (fish/m^2)	Coefficient			R^2
		A	B	k	
Weight (g)	10	11.5248	3.9664	0.1163	0.8696
	25	10.5048	3.3814	0.1092	0.9758
	50	9.4741	2.7595	0.0916	0.9574
	75	7.9215	2.2218	0.0880	0.9668
	100	6.9491	1.6775	0.0684	0.9095
Length (cm)	10	8.8544	0.6089	0.0748	0.9149
	25	8.6901	0.5734	0.0676	0.9738
	50	8.4694	0.5199	0.0604	0.9632
	75	8.2067	0.4706	0.0534	0.9592
	100	7.5763	0.3503	0.0526	0.9153

*Logistic model: $y = A\,(1 + Be^{-kt})^{-1}$; A: asymptotic or estimated final size; B: model constant; K: relative growth rate; t: days.

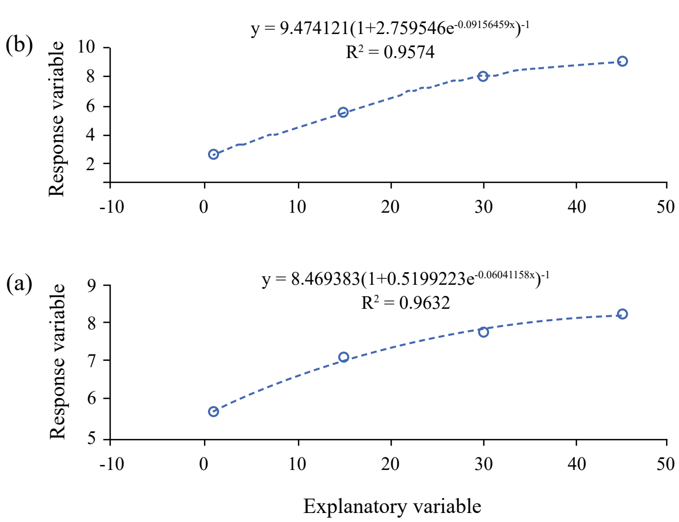

Figure 1. Logistic growth curves adjusted to data on (a) length and (b) weight (response variable) as function of 45-day production cycle (explanatory variable) illustrated for the lambari at the stocking density of 50 fish/m^2.

There was a linear adjustment (Fig. 2), inversely proportional to the stocking density, for daily weight gain ($p < 0.05$, $R^2 = 0.77$) and specific growth rate ($p < 0.05$, $R^2 = 0.74$). Lambari at densities of 10 and 25 fish/m^2 showed higher individual growth (DWG and SGR) than at 75 and 100 fish/m^2 ($p < 0.05$, Table 3), while growth at 50 fish/m^2 was intermediate. The fish biomass produced per area also followed a linear adjustment, but directly proportional to the stocking density ($p < 0.05$, $R^2 = 0.92$, Fig. 3), as expected, due to the maintenance of the number of fish produced per area close to that of the initial stocking ($p < 0.05$; $R^2 = 0.97$). The highest biomass produced at the end of the production cycle occurred at the density of 100 fish/m^2, followed by 75 and 50 fish/m^2, while 10 and 25 fish/m^2 produced the lowest biomasses (Table 3). Additionally, the condition factor was influenced by stocking density ($p < 0.05$), with higher values observed at lower densities, while no differences were observed for feed conversion rate ($p > 0.05$).

