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GROWTH OF *Geophagus brasiliensis* REARED AT DIFFERENT TEMPERATURES AND FEEDING REGIMES

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ABSTRACT

The aim of this study was to evaluate the growth performance of *Geophagus brasiliensis* reared under distinct temperatures (24.3 ± 0.9, 28.1 ± 1.0, and 31.7 ± 0.8°C) and feeding regimes (apparent satiety and a supply of 4% of the total biomass). About 500 wild-caught individuals were sorted and identified, to screen 180 fish to be used in the experiment (6.81 ± 1.15 g and 7.51 ± 0.47 cm). After a 55-day acclimatization period, the fish were distributed in experimental tanks, considering a double factorial randomized blocks scheme, composed of six treatments and three replicates. Growth performance parameters, somatic indexes and carcass yield were evaluated at the end of the experimental period (72 days). Fish fed to the point of apparent satiety presented higher (p <0.05) final weight, weight gain, specific growth rate and hepatosomatic index. The animals reared at a temperature of 24.3°C displayed higher (p <0.05) final weight, weight gain, specific growth, hepatosomatic index, lower visceral fat, and feed conversion index. It was concluded that *G. brasiliensis* presents higher productive indexes when fed until apparent satiety and reared in temperatures close to 24.3°C.

Keywords: cará; Cichlid; water recirculation; native species.

CRESCIMENTO DE *Geophagus brasiliensis* CULTIVADO EM DIFERENTES TEMPERATURAS E REGIMES DE ALIMENTAÇÃO

RESUMO

O objetivo deste estudo foi avaliar o desempenho zootécnico de *Geophagus brasiliensis* criado sob diferentes temperaturas (24,3 ± 0,9, 28,1 ± 1,0 e 31,7 ± 0,8°C) e regimes alimentares (saciedade aparente e taxa de arraçoamento de 4% da biomassa total). Foram selecionados e identificados cerca de 500 indivíduos capturados na natureza, para a triagem de 180 peixes a serem utilizados no experimento (6,81 ± 1,15 g e 7,51 ± 0,47 cm). Após um período de aclimatação de 55 dias, os peixes foram distribuídos em tanques experimentais, considerando um esquema de blocos ao acaso em fatorial duplo, composto por seis tratamentos e três repetições. O desempenho zootécnico, os índices somáticos e o rendimento de carcaça foram avaliados ao final do período experimental (72 dias). Os peixes alimentados até a saciedade aparente apresentaram maiores (p <0,05) peso final, ganho de peso, taxa de crescimento específico e índice hepatossomático. Os animais criados em temperatura de 24,3°C apresentaram maior (p <0,05) peso final, ganho de peso, crescimento específico, índice hepatossomático, menor índice de gordura visceral e de conversão alimentar. Concluiu-se que *G. brasiliensis* apresenta maiores índices produtivos quando alimentado até a saciedade aparente e criado em temperaturas próximas a 24,3°C.

Palavras-chave: cará; Ciclídeo; recirculação de água; espécies nativas.

INTRODUCTION

Understanding the thermal behavior of fish is a useful tool for aquaculture development (Gómez, 2014; Gómez and Volpedo, 2017). Water temperature is one of the most relevant parameters that affects fish growth, development, and survival (Castillo-Vargasmachuca et al., 2013; Silva, 2016; Islam et al., 2019), and feeding rates are directly correlated with this variable (Kubitza, 2011), seen that the animal's metabolism is regulated by the environment thermal conditions (Zeni et al., 2016; Islam et al., 2019). Thus, knowing the ideal temperature for the development of commercial species is an essential information, as it affects production costs (Rebouças et al., 2014).

A viable and last-longing fish production is directly related to feeding, thus the costs with feed must be carefully monitored, as it may represent more than 60% of total production costs (Muñoz and Barroso, 2016; Trombeta et al., 2017; Milanez et al., 2019). In this sense, an adequate feeding regime might favor fish development, while avoiding economic losses associated with feed remains, besides mitigating negative impacts of the decomposing feed in water quality parameters (Américo et al., 2013).

