BOLETIM DO INSTITUTO DE PESCA
Scientific Article

Feeding rates for tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*): Effects on zootechnical performance and physiology parameters

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ABSTRACT

The study evaluated the impact of feeding rates (6, 8, 10, and 12% of biomass) on the growth and physiological responses of *Colossoma macropomum* × *Piaractus brachypomus* over 40 days. A total of 600 juveniles (1.61 ± 0.30 g, 4.1 ± 0.9 cm) were distributed in 12 tanks. Performance parameters were measured every 10 days, and biochemical, hematological, and somatic indices were analyzed after 40 days. Growth indicators such as final weight and feed conversion ratio improved with higher feeding rates during specific periods. Plasma glucose and red blood cells showed a quadratic response to feeding rates, while mean corpuscular volume increased proportionally. A 12% feeding rate was optimal for the initial 10 days, enhancing zootechnical indices. From 11 to 40 days, a 6% feeding rate is recommended, as growth performance did not significantly vary across rates. Feeding rates had minimal effects on biochemical, hematological, and somatic indices during the trial.

Keywords: Food management; Freshwater fish; Hybrid fish; Recirculating aquaculture system.

Taxa de arraçoamento para tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*): Efeitos no desempenho zootécnico e parâmetros fisiológicos

RESUMO

O estudo avaliou o impacto das taxas de arraçoamento (6, 8, 10 e 12% da biomassa) no crescimento e nas respostas fisiológicas de *Colossoma macropomum* × *Piaractus brachypomus* ao longo de 40 dias. 600 juvenis (1,61 ± 0,30 g, 4,1 ± 0,9 cm) foram distribuídos em 12 tanques. Os parâmetros de desempenho foram medidos a cada 10 dias, e os índices bioquímicos, hematológicos e somáticos foram analisados após 40 dias. Indicadores de crescimento, como peso final e taxa de conversão alimentar, melhoraram com maiores taxas de arraçoamento durante períodos específicos. A glicose plasmática e as hemácias mostraram uma resposta quadrática às taxas de arraçoamento, enquanto o volume corpuscular médio (VCM) aumentou proporcionalmente. Uma taxa de arraçoamento de 12% foi ótima para os 10 dias iniciais, melhorando os índices zootécnicos. De 11 a 40 dias, uma taxa de arraçoamento de 6% é recomendada, pois o desempenho do crescimento não variou significativamente entre as taxas. As taxas de arraçoamento tiveram efeitos mínimos nos índices bioquímicos, hematológicos e somáticos durante o teste.

Palavras-chave: Manejo alimentar; Peixes de água doce; Peixes híbridos; Sistema de recirculação de água.

Received: May 3, 2025 | **Approved:** August 25, 2025
Section editor: Fabiana Garcia

INTRODUCTION

Understanding the best feeding rate to be offered for fish is fundamental, as it varies depending on species, age, production system, among other aspects (Catarino et al., 2019; El-Araby et al., 2020; Manley et al., 2015). Feeding rate represents a direct factor in the economic return of production, since it can affect growth performance, feed efficiency, and minimize size heterogeneity, feed waste, water quality deterioration in fish farming (Hassan et al., 2021; Lawrence et al., 2012; Lee et al., 2023; Mohammady et al., 2023; Oliveira et al., 2021; Yang et al., 2019), and physiological responses (Melo et al., 2024; Rodrigues et al., 2024). Besides, excessive supply can lead to increased production costs and decreased water quality (Kim et al., 2021; Oh et al., 2019; Yang et al., 2019). So determining the best feeding rate becomes decisive in the successful production of different species and in different cultivation systems, like cultivation in earthen ponds, in which these feeding rates may be lower than those used in RAS, due to the presence of natural food, such as phyto and zooplankton, which serve as complementary food for many species of fish, for example, the tambaqui *Colossoma macropomum* (Rodrigues et al., 2024) and tilapia *Oreochromis niloticus* (Azab et al., 2018).

Studies using hybrid fish have gained prominence in the literature, and the results of these crossings have enabled significant progress in aquaculture by providing fish with excellent commercial value and good acceptance in the consumer market (Hashimoto et al., 2012). These hybrid animals are superior to their parental species in terms of zootechnical performance, such as accelerated growth and increased rusticity and tolerance to variation in water temperature and oxygen (Hashimoto et al., 2012; Martino, 2002; Welengane et al., 2019). Tambatinga is one such hybrid, being obtained by crossing two round-shaped fish: a female of tambaqui (*C. macropomum*) and a male of pirapitinga (*Piaractus brachypomus*). It has an omnivorous/filter feeding habit and can reach 3 kg in one year of production when managed properly (Gilson et al., 2024), in addition to presenting good carcass yield (Bomfim et al., 2021; Guimarães & Martins, 2015).

Despite the scarcity of research involving the tambatinga production in RAS (Santos et al., 2020; Sousa et al., 2020), many studies, using its pure parents, such as *C. macropomum* and *P. brachypomus*, have shown excellent adaptability responses of these animals in this production system (Ananias et al., 2024; Boaventura et al., 2021; Favero et al., 2021; Favero et al., 2022; Ferreira et al., 2023; Santos et al., 2022; Santos et al., 2023; Silva et al., 2021). Furthermore, due to the lack of information on food management for tambatinga juveniles, this study aimed to evaluate the effects of feeding rate on growth performance, biochemical and hematological parameters, and somatic indices of juveniles of tambatinga (*C. macropomum* × *P. brachypomus*) in RAS.