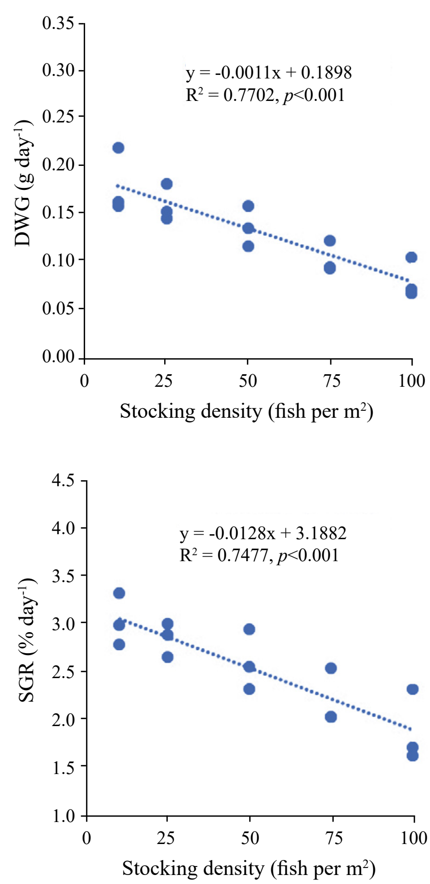

Figure 2. Lambari daily weight gain (DWG) and specific growth rate (SGR) at different stocking densities after 45-day productive cycle. Regression analysis curves are adjusted to linear models, and data refers to three production cycles (N = 3).

Table 3. Productive performance of lambari at the end of 45-day cycle at five stocking densities.*

	Stocking density (fish/m²)					*Pooled SEM*	*p value-Block*	*p value-Trat.*
	10	**25**	**50**	**75**	**100**			
Number (fish/m²)	10.0^{e}	23.8^{d}	51.1^{c}	71.2^{b}	95.8^{a}	7.1	0.016	<0.001
Biomass (kg/m²)	0.111^{d}	0.243^{c}	0.461^{b}	0.532^{b}	0.618^{a}	0.040	0.261	<0.001
DWG (g day^{-1})	0.18^{a}	0.16^{ab}	0.14^{abc}	0.10^{bc}	0.08^{c}	0.03	0.205	0.002
SGR (% day^{-1})	3.04^{a}	2.86^{a}	2.62^{ab}	2.21^{bc}	1.89^{c}	0.38	0.044	0.001
Condition factor	1.66^{a}	1.63^{a}	1.56^{ab}	1.48^{ab}	1.57^{b}	0.09	0.049	0.020
FCR	1.44	1.57	1.47	1.57	1.58	0.21	0.304	0.716

*Means followed by different letters, within the same row, indicate significant difference ($p < 0.05$). Means are average values of three production cycles (N = 3); SEM: standard error of mean; Initial biomass, kg/m² (mean ± standard deviation): 0.027 ± 0.002; 0.067 ± 0.004; 0.134 ± 0.008; 0.201 ± 0.012; 0.267 ± 0.016, respectively, at 10, 25, 50, 75, and 100 fish/m²; DWG: daily weight gain; SGR: specific growth rate; FCR: feed conversion rate.

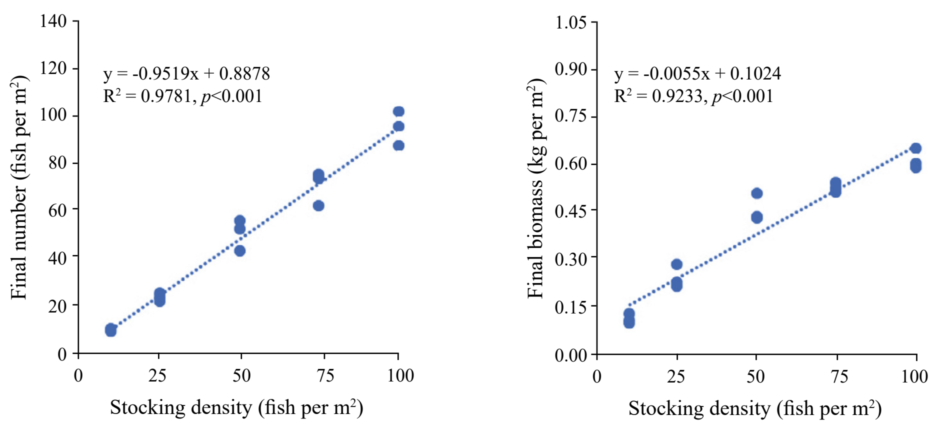

Figure 3. Lambari number and biomass per area at different stocking densities after a 45-day productive cycle. Regression analysis curves are adjusted to linear models, and data refers to three production cycles (N = 3).