Among several neotropical cichlids, the species *Geophagus brasiliensis* (*geo* = earth + *phagus* = eat) stands out due to its morphometric similarities with tilapia (*Oreochromis niloticus*) (Furtado, 1995), which is the second most produced fish species worldwide (Peixe BR, 2020). *G. brasiliensis* is a Brazilian native species, distributed from the Amazon Basin to the north region of Argentina and Uruguay (Rantin and Petersen, 1985; Kullander et al., 2003), which presents omnivorous feeding habits (Abelha and Goulart, 2004) and can reach up to 35 cm total length (Beatty et al., 2013)

This fish can be found in water bodies with distinct characteristics, including in estuaries (Monteiro-Neto et al., 1990; Malabarba et al., 2013), which makes it an option for mariculture in such regions. The group *Geophagus* covers 10 species/lineages (Argolo et al., 2020), and it is popularly known as cará or acará. It presents gray coloration with shades varying from blue to green (Weis et al., 1981), making it a much appreciated species in fishkeeping (Beatty et al., 2013). According to Franco (1999), the species presents good nutritional characteristics for human consumption; however, quantitative data on its commercial production, processing and consumption are scarce.

The use of *G. brasiliensis* for food consumption has been reported almost exclusively in artisanal fisheries contexts, as it is considered one of the most representative species in catches in this scenario (Alves da Silva et al., 2009; Massena et al., 2014; Morales, 2018). This species is sold informally in popular markets (Pinto et al., 2011; Silva e Siebert, 2019).

Baldisserotto (2009) and Amaral Júnior et al. (2011) mentioned this species as a possible option for commercial fish farming, but so far, the main focuses of studies with the species are related to its ecological aspects in natural environments (Abelha and Goulart, 2004; Santos et al., 2004; Beatty et al., 2013) and its use as a bioindicator in ecotoxicology studies (Morais et al., 2016; Doria et al., 2017; Merçon et al., 2019).

The potential of cultivating the species remains little investigated. Thus, evaluations of its productive performance indexes allied with feeding regimes and physico-chemical variables in the water might enable a better understanding on its possible commercial production.

Several studies demonstrated that water temperature influences fish metabolism, which leads to differential feed consumption, digestibility indexes, feed conversion and growth (Dias, 1998; Piedras et al., 2005, 2006). According to Pereira et al. (2018), levels of oxygen saturation combined with distinct temperatures affect the metabolism of *G. brasiliensis* in hypoxia conditions, causing the species to use anaerobic pathways to supply its energy demands.

Based on the hypothesis that environmental conditions and feed management would also affect growth and development of *G. brasiliensis*, this study aimed evaluating different temperatures and feeding regimes on the growth and somatic indexes of this fish species-reared in a water recirculating system.

MATERIAL AND METHODS

Animals and experimental design

A survey followed the procedures recommended by CONCEA for the use and handling of animals in the laboratory.

Around 500 wild specimens of *G. brasiliensis* were collected in a pond located in the municipality of Laguna/SC, Brazil (28°27’S, 48°46’W), with the aid of artisanal traps and cooked rice as attractant. The collected fish were sorted and identified using identification guidelines (Mega and Bemvenuti, 2006; Buckup et al., 2014). Subsequently, the individuals were placed in 1000-L tanks disposed in a water recirculation system, remaining for an acclimatization period of 55 days prior to the experiment, with natural photoperiod. Throughout this acclimatization period, the animals were fed with an extruded commercial diet (4 mm) containing 32% crude protein (CP) and 6% ether extract, until apparent satiety, aiming at the batch’s homogeneity.