MATERIAL AND METHODS

Animals and conditions

The present study was carried out at the Laboratório de Aquacultura of Universidade Federal de Minas Gerais (UFMG) and approved by the Comissão de Ética no Uso de Animais da UFMG (Protocol no. 195/2022).

A total of 600 juvenile tambatinga (*C. macropomum* × *P. brachypomus*) were used, with an initial weight of 1.61 ± 0.30 g and total length of 4.1 ± 0.9 cm. The fish were randomly distributed in 12 rectangular tanks with a useful volume of 100 L, at a density of 0.5 fish·L^{-1}, in RAS, equipped with mechanical and biological filters, temperature control, and supplementary aeration.

During the first 30 days, the fish were fed an extruded commercial diet measuring 1.3–1.5 mm in diameter (Wean prime, Bernaqua, ADM; 45% crude protein, 5% ether extract, and 15% ash). From day 31 onward, the fish were fed a commercial diet measuring 2–3 mm in diameter (Pirá Evolution Fry, GUABI; 40% crude protein, 8% ether extract, and 14% ash). Both diets were supplied three times a day (8, 12, and 16 h) at the following feeding rates: 6, 8, 10, and 12% of the biomass, adjusted during biometrics of 10, 20, 30, and 40 days after cultivation. The experimental design was completely randomized, consisting of four groups (four feeding rates) and three replicates.

Uneaten feed was collected after 30 min of each feeding, dried in an oven for drying and sterilization (Ethik Technology) at 55°C, and weighed to calculate the feed intake and uneaten feed. The uneaten feed was carried out to observe whether the tested feeding rates presented a food surplus.

During the experiment, photoperiod was 12L:12D, monitored by a digital timer (Key West DNI group); water temperature was 29.00 ± 0.76°C, salinity was 1.62 ± 0.52 g salt·L^{-1}, electrical conductivity was 3.24 ± 1.04 mS·cm^{-1}, and pH was 7.41 ± 0.37, measured using a multiparameter probe (Hanna Instruments HI98130); dissolved oxygen was 4.12 ± 0.67 mg·L^{-1}, measured with a multiparametric probe (Yellow Springs Instrument, EcoSense DO200A); and total ammonia was kept below 0.5 mg·L^{-1}, determined using a colorimetric kit (Labcon Test, Alcon, Camboriú, Santa Catarina, Brazil).

Biometrics, growth performance parameters, and survival

After 10, 20, 30, and 40 days of experiment, the fish were collected for biometrics. In this way, the fish were anesthetized with eugenol (20 $mg \cdot L^{-1}$) (Santos et al., 2021), weighed individually in a semi-analytical digital scale (Marte AS5500), and their total length was measured in a digital caliper (Starret, 799 series). Thus, the following parameters were calculated:

- Weight gain = final body weight (g) - initial body weight (g);
- Daily weight gain ($g \cdot day^{-1}$) = weight gain (WG)/days of experiment;
- Net yield ($kg \cdot m^{-3}$) = (final biomass × water volume) × 1,000;
- Specific growth rate (SGR) (% day^{-1}) = 100 × [(*ln* final body weight) - (*ln* initial body weight)] / interval between biometrics (days);
- Feed conversion ratio (FCR) = feed intake (g)/weight gain (g);
- Uniformity = (total number of animals with weight ± 20% within the average live weight, in each experimental unit / total number of animals in the tank) × 100 (Couto et al., 2018).

Survival rate was determined at the end of the experiment (after 40 days) by directly counting the animals using Eq. 1:

$$\text{Survival rate (\%)} = (\text{Final number of animals}/\text{Initial number of animals}) \times 100 \quad (1)$$

Blood parameters

At the end of the experiment, fish were fasted for 24 hours, and blood was collected from 12 fish per treatment, by caudal venipuncture with heparinized syringes. Samples were dispensed into microtubes containing sodium heparin anticoagulant (10%) to determine hematocrit (Hct) by the microhematocrit method (Goldenfarb et al., 1971) using capillary tubes. Total proteins in plasma were determined with an analog refractometer (Brix, RHB0-90, 0–90%) after rupture of the microhematocrit tube. Red blood cell (RBC) count was determined by diluting 10 µL of whole blood in 2 mL of formaldehyde citrate and then counting using a Neubauer hemocytometer under an optical microscope at 400x magnification. Hemoglobin (Hb) concentration was determined by a commercial colorimetric kit (Bioclin/Quibasa) using the cyanomethemoglobin reaction.

The remaining whole blood was centrifuged (4,000 RPM for 10 min) to separate the plasma and determine biochemical parameters (glucose, triglycerides, and cholesterol) by colorimetric method using commercial kits (Bioclin/Quibasa), with readings via spectrophotometer (Biochrom Libra, S22 UV-VIS, Biochrom Instruments).

