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Weight and body yield of selectively bred tambaqui *(Colossoma macropomum)* farmed in different environments

REBECA MARCOS, RUY A.C. CORRÊA FILHO, JANESSA S. DE ABREU, GUILHERME N. SERAPHIM, ANA C.C. SILVA, DARCI C. FORNARI, RICARDO P. RIBEIRO, YASMIN A. FERREIRA, KAMYLA F.S. GAMA & JAYME A. POVH

Abstract: The objective of this study was to evaluate the weight and body yield of two families of selectively bred tambaqui farmed in different environments. Two families (FA and FB) were reared in the municipalities (environments) of Santo Antônio de Leverger (MT) and Campo Grande (MS) for 431 days. Pre-bleeding weight, body yield, and the interaction effect between families and environments on these traits were investigated. No interaction effect between the evaluated families and environments was detected on the evaluated traits. Pre-bleeding weight did not differ significantly between the families in MT (FA: 2,421.7g; FB: 2,478.0g) or in MS (FA: 1,138.7g; FB: 1,389.8g), but the fish from MT had a higher (P<0.05) pre-bleeding weight than those farmed in MS. The visceral fat yield (considering the two environments) was higher (P<0.05) in FB family (3.8%) than in FA family (3.3%).Fish from MS showed higher (P<0.05) offal yield (10.6%) and visceral fat yield (3.9%) but a lower clean-trunk yield (70.6%) than the tambaqui farmed in MT (offal: 7.7%; visceral fat: 3.1%; and clean trunk: 72.6%). In conclusion, the MT environment provides higher pre-bleeding weight and clean-trunk yield and lower offal and visceral-fat yields than the MS environment.

Key words: Aquaculture environment, carcass yield, genotype × environment interaction, native fish.

INTRODUCTION

The tambaqui (*Colossoma macropomum* Cuvier, 1818) is one of the most important freshwater fish in South America, especially in Brazil, whose total production in 2016 was 137,000 t (IBGE 2018). This species belongs to the order Characiforme, the family Characidae, and the sub-family Myleinae. Autochthonous to the Amazon River basin, tambaqui is widely distributed across the tropical part of South America and Central Amazon (Taphorn 1992, Silva et al. 2000, Val et al. 2000, Reis et al. 2003, Araújo-Lima & Gomes 2013).

In production terms, tambaqui has good performance and economic viability, is resistant to the imposed management conditions, and is widelyaccepted by the consumer market (Gomes et al. 2003, Gonçalves et al. 2003, Nunes et al. 2006, Araújo-Lima & Gomes 2013). These traits arouse great commercial interest in the species, which culminated in the development of a selective-breeding program for tambaqui in the year 2008 aiming at the selection of fish with high weight gain. The first selectively bred generation (G1) of tambaqui was obtained in the reproductive season of 2011/2012, and the second in 2015 (Marcos et al. 2016).

Body yield is a parameter that makes it possible to determine whether the higher weight gain of generations from selective breeding is being converted into increased productivity of edible parts or in non-edible parts (ex: offal, visceral fat, and head), thereby indicating the efficiency of the program. The study of body yield in fish is important from the economic standpoint because, based on this information; both the producer and the processing unit can assess the production yield as well as the final quality of the fish (Silva et al. 2009, Turra et al. 2012, Honorato et al. 2014).

This is the first investigation of weight and body yield in fish originating from a Brazilian native species breeding program. The aim of this study was to evaluate the weight and body yield of two families of selectively bred tambaqui farmed in different environments.

MATERIALS AND METHODS

Location and animals

The fish were farmed in two different locations: in the Fish-Farming Unit of the Experimental Farm of the Universidade Federal de Mato Grosso, located in the municipality of Santo Antônio de Leverger (average annual temperature: 26.1°C; average annual precipitation: 1454.5 mm; and average annual insolation: 2270.9 h) - MT, Brazil (15° 51' 56'' S and 56° 04' 36'' W); and in the Experimental Fish Farming Unit of the Universidade Federal de Mato Grosso do Sul, located in the municipality of Campo Grande (average annual temperature: 23.3°C; average annual precipitation: 1455.3 mm; and average annual insolation: 2600.6 h) - MS, Brazil (20° 29' 59'' S and 54° 36' 53'' W) (INMET 2018). The experimental period was 431 days (MT: November 2015 – January 2017; MS: December 2015 – February 2017). This study was approved by the Ethics Committee on Animal Use of UFMS (approval no. 641/2014 – CEUA, FAMEZ, UFMS).