The carcass yield of eviscerated fish without scales ranged from 82 to 84%, with the lowest yield obtained at the highest stocking density (Table 4, $p < 0.05$). The carcass yield of eviscerated lambari, without scales, fins, and head, was also evaluated and ranged from 58 to 63%. Stocking densities did not influence body proximal composition of the lambari (Table 5, $p > 0.05$). The range of results were 62.70 to 64.68% moisture; 19.19 to 20.39% protein; 14.23 to 15.71% lipids; and 3.51 to 3.84% ash.

Table 4. Carcass yield of lambari at the end of the 45-day production cycle at five stocking densities*,**.

	Stocking densities (fish/m²)					*Pooled SEM*	*p*-value *Block*	*p*-value *Trat.*
	10	**25**	**50**	**75**	**100**			
Carcass yield 1 (%)	82.76^{ab}	83.85^{a}	83.52^{ab}	83.07^{ab}	82.00^{b}	0.86	< 0.001	0.005
Carcass yield 2 (%)	62.37^{a}	62.35^{a}	60.79^{b}	60.16^{b}	58.41^{c}	0.66	< 0.001	< 0.001

*Means followed by different letters, within the same row, indicate significant difference ($p < 0.05$). Means are average values of 50 analyses of three production cycles (N = 150); **carcass yield 1: eviscerated fish without scales; carcass yield 2: eviscerated fish, without scales, head and fins; SEM: standard error of mean.

Table 5. Body proximal composition of lambari at the end of the 45-day production cycle at five stocking densities*.

	Stocking densities (fish/m^2)						Pooled SEM	p-value Block	p-value Trat.
	Initial	10	25	50	75	100			
Moisture (%)	70.78	63.14	62.77	62.70	64.68	64.17	1.88	0.321	0.257
Protein (%)	18.61	20.39	19.40	19.39	19.89	19.19	2.08	0.115	0.913
Lipid (%)	9.20	15.27	15.71	15.56	14.23	14.62	2.04	0.219	0.679
Ash (%)	3.55	3.64	3.61	3.71	3.51	3.84	0.24	0.223	0.170

*Means are average values of three production cycles (N = 3); SEM: standard error of mean.

Water quality

There was a decline in water quality of the rearing ponds with increasing stocking density. We can highlight early morning measurements of dissolved oxygen ($p < 0.05$, $R^2 = 0.45$ and 0.68, Fig. 4) and oxygen saturation ($p < 0.05$; $R^2 = 0.43$ and 0.67, Fig. 4), which exhibited a significant inverse linear relationship with stocking density throughout the experimental period. A stronger fit of the regression curve in the latter half of the production cycle indicates consistent decline in water quality during this phase. In ponds stocked at densities of 10 and 25 fish/m^2, dissolved oxygen and oxygen saturation were higher than in the other treatments, but at the end of the experiment these two treatments also differed from each other ($p < 0.05$, Table 6). Lambari stocking densities equal to or exceeding 50 fish/m^2 resulted in oxygen saturation levels below 50%.