The hematimetric indices of mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentrations (MCHC) were calculated according to Eqs. 2, 3, and 4, established by Wintrobe (1933):

$$\text{MCV (fL)} = (\text{Hct} \times 10)/(\text{RBC } 10^6\ \mu \cdot L^{-1}) \quad (2)$$

$$\text{MCH (pg)} = (\text{Hb} \times 10)/(\text{RBC } 10^6\ \mu \cdot L^{-1}) \quad (3)$$

$$\text{MCHC } (g \cdot dL^{-1}) = (\text{Hb} \times 100)/(\text{Hct}) \quad (4)$$

Somatic indices

The same 12 fish/treatment used for blood collection at the end of the experiment were euthanized with 285 $mg \cdot L^{-1}$ eugenol solution (Mattioli et al. 2017) to determine somatic indices. Liver was removed to calculate the hepatosomatic index (HSI) and the mesenteric fat and viscera (stomach, intestine, pyloric cecum, and spleen) were removed and weighed to calculate the viscerosomatic index (VSI), according to the Eqs. 5 and 6, respectively:

$$\text{HSI (\%)} = (\text{Weight of liver})/\text{Body weight}) \times 100 \quad (5)$$

$$\text{VSI (\%)} = (\text{Weight of viscera}/\text{Body weight}) \times 100 \quad (6)$$

Statistical analysis

Data were tested for homogeneity of variances and normality of residuals using Levene's and Shapiro-Wilk tests, respectively, and then subjected to analysis of variance (ANOVA) followed by regression analysis. The significance level was set to $p < 0.05$. All data were analyzed using SAS statistical software, version 9.4 (SAS Institute Inc., Cary, NC, United States of America).

RESULTS

Growth performance parameters and survival

During 10 days of cultivation, final weight (Fig. 1a), weight gain (Fig. 1b), daily weight gain (Fig. 1c), FCR (Fig. 1d), net yield (Fig. 1e), and uneaten feed (Fig. 1f) increased proportionally with the increase in feeding rate, while there were no significant differences for total length, SGR, and uniformity (Table 1).

Between 11 and 20 days, only FCR (Fig. 2a) and uneaten feed (Fig. 2b) were directly related to the increase in feeding rate, while weight, total length, weight gain, daily weight gain, net yield, SGR, and uniformity did not differ significantly among the treatments (Table 1).

In the period from 21 to 30 days, the final weight (Fig. 3a) and uneaten feed (Fig. 3b) showed a linear effect with the feeding rates, and in the period from 31 to 40 days, the feeding

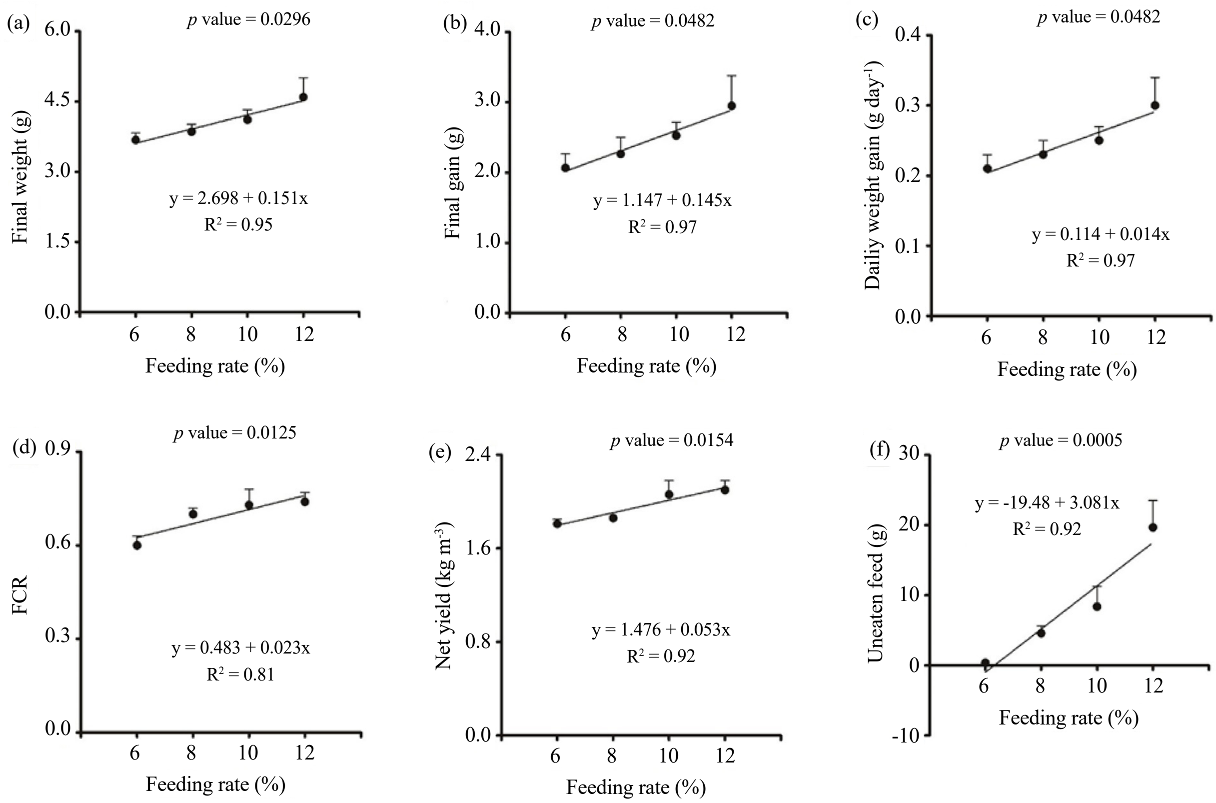

Figure 1. Mean values (± standard error) for (a) final weight, (b) weight gain, (c) daily weight gain, (d) feed conversion ratio (FCR), (e) net yield, and (f) uneaten feed of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates in the period of 10 days of cultivation.