The experiment was carried out in the Laboratory of Aquaculture of the Santa Catarina State University (LAQ-UDESC), located in Laguna/SC, Brazil, and lasted for 72 days, under a natural photoperiod. Using a two-factor randomized blocks design, the experiment consisted in evaluating three water temperatures (24.3 ± 0.9, 28.1 ± 1.0, and 31.7 ± 0.8°C) and two feeding regimes (apparent satiety and a rate of 4% of the biomass), thus resulting in six treatments with three replicates.

The experimental device consisted of six independent water recirculation systems (RAS), totaling 18 experimental units. Each temperature evaluated was allocated in two systems, whilst the different feeding regimes were randomly assigned to different experimental units (Figure 1). Ten *G. brasiliensis* specimens were placed in each experimental unit, totaling 180 animals with a mean initial weight of 6.81 ± 1.15 g, and 7.51 ± 0.47 cm of total length. Each system was composed by three experimental units (250-L circular polyethylene tanks with useful volume of 200 L), connected to a treatment tank (sump) equipped with mechanical and biological filters, as well as a water heating system and a pump.

A bag-type mechanical filter produced with geotextile (Bidim®) was used for solids removal, while the biological filter (pool lanes with 10 cm diameter) provided surface area for colonization by nitrifying bacteria. The water heating system was composed by thermostat-heaters (300 W in a relation 1W L^{-1}), regulated at 24, 28 or 32°C. Water recirculation was maintained by a submerged pump (80 W and capacity of 3500 L h^{-1}), which was

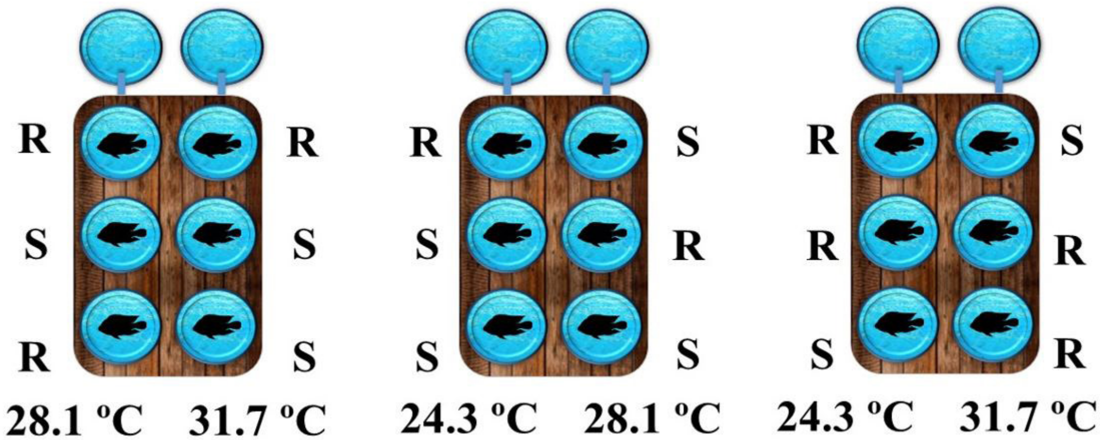

Figure 1. Schematic representation of the experimental design composed of six independent water recirculation systems. The letter R represents the experimental units that received a fixed rate ration, whilst the letter S indicates the units that received ration until apparent satiety.

also responsible for the hydrodynamics of the system. In each sump tank, an aeration system was installed with porous stones, maintained by a 2-CV radial compressor unit (blower), located external to the laboratory.

Water Quality

Daily, a digital oximeter (YSI®, model DO200A) was used to verify water temperature (°C) and dissolved oxygen (mg L^{-1}), while pH was measured by a pHmeter (ALFAKIT®, model AT-355) in each experimental unit. Nitrogen compounds and orthophosphate concentrations were measured weekly in each RAS by means of colorimetric analysis (ALFAKIT®, model AT-100P), while alkalinity was evaluated by volumetric titration, using a commercial analysis kit ALFAKIT® 2058 and 2460. In order to avoid solids accumulation in the systems, a daily maintenance was performed in the mechanical filter.

