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PRODUCTION PERFORMANCE OF TAMBAQUI JUVENILES SUBJECTED TO SHORT FEED-DEPRIVATION AND REFEEDING CYCLES

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ABSTRACT

This study proposes to investigate whether short restricted-feeding cycles during the pre-fattening phase of tambaqui (*Colossoma macropomum*) juveniles affect their production performance and yield in a semi-intensive system and if this practice can be introduced as an alternative to reduce production costs in the pre-fattening phase of this species. The fish (8.07 ± 0.07 g) were subjected to short restricted-feeding periods under controlled laboratory conditions (experimental boxes) for 60 days (Phase I). Three feeding strategies were tested, namely: dairy feeding (Control); five days of feeding followed by two days of deprivation (5F/2D); and two days of feeding followed by four days of deprivation (2F/4D). Subsequently, the fish from each treatment (feeding regimes) evaluated in Phase 1 were transferred to an excavated pond with low water exchange and no supplemental aeration (semi-intensive system) where they were fed continuously for 65 days (Phase II). At the end of both phases, performance, metabolic and hematological parameters and the centesimal composition of the filets were analyzed and an economic assessment was undertaken based on the total operating cost (TOC) of production in the different feeding regimes. The restricted-feeding cycles 2F/4D and 5F/2D (Phase I) affected the performance of the fish, which showed lower daily weight gains and specific growth rates (SGR), resulting in lower viscerosomatic index (VSI) and morphometric measurements. However, apparent feed conversion did not differ across the treatments. The feed-deprived fish used triglycerides as an energy source, maintaining their blood glucose levels close to those of the continuously fed group (control). When they started to be feed daily for 65 days (Phase II), the metabolic (triglycerides) and hematological parameters (hematocrit and hemoglobin) equaled those of control group. Nevertheless, their final weight and morphometric measurements were lower than those of non-restricted feed, indicating a partial compensatory growth in tambaqui juveniles. Short restricted-feeding cycles applied in the pre-fattening phase for 60 days negatively affected performance and led to metabolic and hematological alterations in tambaqui (*Colossoma macropomum*) juveniles. Although these short restricted-feeding cycles resulted in less expenditure on labor and feeding, the fish under those conditions did not develop equally to those fed daily, culminating in less biomass produced during the fattening period in a semi-intensive system for 65 days. Ultimately, this led to a higher total operating cost per gram of produced fish, demonstrating the economic infeasibility of this practice for tambaqui juvenile production.

Key words: economic analysis; feeding management; centesimal composition; blood parameters; fish farming; *Colossoma macropomum*.

PRODUTIVIDADE DE JUVENIS DE TAMBAQUI SUBMETIDOS A CICLOS CURTOS DE RESTRIÇÃO ALIMENTAR E REALIMENTAÇÃO

RESUMO

Nesta pesquisa foi avaliado se ciclos curtos de restrição alimentar durante a recria de juvenis de tambaqui (*Colossoma macropomum*) afetam o desempenho zootécnico e a sua produtividade em sistema semi-intensivo e se essa prática pode ser apresentada como alternativa para reduzir os custos de produção na fase de recria desta espécie. Os peixes (8,07 ± 0,07 g) foram submetidos à curtos períodos de restrição alimentar em condições laboratoriais controladas (caixas experimentais) por 60 dias (Fase I) em três estratégias alimentares: alimentação diária (Controle); cinco dias de alimentação seguido de dois dias de jejum (5A/2J) e dois dias de alimentação seguido de quatro dias de jejum (2A/4J). Posteriormente, os peixes de cada um dos tratamentos (regimes alimentares) avaliados na Fase 1 foram transferidos para viveiro escavado, com baixa renovação de água e sem aeração suplementar (sistema semi-intensivo), onde foram alimentados continuamente por 65 dias (Fase II). Ao final de ambas as fases, foram avaliados parâmetros de desempenho, metabólicos, hematológicos, composição centesimal do filé e foi realizada análise econômica por meio do custo operacional total (COT) da produção nos diferentes regimes alimentares. Os ciclos de restrição alimentar 5A/2J e 2A/4J (Fase I) afetaram o desempenho dos peixes, que apresentaram menor ganho de peso diário e menor taxa de crescimento específico (TCE), resultando em menor índice viscerossomático (IVS) e menores medidas morfométricas. No entanto, a conversão alimentar aparente não diferiu entre os tratamentos. Os peixes restritos usaram triglicerídeos como fonte energética, mantendo as concentrações de glicose no sangue próximas às dos animais alimentados continuamente (controle). Quando passaram a ser alimentados diariamente por 65 dias (Fase II) equipararam parâmetros metabólicos (triglicerídeos) e hematológicos (hematócrito e hemoglobina) aos do grupo controle. No entanto, o peso final e medidas morfométricas foram menores quando comparado aos dos peixes não restritos, evidenciando crescimento compensatório parcial dos juvenis de tambaqui. Ciclos curtos de restrição alimentar aplicados na recria por 60 dias afetaram negativamente o desempenho e promoveram alterações metabólicas e hematológicas em juvenis de tambaqui (*Colossoma macropomum*). Embora estes ciclos curtos de restrição alimentar tenham proporcionado menor gasto com mão de obra e ração, os peixes nestas condições não se desenvolveram da mesma forma que os alimentados diariamente, resultando em menor biomassa produzida durante engorda em sistema semi-intensivo por 65 dias, o que levou a maior custo total operacional por grama de peixe produzido, evidenciando não ser uma prática viável economicamente para produção de juvenis de tambaqui.