The second generation (G2) of selection for weight gain in tambaqui was formed in the reproductive season of 2015 in the breeding center located in the northern region of Mato Grosso - MT, Brazil (12°51'56,40''S and 55° 50'03,30''W), according to the reproduction protocol of Woynarovich & Horváth (1983). The two G2 families (FA and FB) evaluated in this experiment originated from the crossing of males and females from the first generation (G1) of distinct families (female from one family × male from another family). The incubation management until identification (VERI-TAG microchip, 134.2 Khz, anti-migration) of the fingerlings was applied as described by Marcos et al. (2016).

Experimental units, feeding, and water analysis

After individualization, the FA and FB tambaqui families were distributed into two different environments for the experiment: Santo Antônio de Leverger, Mato Grosso, in the state of Mato Grosso (MT), and Campo Grande, in the state of Mato Grosso do Sul (MS). A total of 1,200 fish with an initial live weight of 130.2 ± 1.9 g and total length of 21.0 ± 1.8 cm were assigned at random to the two farmed sites, with 600 fish in each environment (MT and MS). In the two locations, the fish were allocated to two ponds with 10% water renewal per day, each of which received 150 fish of each family. A final biomass of 0.8 kg fish/m^2 was estimated in both production environments.

All fish were fed a commercial extruded diet (32% crude protein, 6.5% ether extract, 4% crude fiber, 14% mineral matter, and 88% dry matter) twice daily (09h00 and 16h00). The diet pellet size was adjusted according to the production phase. Feed was supplied to satiety and interrupted based on observations of the feeding behavior.

Water parameters were measured weekly throughout the experimental period. In the ponds of Santo Antônio de Leverger (MS), temperature and dissolved oxygen were measured with a digital oxymeter (Yellow Springs Instruments - YSI Pro 20) and the pH was read using a digital pH meter (Quimis® Q400BC). In the ponds of Campo Grande (MS), the same analyses were carried out using a multi-parameter meter (YSI Professional Plus). Total alkalinity (based on the methyl orange indicator solution) and non-ionized ammonia (Emerson et al. 1975) were also measured in both environments.

Slaughter and determination of body yield

Sixty fish were slaughtered in each experimental location (MT and MS), consisting of 30 of FA family (15 from each pond) and 30 of FB family (15 from each pond).

For slaughter, the fish were stunned by a thermal shock by being fully immersed in water and ice at a temperature between 2 and 4 °C for ten minutes. Right after slaughter, the fish were decapitated. After 2 minutes the bleeding, the fish were weighed again post-mortem for the removal of scales, skin, fins (trimmings), and offal. Visceral fat, head, and, lastly, the clean trunk, were then separated. All processed fish parts were weighed individually to calculate the yield. This part of processing was entirely manual, following similar hygiene procedures as those adopted by the fish industry, with previous sanitation of the area and utensils used as well as use of appropriate clothing by the handler (employee), who was properly trained.

Pre-bleeding weight and the yield of the following parts were measured: bled carcass (whole fish after bleeding for two minutes post-slaughter), offal (content of the coelomic cavity), visceral fat (fat layer around the offal and abdominal wall), head (sectioned from the body at the junction with the spine including the gills), and clean trunk (bled carcass – (head + offal + visceral fat)). The yield was calculated in percentage terms relative to the total chilled fish weight (pre-bleeding), given by the following equation: YEP (%) = (WEP/PBW) × 100, where YEP = yield of the evaluated part (bled carcass, offal, visceral fat, head, or clean trunk); WEP = weight of the evaluated part; and PBW = pre-bleeding weight.

Statistical analysis

The experiment was set up as a completely randomized design with a 2 × 2 factorial arrangement represented by two production locations (MT and MS) and two selectively bred families (FA and FB). Each tambaqui was considered a replicate (the fish were individualized with microchips). Body yield data were subjected to analysis of variance, whose causes of variation were the effects of family (FA and FB), location (MT and MS), family × location interaction, and covariable (pre-bleeding weight). All analyses were carried out using the GLM procedure of SAS software v. 9.0. ANOVA's "F" test was applied at the 5% probability level for comparisons between the families and between the locations.

RESULTS

In the ponds of Santo Antônio de Leverger (MT), the initial (November 2015) temperature was 24.7 °C, which rose continuously until March2016 (31.0 °C), dropped in the winter (24.6 °C), and increased again at the end (January 2017) of the experiment (28.5 °C). Dissolved oxygen was at a moderate concentration (2.7 mg/L) at the start of the experiment, with peaks of extreme variation throughout the experimental period (1.2 mg/L in February to 7.2 mg/L in July), and reached a moderate concentration again at the end (2.2 mg/L). pH was moderate at the start of the experiment (8.1), with medium variations over its course (6.2 in December to 8.9 in July) and lower values at the end of the experiment (6.4) (Figure 1).