The water temperature in each experimental setup was found to be 24.3, 28.1 and 31.7°C, with a 4.0°C different between treatments (Table 1).

Feeding regime

In view of the lack of information on daily feeding rates for *G. brasiliensis*, it was determined a feeding rate of 4% of the live weight biomass in one treatment, whilst in the other treatment, feed was supplied until apparent satiety, i.e., when a reduced agitation in search of food was observed in the experimental tanks.

Feeding was made three times a day (8:00 h, 13:00 h and 17:00 h). An isoproteic and isoenergetic extruded diet (4 mm) containing 32% of crude protein (CP) and 6% of ether extract was used, and biometrics were performed every 15 days, with the necessary adjustments of the feed amounts being performed subsequently.

Growth performance and somatic indexes

After the experimental period, biometrics were performed with all fish, in order to verify their growth parameters. For the evaluation of somatic indexes, three fish from each experimental unit were randomly selected, totaling 54 animals evaluated. The fish were then euthanized using eugenol, and then an incision in the ventral region was made for organs collection.

Biometric and feeding data were used for the evaluation of the following growth performance indexes: survival (SURV (%) = (final number of fish / initial number of fish) x 100); final weight (FW); weight gain (WG = final weight – initial weight); apparent feed conversion (AFC = feed consumption / weight gain); specific growth rate (SGR = [(ln final weight – ln initial weight) / experimental time] x 100); Kn relative condition factor (Kn = observed weight / expected weight Y), being $Y = a*x^b$, where a is the intercept and b is the coefficient of regression.

For the evaluation of somatic indexes were calculated: hepatosomatic index (HSI = (liver weight / total weight) x 100); visceral fat (VF = (visceral fat weight / total weight) x 100); and carcass yield (CY = (weight of gutted fish with head and fins / total weight) x 100).

Statistical analysis

The effects of water temperature and feeding regimes on growth parameters at the end of the experimental period were evaluated by means of a variance analysis (two-way ANOVA), as well as by a unilateral ANOVA regarding the water quality parameters over time, after meeting the premises of normality (Shapiro-Wilk) and homoscedasticity (Levene). Subsequently, the Tukey multiple comparison of means test was performed, considering a 5% probability level (Sokal and Rohlf, 1995). The analyses were performed with the aid of the statistical software Statistica 7.0.

Table 1. Water physico-chemical parameters in the cultivation of *Geophagus brasiliensis* in RAS during 72 experimental days. Values are presented as means ± standard deviation.

Parameters	Treatments			*p* value
	24.3°C	28.1°C	31.7°C	
Temperature (°C)	24.29±0.84^A	28.08±1.02^B	31.71±0.87^C	0.000
Dissolved oxygen (mg L^{-1})	8.32±0.50^A	7.32±0.50^B	6.76±0.48^C	0.000
pH	7.35±0.28	7.32±0.21	7.48±0.18	NS
Total ammonia (mg L^{-1})	0.23±0.44	0.25±0.41	0.36±0.50	NS
Nitrite (mg L^{-1})	0.00±0.00	0.00±0.00	0.00±0.00	NS
Nitrate (mg L^{-1})	0.25±0.18	0.33±0.50	0.47±0.56	NS
Orthophosphate (mg L^{-1})	1.01±0.37	1.25±0.70	1.47±0.46	NS
Alkalinity (mg L^{-1})	13.11±9.22	30.75±10.16	32.25±9.12	NS

NS: not significant. Means followed by distinct letters in the same line indicate significant differences (p <0.05).

RESULTS

The interaction between water temperature and feeding regimes did not result in significant effects in any of the evaluated indexes (Table 2). Therefore, in order to clarify the obtained results, these were compared considering the effects of feed management and water temperature in fish's growth as isolated variables (Table 3).

Despite being wild-caught fish, the specimens presented high domesticity to the rearing system, with a mean survival of 97.2%. Except for survival and Kn relative condition factor, water temperature variations caused changes in all other parameters evaluated (Table 3). Feeding regime was also found to impact weight gain, final weight, specific growth rate and the hepatosomatic index.