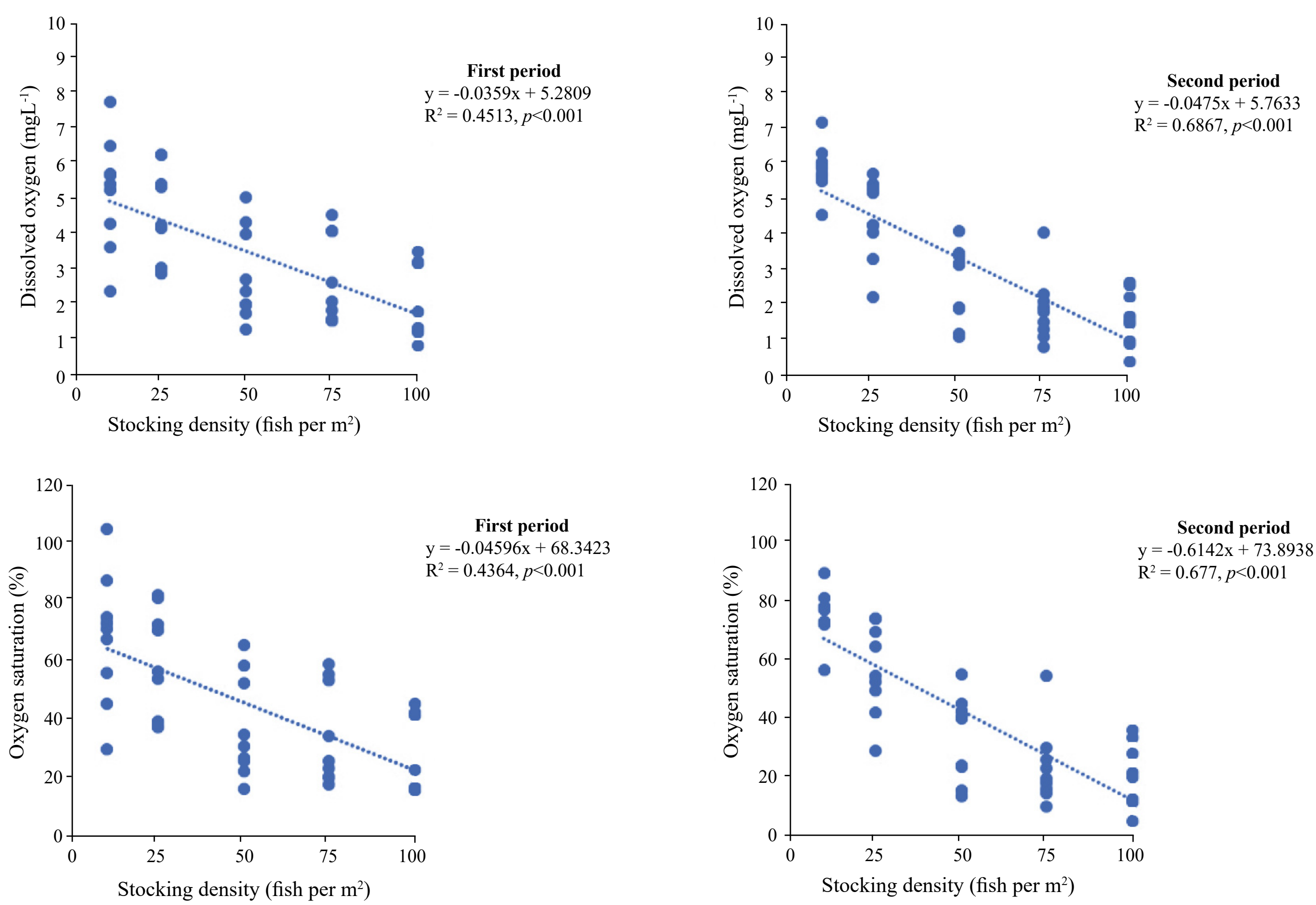

Figure 4. Water dissolved oxygen and oxygen saturation of lambari rearing ponds at five stocking densities, in two periods of the productive cycle. Regression analysis curves are adjusted to linear models. Data refers to nine analyses: three production cycles of six weeks, divided into two periods (three analyses per period).

Table 6. Water quality of rearing ponds of lambari at five stocking densities, in two periods of the productive cycle.*