Table 1. Mean values (± standard error) for growth performance and survival of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates for 40 days of cultivation.

Parameters	Feeding rate (%)				*p* value		
	6	8	10	12	Overall	Linear	Quadratic
			1–10 days				
Total length (cm)	6.15 ± 0.17	6.26 ± 0.12	6.24 ± 0.02	6.54 ± 0.13	0.2635	0.0882	0.5229
SGR (% day^{-1})	8.29 ± 0.73	8.86 ± 0.80	9.51 ± 0.39	10.19 ± 1.08	0.4084	0.1088	0.9445
Uniformity (%)	68.88 ± 2.22	64.44 ± 5.87	64.44 ± 8.01	62.22 ± 19.75	0.9778	0.6979	0.9228
			11–20 days				
Final weight (g)	6.21 ± 0.41	6.31 ± 0.28	6.90 ± 0.21	6.94 ± 0.67	0.5211	0.1829	0.9416
Total length (cm)	7.66 ± 0.25	7.18 ± 0.11	7.36 ± 0.06	7.35 ± 0.19	0.3080	0.3505	0.2017
Weight gain (g)	2.53 ± 0.37	2.46 ± 0.24	2.78 ± 0.12	2.34 ± 0.30	0.7188	0.8467	0.5267
Daily weight gain (g·day^{-1})	0.25 ± 0.04	0.25 ± 0.02	0.28 ± 0.01	0.23 ± 0.03	0.7188	0.8467	0.5267
Net yield (kg·m^{-3})	3.02 ± 0.05	2.93 ± 0.06	3.37 ± 0.26	3.42 ± 0.20	0.1786	0.0621	0.7186
SGR (% day^{-1})	5.21 ± 0.59	4.93 ± 0.41	5.17 ± 0.31	4.11 ± 0.25	0.2724	0.1329	0.3716
Uniformity (%)	66.66 ± 3.84	77.77 ± 5.87	57.77 ± 2.22	64.44 ± 9.68	0.2136	0.3559	0.7245

Continued...

Continuation

21–30 days							
Total length (cm)	7.99 ± 0.18	7.71 ± 0.09	7.99 ± 0.13	8.16 ± 0.18	0.2855	0.2862	0.1781
Weight gain (g)	2.07 ± 0.27	1.19 ± 0.49	1.78 ± 0.40	1.39 ± 0.06	0.3361	0.3787	0.4953
Daily weight gain (g·day^{-1})	0.21 ± 0.03	0.12 ± 0.05	0.18 ± 0.04	0.14 ± 0.01	0.3361	0.3787	0.4953
Net yield (kg·m^{-3})	4.17 ± 0.08	3.61 ± 0.20	4.17 ± 0.34	4.37 ± 0.26	0.2153	0.3141	0.1512
SGR (% day^{-1})	2.88 ± 0.37	1.73 ± 0.71	2.26 ± 0.40	1.85 ± 0.17	0.3399	0.2458	0.4355
FCR	1.11 ± 0.02	2.22 ± 0.59	2.35 ± 0.36	2.24 ± 0.10	0.1132	0.0564	0.1203
Uniformity (%)	51.11 ± 9.68	75.55 ± 5.87	44.44 ± 8.01	57.77 ± 2.22	0.0645	0.7328	0.4520
31–40 days							
Final weight (g)	9.60 ± 0.46	9.10 ± 0.55	10.06 ± 1.27	9.51 ± 0.53	0.8559	0.8505	0.9760
Total length (cm)	8.70 ± 0.13	8.39 ± 0.21	8.72 ± 0.27	8.52 ± 0.18	0.5403	0.7943	0.7606
Weight gain (g)	1.95 ± 1.22	1.60 ± 0.59	2.03 ± 0.39	1.18 ± 0.23	0.7595	0.5276	0.7017
Daily weight gain (g·day^{-1})	0.20 ± 0.12	0.16 ± 0.06	0.20 ± 0.04	0.12 ± 0.02	0.7595	0.5276	0.7017
Net yield (kg·m^{-3})	4.87 ± 0.04	4.23 ± 0.32	4.94 ± 0.50	5.12 ± 0.33	0.2991	0.3799	0.2812
SGR (% day^{-1})	2.21 ± 1.38	1.92 ± 0.70	1.98 ± 0.25	1.36 ± 0.35	0.8506	0.4782	0.8300
FCR	2.06 ± 0.56	2.70 ± 0.67	3.22 ± 0.62	3.05 ± 0.28	0.5036	0.1854	0.4886
Uniformity (%)	57.77 ± 13.51	71.11 ± 8.01	43.33 ± 10.00	44.44 ± 2.22	0.2148	0.1412	0.5436
Survival	98.00 ± 0.00	97.33 ± 0.67	98.00 ± 0.00	98.00 ± 1.15	0.8592	0.8287	0.6305

FCR: feed conversion ratio; SGR: specific growth rate.