The relation between expected and observed weight is described by the Kn index. From this relation, condition factors close to 1.0 were observed among all treatments, indicating the animals' well-being in the evaluated conditions (Figure 2).

DISCUSSION

The thermal comfort of tropical fish ranges between 26 and 30°C, and it was reported that temperatures below this range cause appetite reduction and a consequent reduced growth, while higher temperatures the appetite is still reduced, but a decreased resistance of the fish to handlings and diseases is verified (SENAR, 2019). In this study, it was possible to observe that even though *G. brasiliensis* is a tropical species, its development does not follow this pattern, seen that the best growth parameters were found when the species was cultivated under 24.3°C.

In the study of Rantin and Petersen (1985), the authors evaluated lethality (L50) of water temperature on *G. brasiliensis* in function of previous acclimatization at a range of 12.5 - 32.5°C, and found that the minimum temperature limit for this species is 7.8°C, while the maximum limit is 38.5°C. The data presented in the present study are in accordance with Rantin and Petersen (1985), as the fish presented high survival (above 90%) in the range between 24.3 and 31.7°C (Tables 2 and 3).

The interaction between temperature and dissolved oxygen may cause stress in fish in situations of scarcity, impairing growth performance (McBryan et al., 2013). However, in the experimental conditions of this study, the different temperatures evaluated presented dissolved oxygen concentrations above 6.5 mg/L in all treatments, supplying the metabolic needs required for an optimal development of tropical fish (SENAR, 2019), thus indicating that under these circumstances, dissolved oxygen in function of water temperature did not cause negative effects on the species' development.

The lower apparent feed conversion (AFC) was observed at 24.3°C (2.42), which was significantly below the one observed by Amaral Júnior et al. (2011), when rearing the *G. brasiliensis* using a pelletized commercial feed with 40% CP, or even live feed (*Daphnia magna*), which resulted in an AFC of 6.0. This fact could be explained by the different feed types and feeding regimes used in these experiments, seen that the extrusion process results in a higher availability of nutrients (Moro, 2015), resulting in higher growth in comparison to animals fed a pelletized diet (Kleemann, 2006; Silva, 2008), even when the fish received a supplementation with live feed.

Despite the high AFC values observed in this study, it is noteworthy that studies developed with tilapia species until the 1990's decade commonly showed high feed conversions, close to 3.0 (Siddiqui et al., 1988; El-Sayed, 1990; Likongwe et al., 1996), and currently this is the most produced species in the world, thanks to significant advances achieved in the whole productive chain. Considering that a specific diet was not used for *G. brasiliensis* and that the animals used in this study were caught from the natural environment, the obtained data are subject to improvement, considering that this species must be properly domesticated and studies thoroughly.

Among the evaluated temperatures, *G. brasiliensis* displayed the highest growth rates and weight gains when reared at low temperatures, different from previous results with other species of tropical fish (Piedras et al., 2005; Oliveira et al., 2013); thus, the thermal comfort of this species might be somewhere near 24.3°C. According to Jobling (1994), fish basal metabolism accelerates with increasing temperatures, which results in higher energy demands for the maintenance of physiological functions and may result in lower available energy for growth. In this regard, this fact was observed in this study, seen that visceral fat indexes were reduced with increased water temperature, possibly in order to supply energetic needs according to the metabolic rate of fish in each treatment.

According to Gómez (2014), fish from unstable habitats that present high oscillations of environmental conditions have a higher tolerance to variations in water temperature. Considering that the fish used in this study were collected from the natural environment, in a spot located in a subtropical region, it is possible that its growth is correlated to biogeographic characteristics.

Table 2. Mean values (± standard deviation) of growth performance variables of *Geophagus brasiliensis* juveniles, in relation to distinct water temperatures and feed management. *(T = rate of 4% of the biomass and S = apparent feed satiety).