In the ponds of Campo Grande (MS), the temperature at the onset (December 2015) of the experiment was 26.3 °C, which remained stable until March 2016 (26.0 °C), declined markedly in the winter (19.8 °C), and rose again at the end (February 2017) of the experiment (27.0 °C), always at a lower magnitude than those observed in MT. Dissolved oxygen was higher at the beginning (3.4 mg/L) than at the end of the experiment (1.5 mg/L), with great variations throughout the experimental period (1.5 mg/L in February to 8.7 mg/L in September). pH varied little throughout the experiment (8.3 at the start to 7.9 at the end of the experiment) (Figure 1).

Total alkalinity was 28.2 ± 14.4 mg/L and 58.8 ± 4.9 mg/L in the MT and MS environments, respectively. The concentration of non-ionized ammonia in MT and MS was 0.0025 ± 0.0034 mg/L.

There was no interaction effect between families and production environments on the evaluated body yields (Table I). The pre-bleeding weight of the fish of the FA (2421.7 ± 435.4 g) and FB (2478.0 ± 298.0 g) families from the MT location did not differ significantly. Likewise, the pre-bleeding weight of the fish of the FA (1138.7 ± 160.5 g) and FB (1389.8 ± 230.0 g) families from MS did not differ significantly. By contrast, the pre-bleeding weight of the fish of the FA and FB families was higher (P<0.05) in MT than in MS.

Visceral fat yield was higher (P<0.05) in FB family as compared with FA. The other measured yields did not differ statistically between the two families. Fish farmed in MS had higher (P<0.05) offal and visceral-fat yields, while those farmed in MS showed a higher (P<0.05) clean-trunk yield. The bled carcass and head yields did not differ significantly between the fish farmed in the two environments (Table I).

DISCUSSION

This is the first study investigating the body yield of selectively bred tambaqui reared in two environments. The families did not show significant differences for the pre-bleeding weight, regardless of the production site. However, the fish farmed in MT stood out for being almost twice as heavy as the fish from MS.

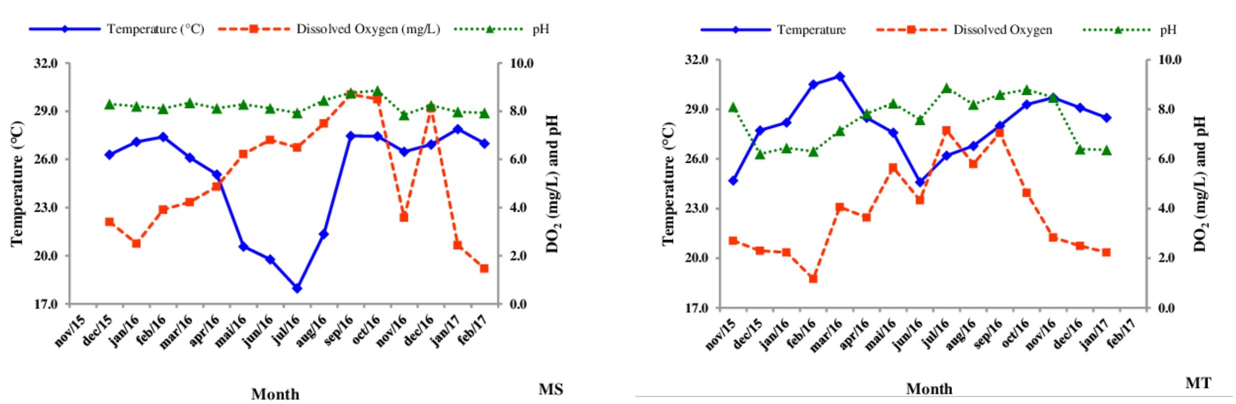

Figure 1. Mean temperature (ºC), dissolved oxygen (DO_2), and pH of the water in the excavated tanks for the farming of the tambaqui (*Colossoma macropomum*) families (FA and FB) from the second generation of selective breeding, cultivated for 431 days, in Santo Antônio de Leverger (MT: Mato Grosso) and Campo Grande (MS: Mato Grosso do Sul).

Table I - Body yields of two tambaqui (*Colossoma macropomum*) families (FA and FB) from the second generation of selective breeding, farmed in excavated ponds for 431 days, in Santo Antônio de Leverger (MT: Mato Grosso) and Campo Grande (MS: Mato Grosso do Sul).