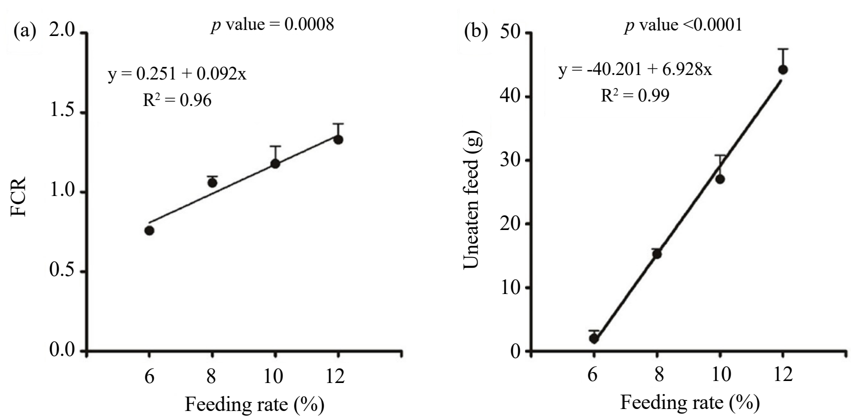

Figure 2. Mean values (± standard error) for (a) feed conversion ratio (FCR) and (b) uneaten feed of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates in the period from 11 to 20 days of cultivation.

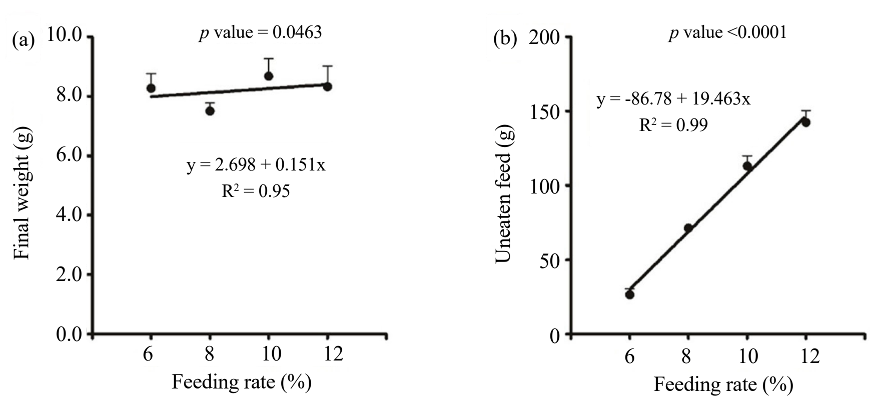

Figure 3. Mean values (± standard error) for (a) final weight and (b) uneaten feed of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates in the period from 21 to 30 days of cultivation.

rates influenced only the uneaten feed (Fig. 4), resulting also in a positive linear effect. It was observed that, after 40 experimental days, the survival rate did not show significant differences between feeding rates (Table 1).

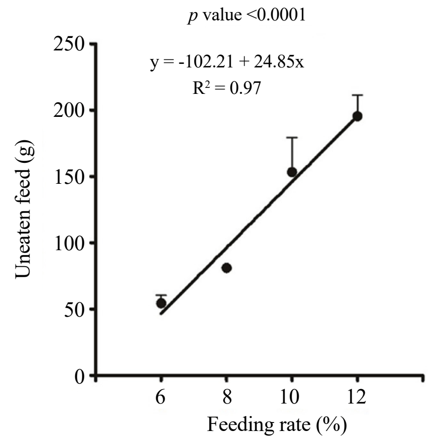

Figure 4. Mean values (± standard error) for uneaten feed of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates in the period from 31 to 40 days of cultivation.

Blood parameters

Glucose levels in plasma (Fig. 5a) and RBC (Fig. 5b) showed a quadratic response with maximum points estimated by the derivation of the equation at 86.24 and 0.83, with feeding rates of 9.06 and 8.2%, respectively. MCV (Fig. 5c) had a linear effect on feeding rates.