	Stocking density (fish/m^2)					*Pooled SEM*	*p value-Block*	*p value-Trat.*
	10	25	50	75	100			
First period								
Dissolved oxygen (mg L^{-1})	5.17^a	4.51^a	2.81^b	2.63^b	1.93^b	0.99	0.029	<0.001
Oxygen saturation (%)	67.5^a	58.8^a	36.8^b	34.2^b	25.7^b	13.2	0.037	<0.001
pH	6.80	6.68	6.65	6.64	6.63	0.16	0.048	0.414
Alkalinity (mg L^{-1})	21.7^b	27.4^a	27.1^a	24.9^{ab}	29.4^a	2.8	0.002	0.005
Total ammonia (mg L^{-1})	0.055^b	0.058^b	0.211^{ab}	0.279^{ab}	0.469^a	0.180	0.122	0.004
Non-ionized ammonia (mg L^{-1})	0.034^{ab}	0.015^b	0.063^{ab}	0.119^a	0.112^{ab}	0.065	0.015	0.016
Nitrate (mg L^{-1})	0.055	0.063	0.044	0.053	0.070	0.026	0.161	0.623
Second period								
Dissolved oxygen (mg L^{-1})	5.92^a	4.44^b	2.62^c	1.89^c	1.61^c	0.71	0.197	<0.001
Oxygen saturation (%)	75.6^a	56.9^b	33.5^c	23.6^c	20.1^c	9.5	0.098	<0.001
pH	6.64^a	6.52^{ab}	6.43^b	6.42^b	6.49^{ab}	0.14	<0.001	0.018
Alkalinity (mg L^{-1})	18.4^c	20.7^{bc}	22.0^{bc}	24.0^b	28.9^a	4.0	<0.001	<0.001
Total ammonia (mg L^{-1})	0.047^b	0.110^b	0.256^{ab}	0.464^{ab}	0.605^a	0.281	0.023	0.009
Non-ionized ammonia (mg L^{-1})	0.015^b	0.024^b	0.044^{ab}	0.087^{ab}	0.122^a	0.050	0.072	0.008
Nitrate (mg L^{-1})	0.069	0.071	0.068	0.056	0.082	0.025	0.509	0.556

*Means followed by different letters, within the same row, indicate significant difference ($p < 0.05$). Means are average values of nine analyses (N = 9): three analyses per period at three production cycles. Production cycles of 6 weeks are divided into two periods. Overall minimum and maximum water temperature (mean ± standard deviation): 26.6 ± 1.3 °C e 32.1 ± 1.9 °C. SEM: standard error of mean.

Among nitrogen compounds, total ammonia and non-ionized ammonia showed the most relevant values for water quality, with higher concentrations observed especially at the highest density of 100 fish/m^2 ($p < 0.05$, Table 6). In the present study, ammonia was the predominant nitrogen compound in the water, no nitrite was detected, and nitrate levels were very low and not associated with fish density ($p > 0.05$).

Water pH values remained close to neutral, but ponds with higher fish densities exhibited lower pH levels during the second half of the production cycle ($p < 0.05$, Table 6). Alkalinity tended to increase with stocking density over the production cycle ($p < 0.05$).

Water transparency in the grow-out ponds was assessed weekly and remained above 60 cm, allowing for the visualization of the pond bottom and the proliferation of filamentous algae in all treatments and production cycles. Water temperature in the experimental units showed minimal variation, even among experimental cycles, as all were carried out in the summer. The weekly minimum and maximum temperatures (means ± standard deviation) were: 25.2 ± 0.9 and 30.6 ± 2.1°C in cycle 1; 26.6 ± 0.4 and 31.8 ± 1.0°C in cycle 2; and 27.9 ± 0.6 and 33.7 ± 0.6°C in cycle 3.

DISCUSSION

Growth curve and productive performance

In the present study, the growth of lambari at different stocking densities followed the logistic model, with faster growth at the lower densities. Considering the commercial target size of 7 to 11 cm (average of 8.5 cm) for culinary use or as live bait in sport fishing, lambari reached or exceeded this size as the asymptotic length at densities of 10, 25, and 50 fish/m^2. Gervaz et al. (2023) emphasized the importance of analyzing growth curves in addition to final fish performance parameters in aquaculture.

In the present study, lambari fed to apparent satiation showed higher initial feed intake at lower stocking densities, but intake decreased by the end of the grow-out period in all densities. This behavior was associated with initial faster growth at lower densities and increase in fish biomass up to a critical value, impairing water quality in all densities. Nonetheless, in the present study an initial feeding intake of 5–6% of live weight per day and feed conversion rate between 1.4 and 1.6 supported growth to market size at stocking densities of 10, 25, and 50 fish/m^2. Meurer et al. (2005) reported better growth of lambari at a feeding rate of 11.5% of live weight, although 4% also resulted in good growth and feed conversion below 1.5.