		Yield (%)				
		Bled carcass	**Offal**	**Visceral fat**	**Head**	**Clean trunk**
Family	**FA**	97.5 ± 0.7A	9.1 ± 0.6A	3.3 ± 0.6B	16.6 ± 0.6A	71.9 ± 1.2A
	FB	97.3 ± 0.8A	9.3 0.8A	3.8 ± 0.4A	16.5 ± 1.4A	71.3 ± 1.9A
Location	**MT**	97.4 ± 1.7a	7.7 ± 0.9b	3.1 ± 0.6b	16.7 ± 1.6a	72.6 ± 2.5a
	MS	97.3 ± 1.6a	10.6 ± 1.1a	3.9 ± 0.8a	16.5 ± 1.6a	70.6 ± 2.4b
	Location × Family (P-value)	0.0658	0.7906	0.2051	0.8929	0.3246
	CV (%)	1.35	9.47	18.38	8.16	2.87

Table caption: Means followed by uppercase letters compare families regardless of location, and means followed by lowercase letters compare locations regardless of family. Common letters indicate that means do not differ statistically, according to ANOVA's "F" test (P<0.05).

This difference in final weight between the fish farmed in the two environments corroborates the influence of temperature on the development of this species, with higher temperatures (MT) leading to higher pre-bleeding weights in both families. Nevertheless, other environmental factors might have contributed to the higher pre-bleeding weights of the families in the MT location.

Results observed for the water temperature in the ponds in MT revealed a variation of 6.4 °C during the 431 experimental days. The lowest recorded temperature occurred in the winter (24.6 °C), albeit near the range deemed adequate by Boyd (1998) for tropical fish (25.0 to 32.0 °C). In the MS ponds, the temperature variation was 9.9 °C in the same experimental phase, which was much higher than that observed in MT. In the winter, the minimum temperature was 18.0 °C, which corresponds to a 6.6 °C lower temperature in comparison with MT in the same period, and which is farther from the temperature range considered ideal for topical fish. This fact had a negative impact on the pre-bleeding weight of the families farmed in MS.

Dissolved oxygen in the water remained at an adequate concentration or close to the adequate concentration (above 5 mg/L) (Boyd 1998) in the MS location in relation to MT. However, in both locations, there were great fluctuations in the oxygen concentration throughout the experimental period. This situation may occur in semi-intensive production systems (Ribeiro et al. 2001, Rodrigues et al. 2016), especially in long production periods, as was the case of the present study (431 days). Given the low density of fish used (we used the density recommended for a semi-intensive system without oxygen supplementation) (Ribeiro et al. 2001, Sousa et al. 2020) and the tolerance of tambaqui to low oxygen levels (Araújo-Lima & Gomes 2013), this characteristic might have not had the same impact as water temperature on the pre-bleeding weight and body yield of the fish in the different locations.

The water pH in both environments (MT and MS) throughout the experimental period was within the range of 6 to 9 recommended by Boyd (1998) for tropical fish, and the two environments showed close values. Total alkalinity and ammonia (non-ionized) values were within the ranges deemed adequate for tropical fish, which are above 20 mg/L and below 0.1 mg/L, respectively (Boyd 1998). Therefore, these water characteristics must have not interfered with the pre-bleeding weight and body yield of the fish farmed in the two locations.

The FA family did not show significant differences from the FB family for offal yield, but visceral fat yield in the FA family was higher than that obtained by the FB family. Although this result did not lead to a higher yield of clean trunk, the higher percentage of visceral fat may

incur deductions in the price paid by packing plants. In this regard, results can be used to guide future breeding programs aimed at the production of families with higher clean-trunk yield and/or lower incorporation of visceral fat.

The higher offal yield in the abdominal cavity of the fish from MS in comparison with those farmed in MT shows that temperature conditions lower than those recommended for the development of tambaqui, impairing their body development. However, other environmental factors must be exerting an influence, although there are no scientific reports regarding their effect on the studied variables. This finding is confirmed by the higher percentage of visceral fat and lower percentage of clean trunk obtained by the fish farmed in MS than those farmed in MT.

A higher percentage of offal yield (15.5%) was obtained by Lima et al. (2012), and a higher percentage of visceral fat (almost twice higher: 6.0%) was obtained by Fernandes et al. (2010) for tambaqui (non-selectively bred) compared with families of selectively bred tambaqui examined in the present study. Although greater offal deposition is common in farmed fish due to restricted movement (Castelo et al. 1980, Arbeláez-Rojas et al. 2002), the present results indicate that this body yield trait might be improved through breeding. However, selectively-bred families must be evaluated together with non-selectively bred tambaqui (which was not possible in the present experiment) in the same environment and under equal management conditions (especially feeding), since many variables can affect those traits.