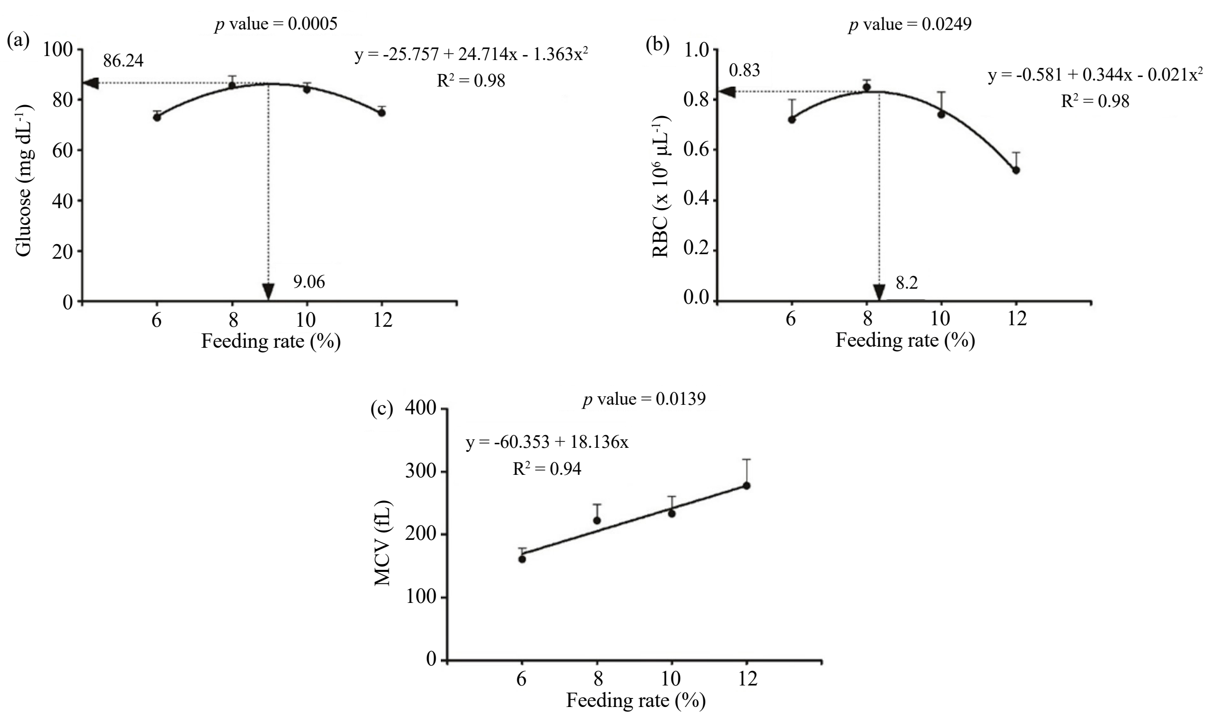

Figure 5. Mean values (± standard error) for (a) glucose, (b) red blood cell (RBC), and (c) mean corpuscular volume (MCV) of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates for 40 days of cultivation. The dashed vertical lines represent values estimated by the equation derived.

Somatic indices

The feeding rates tested did not affect somatic indices (HSI and VSI) after 40 experimental days (Table 2).

Triglycerides, cholesterol, total proteins, Hb, Hct, MCH, and MCHC did not differ significantly among treatments.

Table 2. Mean values (± standard error) for blood parameters and somatic indices of juvenile tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*) fed different feeding rates for 40 days of cultivation.

Parameters	Feeding rate (%)				*p* value		
	6	8	10	12	Overall	Linear	Quadratic
Triglycerides (mg·dL^{-1})	270.57 ± 21.66	231.59 ± 17.25	274.16 ± 18.92	234.11 ± 12.22	0.1961	0.4045	0.9763
Cholesterol (mg·dL^{-1})	99.25 ± 5.54	90.64 ± 6.07	94.28 ± 4.16	93.64 ± 3.97	0.6737	0.5445	0.4281
Total proteins (g·dL^{-1})	5.12 ± 0.17	4.90 ± 0.05	4.91 ± 0.11	4.86 ± 0.05	0.4810	0.1963	0.5348
Hb (g·dL^{-1})	4.72 ± 0.35	4.51 ± 0.37	5.00 ± 0.34	4.23 ± 0.55	0.6089	0.5948	0.5033
Hct (%)	14.83 ± 1.96	17.33 ± 2.26	18.50 ± 1.95	16.92 ± 3.00	0.7327	0.4810	0.3863
MCH (pg)	69.15 ± 4.86	53.56 ± 5.52	78.29 ± 9.83	69.65 ± 8.63	0.1539	0.4412	0.6473
MCHC (g·dL^{-1})	34.70 ± 4.12	33.13 ± 6.07	25.51 ± 1.29	29.04 ± 5.81	0.5644	0.2687	0.6087
HSI (%)	1.64 ± 0.11	1.70 ± 0.12	1.69 ± 0.16	1.80 ± 0.07	0.1838	0.3885	0.8613
VSI (%)	6.70 ± 0.28	6.42 ± 0.27	6.34 ± 0.28	7.09 ± 0.20	0.8122	0.3511	0.0551

Hb: hemoglobin; Hct: hematocrit; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration; HIS: hepatosomatic index; VSI: viscero-somatic index.

DISCUSSION

The feeding rate is an important management to be considered in the cultivation of tambatinga with an initial weight of 1.6 g in RAS, as it had a great impact on the growth performance of these animals during the first 10 days of production in the present study. On the other hand, higher feeding rates promoted greater food waste by fish throughout the experimental period, which can be observed in the responses to uneaten feed. Furthermore, survival rates above 97% found after 40 experimental days showed good adaptation of this hybrid to RAS. For the pure species (*C. macropomum* and *P. brachypomus*), high survival rates were also recorded in this same cultivation system (Ananias et al., 2024; Favero et al., 2022; Melo et al., 2024; Santos et al., 2023). Studies with other species have also shown high survival of animals subjected to different feeding rates, such as *Astyanax bimaculatus* (Meurer et al., 2005), *Hoplias lacerdae* (Salaro et al., 2008), and *Pangasianodon hypophthalmus* (Lee et al., 2023).