The present study is innovative in evaluating stocking density of yellowtail lambari reared in earthen ponds, filling a gap in scientific research applied to commercial production of this species. Field studies on fish stocking density for aquaculture are generally conducted in net cages or small-volume tanks. Vilela and Hayashi (2001) reported a quadratic effect of stocking density on lambari weight and length, a linear effect on total biomass produced, and no significant effect on feed conversion or condition factor, using fish of 0.5 g at densities from 31 to 124 fish/m^3 in net cages. In the present study, stocking density had an inverse linear effect on daily weight gain and specific growth rate, and a direct linear effect on biomass produced per unit area, while no effect was observed on feed conversion. The differences in results between studies can be attributed to variations in rearing system type, production scale, and initial fish weight.

Due to the scarcity of stocking density studies with lambari in earthen ponds, results from Nile tilapia (*Oreochromis niloticus*) were used for comparison. Studies in earthen ponds reported increased productivity of juvenile Nile tilapia with increasing stocking densities until biomass reached about 600 g/m^2 (Chakraborty & Banerjee, 2010; Kabir et al., 2019). This value is similar to the value of 618 g/m^2 observed in the present study with lambari at the highest stocking density (100 fish/m^2), although tilapia had a higher average weight and were stocked at lower densities. Thus, in small-scale fish farming using earthen ponds without mechanical aeration, a biomass around 600 g/m^2 may represent a productivity limit, suggesting that stocking densities above 100 fish/m^2 may not increase lambari biomass yields, although further studies are needed.

In the present study, the lower individual growth of lambari with high stocking densities was confirmed by reductions in both daily weight gain and specific growth rate. In general, the low daily weight gain values (0.08–0.18 g/day) are related to the small body size of the species. However, the specific growth rate of lambari during the grow-out phase was similar to that reported for juvenile Nile tilapia by Chakraborty and Banerjee (2010). Tilapia showed a specific growth rate of 2.4%·day^{-1} at a density of 2 juveniles/m^2 (initial weight of 35.15 g and initial biomass of 70 g/m^2), a value comparable to 2.6%·day^{-1} obtained for lambari at a density of 50 fish/m^2 (initial average weight of 2.67 g and initial biomass of 133 g/m^2).

Silva et al. (2011) characterized the lambari production chain in the western region of São Paulo state, Brazil. Several breeding systems and grow-out methods in earthen ponds were observed. Similarly to the present study, the most advanced producer used induced reproduction of broodstock, with egg incubation and fry rearing separated from the grow-out phase, adopting a density of 50 fish/m^2. In our study, the intermediate density of 50 fish/m^2 resulted in good productive performance in terms of individual growth, biomass and number of fish per area. Furthermore, Silva et al. (2011) reported producers using low densities of lambari (up to 30 fish/m^2) in combination with broodstock or other fish species. In our study, 10 and 25 fish/m^2 in monoculture promoted good individual growth but resulted in low productivity per unit area. Silva et al. (2011) also cited a producer using high densities, close to 90 fish/m^2, along with partial harvestings. In our study, densities of 75 and 100 fish/m^2 resulted in low individual growth but high productivity in terms of fish number per area, suggesting that selective harvesting of the largest individuals could be a viable strategy to maintain overall batch growth.

In general, the primary market for lambari is its use as live bait for sport fishing, although it also has culinary potential. In the present study, the carcass yield of eviscerated fish without scales ranged from 82 to 84%, with the highest yield observed at the lower stocking density. Previous studies have reported similar yields: 85 to 89% for yellowtail lambari reared under experimental conditions (Cotan et al., 2006), and a yield of 83 to 90% for redtail lambari (*Astyanax* sp.) captured in the wild (Feiden et al., 2009). In the present study, lambari processed without viscera, scales, fins, and head had yields ranging from 58 to 63%, representing a reduction of approximately 25% compared to processing that kept the head and fins.