Variables	Feed Management*	Water Temperature			Interaction
		24.3°C	28.1°C	31.7°C	
SURV[1] (%)	T	100.00±0.00	90.00±10.00	100.00±0.00	NS
	S	96.67±5.77	93.33±5.77	96.67±5.77	
FW[2] (g)	T	16.44±0.54	15.68±0.01	13.17±0.28	NS
	S	17.36±0.42	16.11±0.19	13.19±0.22	
WG[3] (g)	T	9.60±0.27	8.41±0.56	6.47±0.25	NS
	S	10.56±0.42	9.59±0.30	7.14±0.90	
AFC[4]	T	2.26±0.06	2.99±0.66	3.02±0.11	NS
	S	2.58±0.34	2.89±0.32	2.97±0.25	
SGR[5] (% day^{-1})	T	1.22±0.01	1.13±0.02	0.94±0.03	NS
	S	1.30±0.04	1.22±0.03	0.99±0.04	
Kn[6]	T	1.02±0.07	0.99±0.04	0.93±0.05	NS
	S	1.06±0.08	1.01±0.02	1.02±0.02	
HSI[7] (%)	T	1.65±0.27	1.14±0.07	0.95±0.37	NS
	S	1.88±0.36	1.50±0.12	1.18±0.07	
VF[8] (%)	T	0.80±0.09	0.55±0.55	0.39±0.09	NS
	S	0.84±0.17	0.74±0.12	0.47±0.09	
CY[9] (%)	T	89.87±0.30	91.14±1.54	91.91±0.90	NS
	S	89.53±0.74	90.87±0.96	91.37±0.37	

[1]survival; [2]final weight; [3]weight gain; [4]apparent feed conversion; [5]specific growth rate; [6]relative Kn condition factor; [7]hepatosomatic index; [8]visceral fat and [9]carcass yield. NS = not significant by the Tukey's test (p <0.05).

Table 3. Unfolding of the growth parameters of the cultivation of *Geophagus brasiliensis* (mean values ± standard deviation). FM = Feed management; WT = Water temperature.

		SURV (%)	FW (g)	WG (g)	AFC	SGR (% day^{-1})	Kn	HIS (%)	VF (%)	CY (%)
T		96.66±5.77	15.09±1.51^{B}	8.16±1.41^{B}	2.76±0.50	1.10±0.12^{B}	0.98±0.06	1.25±0.39^{B}	0.58±0.19	90.98±1.27
S		95.56±1.93	15.55±1.87^{A}	9.10±1.61^{A}	2.81±0.32	1.17±0.14^{A}	1.03±0.05	1.52±0.36^{A}	0.68±0.20	90.59±1.04
24.3°C		98.34±2.35	16.90±0.66^{a}	10.08±0.61^{a}	2.42±0.28^{a}	1.26±0.05^{a}	1.04±0.07	1.77±0.31^{a}	0.82±0.12^{c}	89.70±0.54^{b}
28.1°C		91.67±2.35	15.89±0.27^{b}	9.00±0.76^{b}	2.94±0.47^{b}	1.18±0.05^{b}	1.00±0.03	1.32±0.22^{bc}	0.65±0.13^{b}	91.01±1.16^{a}
31.7°C		98.34±2.35	13.18±0.22^{c}	6.81±0.70^{c}	2.99±0.18^{b}	0.97±0.04^{c}	0.98±0.06	1.07±0.27^{c}	0.43±0.09^{a}	91.64±0.68^{a}
p value	FM	NS	0.010	0.001	NS	0.000	NS	0.035	NS	NS
	WT	NS	0.000	0.000	0.027	0.000	NS	0.001	0.000	0.080

Distinct uppercase letters indicate significant differences between feed management, and distinct lowercase letters indicate significant differences in relation to water temperature, according to the Tukey's test at a 5% probability level. For abbreviations, see Table 2.