Although head yield was not significantly different between the families and locations, selectively bred fish have been found to have a lower head yield when compared with their non-bred versions, as shown in the studies of Lima et al. (2012), who reported head yields of 20.8%. This is an important observation, since lower head yields mean improved utilization of the edible portion (Vandeputte et al. 2017). Future analyses under similar farming conditions for tambaqui (bred and non-bred) are necessary to examine possible reductions in head yield in the selectively bred fish.

The higher clean-trunk yield of the tambaqui from MT results in better utilization of the fish by packing plants and by the consumer. This finding is of great importance, since it means 2.0% more edible parts in fish from MT than in those farmed in MS, which reinforces the importance of the environment in tambaqui farming. Irrespective of family and location, the clean-trunk yield of the selectively bred fish was much higher than that described in other studies with non-selectively bred tambaqui; e.g., Fernandes et al. (2010) (60%) and Lima et al. (2012) (66.6%). Future analyses of selectively bred families with a group of selectively bred fish farmed in the same environment and under the same management conditions may indicate if those differences originate from selective breeding or other factors such as nutrition and water characteristics.

Breeding programs can provide continuous gains, which may vary from 8 to 12% per generation (Nguyen 2016). The tambaqui showed that such desirable gains can be achieved by native fish. (Marcos et al. 2016). Moreover, the present study demonstrated that pre-bleeding weight is not affected by the families evaluated in the tambaqui selective-breeding program, but higher values are obtained in the production conditions of the MT location. Further, the fish farmed in that location had lower offal and visceral-fat yields and a higher clean-trunk yield. Selectively bred families do not have their body yield traits affected by the genotype × environment interaction.

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REBECA MARCOS[1]
https://orcid.org/0000-0001-9925-6062

RUY A.C. CORRÊA FILHO[1]
https://orcid.org/0000-0002-4662-5247

JANESSA S. DE ABREU[2]
https://orcid.org/0000-0002-2129-2538

GUILHERME N. SERAPHIM[1]
https://orcid.org/0000-0001-8479-0932

ANA C.C. SILVA[1]
https://orcid.org/0000-0002-7311-1452

DARCI C. FORNARI[3]
https://orcid.org/0000-0001-5466-2235

RICARDO P. RIBEIRO[4]
https://orcid.org/0000-0001-7752-3692

YASMIN A. FERREIRA[1]
https://orcid.org/0000-0002-0535-1219

KAMYLA F.S. GAMA[2]
https://orcid.org/0000-0003-3244-9454

JAYME A. POVH[1]
https://orcid.org/0000-0003-3315-018X

[1]Faculdade de Medicina Veterinária e Zootecnia, Universidade Federal de Mato Grosso do Sul, Avenida Senador Filinto Müller, 2443, 79074-460 Campo Grande, MS, Brazil

[2]Faculdade de Agronomia e Zootecnia, Universidade Federal de Mato Grosso, Avenida Fernando Corrêa da Costa, 2367, 78060-900 Cuiabá, MT, Brazil

[3]Auburn University, School of Fisheries, Aquaculture and Aquatic Sciences, Auburn, AL 36849, USA

[4]Universidade Estadual de Maringá, Departamento de Zootecnia, Avenida Colombo, 5790, 87020-900 Maringá, PR, Brazil

Correspondence to: **Jayme Aparecido Povh**
E-mail: jayme.peixegen@gmail.com

Author contributions

Each author presented relevant contribution to elaboration of the present manuscript as follows: Rebeca Marcos conducted practical activities in all experimental stages in Cuiabá (MT) and Campo Grande (MS), as well, prepared figures and tables and wrote the paper. The main responsible for the final text. Ruy Corrêa Filho (co-advisor), conducted the statistic, data analysis, interpretation, discussion of the results and reviewed drafts of the paper. Janessa Abreu conducted the orientation of the activities and monitored all the experimental stages in Cuiabá (MT). Guilherme Seraphim conducted practical activities of biometrics, management and slaughter of fish in Campo Grande (MS). Ana Carla Silva conducted practical activities of biometrics, management and slaughter of fish in Cuiabá (MT). Darci Fornari was responsible for the production of the genetically improved tambaqui families and contributed with some financial support. Ricardo Ribeiro contributed to the studies in the formation of the tambaqui genetic improvement program and to the final review of the article. Yasmin Ferreira conducted the laboratory work to analyze body performance in Campo Grande (MS). Kamyla Gama conducted the laboratory work to analyze body performance in Cuiabá (MT). Jayme Povh conducted the orientation of the activities, monitored all the experimental stages (in MS), sampling design, methodology and discussion of the results. Assisted in the writing of the final manuscript. All authors revised the manuscript and approved the final version.