Water quality

Several environmental factors influence aquaculture productivity, including stocking density, farming systems, feeding management, and various climatic and water quality parameters (Abd El-Hack et al., 2022). In the present study, water quality in the rearing ponds decreased with fish density increase, which may have influenced lambari feed intake and growth performance. Dissolved oxygen and oxygen saturation measured in the early morning were particularly affected, showing an inverse relationship with stocking density. Abdel-Tawwab et al. (2015) evaluated three dissolved oxygen levels for Nile tilapia: low (0.1–1.5 mg/L), medium (2.5–3.0 mg/L) and normal (6.0–6.5 mg/L), and reported that suboptimal levels impair growth, feed utilization and innate immunity. Similarly, in the present study, oxygen levels fell below 2 mg/L (low to medium level) at the two highest stocking densities of lambari, oxygen remained between 2.5 and 3.0 mg/L (medium level) at intermediate density, and exceeded 4 mg/L (medium to normal level) at the two lowest densities.

Stocking densities of lambari equal to or greater than 50 fish/m^2 resulted in oxygen saturation levels below 50%. The reduced oxygen uptake likely impaired energy metabolism, feed intake, and growth. Although the influence of dissolved oxygen on fish body composition has been reported for Nile tilapia (Abdel-Tawwab et al., 2015), this effect was not observed in the present study with lambari, in which oxygen levels fluctuated from suboptimal to optimal within the same day, following the photoperiod.

In the present study, total ammonia and consequently non-ionized ammonia were present at relevant concentrations in the water. According to Hargreaves (1998), fish excretion contributes up to 90% of the total nitrogen input into the rearing environment. In the present study, total ammonia levels reached 0.6 mg/L at the highest stocking density, but this is still considered safe for farmed fish. In Nile tilapia, histological alterations in gills, liver and kidneys have been reported only at total ammonia concentrations above 2 mg/L (Benli et al., 2008). Elevated concentrations of nitrogen compounds in the water can also affect fish feed consumption (Hargreaves, 1998), which corroborates the results observed for lambari at high stocking densities. Ammonia was the predominant nitrogenous compound in the present study, while nitrite was not detected and nitrate levels remained low, likely due to nitrogen uptake by photosynthetic organisms despite the occurrence of nitrification.

In the present study, water pH values remained close to neutral, despite slightly lower pH and higher alkalinity observed at higher stocking densities. During the grow-out phase of lambari, pH levels were adequate to maintain low concentrations of non-ionized (toxic) ammonia under high-temperature conditions. In addition, the higher alkalinity, expressed as carbonate and bicarbonate equivalents, helped to prevent large pH fluctuations.

In the present study, we outlined a comprehensive overview of a wide range of stocking densities for lambari during the grow-out phase. Our findings address the need for a better understanding of rearing systems used for lambari, contributing to increase safety and economic return in the activity, as reported by Silva et al. (2011).

CONCLUSION

The yellowtail lambari shows good adaptation to stocking densities ranging from 10 to 100 fish/m^2 in semi-intensive earthen pond system without supplementary aeration or water renewal. Although increasing fish density negatively affects individual growth, it does not compromise productivity in terms of the number of fish and biomass produced. Under the conditions of the present study, intermediate densities between 25 and 50 fish/m^2 are recommended to produce market-size lambari. The combined evaluation of growth curves, final performance and water quality are a valuable approach for understanding production systems under varying stocking densities and for supporting the implementation of good aquaculture practices in small-scale lambari farming.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

Data will be provided upon request.

AUTHORS' CONTRIBUTIONS

Conceptualization: Corrêa, C.F., Enke, D.B.S., Reis Neto, R.V.; **Formal Analysis:** Corrêa, C.F., Reis Neto, R.V.; **Investigation:** Corrêa, C.F., Enke, D.B.S., Reis Neto, R.V., Tamasia, E.P., Collaço, L.L.F.; **Resources:** Corrêa, C.F., Enke, D.B.S., Reis Neto, R.V.; **Supervision:** Corrêa, C.F.; **Data curation:** Corrêa, C.F., Collaço, L.L.F.; **Writing – original draft:** Corrêa, C.F.; **Writing – review & editing:** Corrêa, C.F., Enke, D.B.S., Reis Neto, R.V.; **Final approval:** Corrêa, C.F.

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DECLARATION OF USE OF ARTIFICIAL INTELLIGENCE TOOLS

We declare that no artificial intelligence tools were used in the preparation of this manuscript.

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