The hepatossomatic index in this study was approximately twice as large in the treatment where fish were reared at 24.3°C, in comparison to 31.7°C (Table 3). The same relation was observed by Maciel Júnior (2006), who studied tilapia juveniles in temperatures ranging from 20 to 32°C and observed a linear reduction of liver size with increasing water temperature. According to Barroso et al. (2020), higher temperatures accelerate fish metabolism, causing the accumulated energy reserves in the liver to be depleted, thus reducing the HSI.

Regardless of water temperature or feeding regime, visceral fat levels were reduced, with less than 1% in all treatments. Carcass yield also displayed satisfactory productivity indexes, reaching up to 90%, which is similar to the yield of other commercial cichlid species (Honorato et al., 2014; Nogueira et al., 2016).

Under the evaluated conditions, the feeding regime performed until apparent satiety resulted in higher productivity indexes in comparison to the restrictive feeding regime (4% of the biomass). Such behavior might be related to a higher availability of the feed throughout the feeding event. Considering the operational costs and the stress caused to the animals during biometrics for the definition of the amount of feed to be supplied, the offer of feed until apparent satiety is recommended for *G. brasiliensis*, as also recommended by Santos (2008) when evaluating the ideal feed rates and frequencies for tilapia juveniles. The author observed

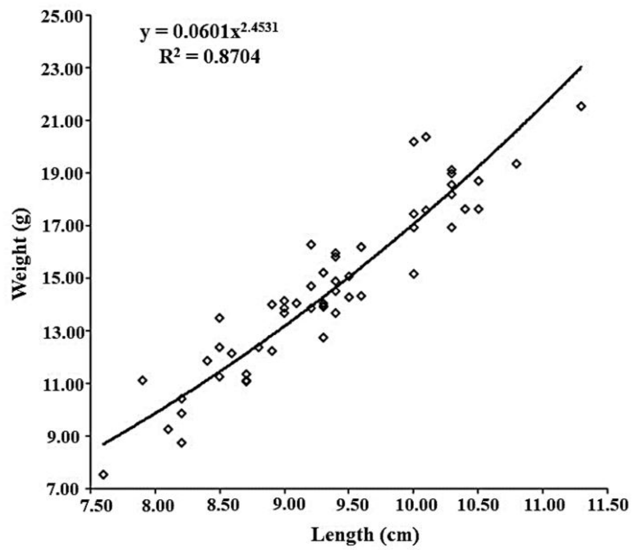

Figure 2. Length-weight relationship in *Geophagus brasiliensis* cultivated in RAS - Recirculating Aquaculture System.

higher productivity indexes when fish were fed three times a day until apparent satiety. Considering the lack of information regarding nutritional aspects of this species, further studies must be conducted to determine feeding rates and feeding frequencies, in order to seek for an optimal production when fish are not fed until satiety, which may result in lower final costs.

From the weight-length relationship, it was observed a coefficient of allometry of 2.4531 for *G. brasiliensis* (Figure 2), while Santos et al. (2002) observed a coefficient of 2.8541 for the same species in natural conditions. Both results (<3.0) indicate a negative allometric growth, i.e., there is a greater increase in length in comparison to weight, being within the range found for most species (2.5 - 4.0) (Le Cren, 1951).

According to Santos et al. (2004), the allometry coefficient is modulated by environmental conditions, while Rossi-Wongtschwki (1977) reported that it is linked to the animal's genetics, and do not vary in function of metabolic or environmental processes. Given the use of wild-caught specimens in this study, the observed growth results may have a direct connection to the inherent characteristics of the studied population. In this sense, the fish used in this study may have presented such a productive performance due to a genetic inheritance to adapt to the lower temperatures that are typical from the south region of Brazil. Therefore, the observed growth performance in the tested conditions could possibly be improved in case the species is domesticated or genetically improved, or even if a specific diet is developed, making it more apt to be reared in aquacultural enterprises.

CONCLUSION

Geophagus brasiliensis juveniles present higher productivity indexes when reared at temperatures close to 24.3°C and fed until apparent satiety.

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