Between one and 10 days of experiment, weight, weight gain, daily weight gain, and net yield showed a direct linear relationship with the increase in feeding rate. According to Guo et al. (2020), higher feeding rates were related to a greater supply of nutrients to the animals and, consequently, resulted in greater weight gain. The highest feeding rate of 6% for *P. hypophthalmus* juveniles also provided the best growth performance results, in which the fish, with an initial average weight of 6.7 g, reached 24.7 g after four weeks of production (Lee et al., 2023). For juvenile pacamã (*Lophiosilurus alexandri*), with an initial weight of 1.3 g, similar to the weight of the fish in the present study, and fed at rates between 2 and 8% of live weight, the authors found that the best survival results occurred for 4.64% in the feeding rate, in addition to better FCR at a rate of 2.70% and greater weight gain at a rate of 5.57% (Melillo Filho et al., 2014), a fact that demonstrates that, in fish of the same size, feeding rates can be very different due to variations, mainly depending on the species studied.

During the first 10 days of cultivation, a linear increase in FCR by the fish was also noted with the increase in feeding rates. Worse FCR due to increased feeding rate was also observed in the study by Signor et al. (2020) with juveniles of *Rhamdia quelen* and by Salaro et al. (2008) with juveniles of *H. lacerdae* (initial average weight of 38.5 g), in which rates of 2, 4, and 6% of live weight did not affect the growth performance of the fish. However, the higher rate (6%) also showed the worst FCR. Guo et al. (2020) concluded that maximum feed conversion efficiency did not occur at levels that guaranteed maximum growth for *Sebastes schlegelii* juveniles.

It is very interesting to observe in the present study that juvenile tambatinga, from 11 days onwards (11 to 40 experimental days), no longer showed satisfactory responses in their growth with the increase in feeding rates. Similar results were found by Meurer et al. (2005), in which juvenile lambari (*A. bimaculatus*), with an initial weight of 0.52 g, showed a linear effect between weight and feeding rate (between 1 and 16%) in the first 12 days of the experiment. When the animals reached 23 and 30 days of cultivation, the best weights were achieved at feeding rates of 12.3 and 11.5% of live weight, respectively. Fiogbé and Kestemont (2003) also observed similar responses, in which the feeding rate for *Perca fluviatilis* decreased from 7.4 to 5.1%, 4.5 and 2.2% of biomass per day, for fish with 0.22, 0.73, 1.56, and 18.9 g of initial weight, respectively, which proves there is a need for changes in feeding rates throughout the production of fish in captivity. However, the results of the present study are interesting when compared to those recommended for tambaquis in ponds. Corrêa et al. (2018) recommend powdered feed for fish between 0.5 and 7 g with a feeding rate of 20–10% of live weight in six daily feedings. In RAS, this management can be much better with less feed use and already using extruded feed.

Throughout the entire experimental period, the uneaten feed by fish had a direct linear effect on feeding rates, a fact also observed by Melillo Filho et al. (2014) in juveniles of *L. alexandri*. These responses show that high feeding rates can result in a large amount of food waste, with possible consequences in increasing feed costs, in addition to worsening water quality. In the present study, as food uneaten were removed 30 minutes after feeding, this management did not affect water quality parameters neither RAS efficiency. At the end of the study, even at the lowest feeding rate (6%), food uneaten was observed in the tanks, which shows the need to study lower feeding rates, thus aiming to improve management efficiency. In the study by Rodrigues et al. (2024), for juveniles of *C. macropomum* weighing 94 g cultivated in earthen ponds, the recommended feeding rate is 3% of the biomass. However, for the same species, weighing 2.67 g and cultivated in cages, the best feeding rate was 10% of live weight in three daily feedings (Silva et al., 2007). In the present study, no significant differences in batch uniformity were observed between the feed rates evaluated. A similar result was also reported by Oliveira et al. (2021) when feeding juvenile *O. niloticus* with different feed rates (0, 2.5, 5.0, 7.5, and 10.0% of live weight).

After 40 experimental days, no changes were observed for most blood parameters (triglycerides, cholesterol, total proteins, hemoglobin concentration, hematocrit, MCH, and MCHC) and indices (HSI and VSI), with the feeding rates tested, which demonstrates the good physiological condition of the fish. Furthermore, water quality was maintained during the experiment due to the efficiency of the RAS and also due to the removal of uneaten food, which promoted a homogeneous environment suitable for all animals. Plasma glucose is an important indicator of animal energy metabolism (Jiang et al., 2017), and in the present study, it showed a quadratic effect in relation to feeding rates, reaching a maximum value (86.24 mg·dL^{-1}) at a rate of 9.06%. However, even with these responses observed according to different feeding rates, it was noted that glucose levels remained in a range considered normal, in accordance with other studies, such as Rodrigues et al. (2016), in which they found values between 68.85 and 78.85 mg·dL^{-1}, in fish under different stocking densities, and Moraes et al. (2017), in which they found a glucose value of 97.3 mg·dL^{-1}, after returning to baseline conditions in tambatinga juveniles exposed to biometric management.

Erythrocytes are the most abundant cells in the circulation, and their main function is the transport of respiratory gases (oxygen and carbon dioxide) through hemoglobin (Fänge, 1994). It is observed, in the present study, that the RBC increased up to the feeding rate of 8.2% of the biomass, in which a maximum value of 0.83 × 10^6 µL^{-1} was found, accompanied also by the increase in MCV, which represents the size or erythrocyte volume. With the increase in feeding rates, a gradual decrease in RBC was observed (0.52 × 10^6 µL^{-1} at the highest feeding rate of 12%), and MCV continued to show a linear increase, with the highest value (277.93 fL) at the highest feeding rate (12%). The increase in MCV may be a low-cost response to the anemic state of some fish species (Witeska et al., 2015), that is, its increase is a form of compensation due to the reduction of other hematological parameters, such as RBC, Hb, and Hct. However, this anemic condition was not found in tambatinga juveniles in the present study, as the fish showed good growth responses and high survival throughout the experimental period. Although water quality parameters remained in appropriate physiological limits in the RAS, it is possible that transient elevations of ammonia occurred at the two highest feed rates had influenced erythrocyte physiology. According to Gao et al. (2021), increased ammonia concentrations can cause significant reductions in RBC due to inhibition of hematopoietic tissues, compromising RBC production. This effect may explain the decrease in RBC observed at feeding rates of 10 and 12% of biomass, without, however, characterizing an anemic condition, since there was physiological compensation evidenced by the increase in MCV. This mechanism likely contributed to the maintenance of tissue oxygenation, thus consistent with the growth results and high survival observed in the study. Although there are not many studies involving hematological parameters in tambatinga, RBC (Fig. 4), Hb, and Hct (Table 2) presented values below those found in the study by Moraes et al. (2017), in tambatinga juveniles weighing around 345 g (RBC 1.9×10^6 μL^{-1}; Hb 12.3 $g \cdot dL^{-1}$ and Hct 46.3%). However, it is very important to highlight that there are numerous factors that can alter hematological parameters, such as stress and the health condition of the animals, nutritional status, water quality, as well as factors related to blood collection, anesthesia, among others (Ahmed et al., 2020; Fazio, 2019; Sahiti et al., 2018; Witeska et al., 2022).

Although most of the hematological and biochemical parameters evaluated remained in normal ranges, it is recommended that future studies also include variables such as cortisol, liver enzymes, and plasma ammonia, as well as markers of oxidative stress, in order to broaden the understanding of the impacts of feeding rates on the physiology of tambatinga in intensive systems.

CONCLUSIONS

The use of a 12% feeding rate during the first 10 days (initial weight 1.61 ± 0.30 g) in RAS improved fish performance. From the 11th day (average weight 4.06 ± 0.23 g) until day 40, a 6% feeding rate is recommended, as no significant differences were observed among treatments. Feeding rates did not affect survival, had little influence on biochemical and hematological variables, and did not impact somatic indices.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

Data will be provided upon request.

AUTHORS' CONTRIBUTIONS

Conceptualization: Silva, S.S., Ananias, I.M.C., Magalhães, T.B., Souza, A.S., Santos, F.A.C., Luz, R.K., Favero, G.C.; **Methodology:** Silva, S.S., Ananias, I.M.C., Magalhães, T.B., Souza, A.S., Santos, F.A.C., Luz, R.K., Favero, G.C.; **Validation:** Silva, S.S., Ananias, I.M.C., Magalhães, T.B., Souza, A.S., Santos, F.A.C., Luz, R.K., Favero, G.C.; **Formal analysis:** Silva, S.S., Ananias, I.M.C., Magalhães, T.B., Souza, A.S., Santos, F.A.C., Luz, R.K., Favero, G.C.; **Resources:** Silva, S.S., Luz, R.K., Favero, G.C.; **Investigation:** Silva, S.S., Ananias, I.M.C., Magalhães, T.B., Souza, A.S., Santos, F.A.C., Luz, R.K., Favero, G.C.; **Writing – Original Draft:** Silva, S.S., Paranhos, C.O., Luz, R.K., Favero, G.C.; **Writing – Review and Editing:** Silva, S.S., Paranhos, C.O., Luz, R.K., Favero, G.C.; **Visualization:** Silva, S.S.; **Funding Acquisition:** Silva, S.S., Luz, R.K., Favero, G.C.; **Visualization:** Paranhos, C.O., Luz, R.K., Favero, G.C.; **Data curation:** Luz, R.K., Favero, G.C.; **Supervision:** Luz, R.K., Favero, G.C.; **Project Administration:** Luz, R.K., Favero, G.C.; **Final approval:** Silva, S.S.

FUNDING

Conselho Nacional de Desenvolvimento Científico e Tecnológico

Grant Nos.: 402952/2021-9, 310170/2023-0, 316901/2021-0, and 402840/2023-2

Fundação de Amparo à Pesquisa do Estado de Minas Gerais

Grant No: APQ-00132-23

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Finance code 001

ACKNOWLEDGMENTS

Not applicable.

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