Palavras-chave: análise econômica; manejo alimentar; composição centesimal; parâmetros sanguíneos; piscicultura; *Colossoma macropomum*.

INTRODUCTION

Brazil produced approximately 691,700 t of fish in the year 2017, which represents a growth of 8% compared with the previous year. The production of native species accounted for 43.7% of the national total, led mainly by tambaqui (*Colossoma macropomum*) farming (Peixe BR, 2018). This species is characterized by its hardiness, rapid growth and good acceptance in the Brazilian market (Pedroza Filho et al., 2016). Because of these valuable characteristics, it is largely cultivated nationwide.

In view of the expansion of fish production, one of the main aspects of management to be evaluated is feeding, because of its representativeness in costs (Barros and Martins, 2012; Sabaini et al., 2015; Brabo et al., 2017), followed by man labor and purchase of fingerlings. The significance of those expenses varies according to the rearing phase and the species in question (Sanches et al., 2013; Brabo et al., 2015; Costa et al., 2016). In this regard, restrictive feeding regimes may have a direct impact on the costs of fish farming in that they allow for a reduction of the total volume of feed consumed in every production cycle as well as a reduction of man labor and use of equipment/materials.

In fish farming, feeding programs involving periods of feed deprivation can be adopted, since many species have a mechanism of compensation of the growth-delay period when fed to satiety after the end of fasting (Navarro and Gutiérrez, 1995; Ali et al., 2003). The adoption of management strategies involving feed restriction and refeeding has been described by many authors aiming to improve the productive performance of several fish species; e.g. cyprinids (Dar et al., 2018), tilapia (Palma et al., 2010), trout (Nikki et al., 2004), sturgeon (Morshedi et al., 2017), sea bass (Pérez-Jiménez et al., 2007) and also native Brazilian species such as pacu (Ortiz et al., 2008), tambaqui (Ituassú et al., 2004; Santos et al., 2010, 2013), pirapitinga (Rodriguez and Landines, 2011) and matrinxã (Urbinati et al., 2014).

This compensatory growth is typically characterized by hyperphagia, better feed conversion and elevated specific growth rate (Won and Borski, 2013). However, several factors such as species, reproductive state, age, temperature, among others, can affect this growth's compensation level (Navarro and Gutiérrez, 1995).

On these bases, daily feed supply in fish farming started to be questioned. The use of short restricted-feeding cycles could maximize the rates of growth and feed utilization for muscle formation, implicating economic benefits to the producer and to the environment. Although it has been documented that restrictive-feeding programs have positive effects on fish farming, little information exists on its effect on profitability, especially in terms of reduction of operating costs through savings on feeding itself and on the man labor required for feeding.

In this scenario, studies investigating which parameters are influenced during restrictive feeding regimes in fish rearing and their economic impact on the activity are necessary to establish better strategies for their application. The present study was thus carried out to determine whether short restricted-feeding cycles during the pre-fattening phase of tambaqui (*Colossoma macropomum*) juveniles affect their production performance and yield in a semi-intensive system and if this practice can be adopted as an alternative to reduce production costs during the pre-fattening phase of this species.

MATERIAL AND METHODS

Experimental design

The study took place in the Fish Farming Section at the Federal University of Mato Grosso (UFMT), located in Santo Antônio de Leverger – MT, Brazil (15° 51' 56" S and 56° 04' 36" W), in the period of April to August 2017. The experimental procedures were previously approved by the Ethics Committee on Animal Use (CEUF/UFMT; approval no. 23108.186540/2016-44).

The experiment was developed in two phases. Throughout the experimental period, the fish were fed an extruded commercial feed for omnivorous fish (VB Alimentos®, Jaciara, Mato Grosso, Brazil) containing 420 g kg^{-1} crude protein and 70 g kg^{-1} ether extract, with a pellet size of 2 to 3 mm.

In Phase I, which was developed under laboratory conditions for 60 days, no natural food was available to the animals, meaning they were fed only with the feed. A total of 240 tambaqui (*Colossoma macropomum*) juveniles with an initial weight of 8.07 ± 0.07 g (mean ± standard error) was allocated at random to 12 polyethylene cages with 150-L capacity (20 fish per cage) in an open system with recirculation of water collected by a semi-artesian well (exchange rate of 4 L min^{-1}) and constant aeration. The photoperiod was controlled by an automatic illumination system with 12 h of light and 12 h of darkness. Fish were fed *ad libitum* for 60 days, twice daily (09h00 and 15h00), according to the following treatments: daily feed supply (Control); five days of feeding followed by two days of deprivation (5F/2D); and two days of feeding followed by four days of deprivation (2F/4D).

On the 61st day, after a feed-deprivation period of 24 h, the fish (n = 20 per treatment) were anesthetized with eugenol (10 mg L^{-1}), following the methodology of Inoue and Moraes (2007) and weighed. Subsequently, the following variables were measured using a fish measuring device (ictiometer) and a caliper rule: total length (TL), standard length (SL), head size (HS), body height (BH) and body width (BW). Afterwards, the animals had their blood drawn by caudal puncture to evaluate their metabolic and hematological responses and were killed (by sectioning the branchial arch) for removal of offal and filetting.

Next, the remaining fish were marked with a microchip (inserted in the back musculature near the head) and transported inside plastic bags with oxygen and water with common salt (3 g NaCl L^{-1}) to an excavated pond without water exchange or supplemental aeration. The pond was subdivided with screens into three 133-m^2 units, each of which housed fish that were subjected to the same feeding regime in Phase 1 (60 fish/unit), initiating Phase 2 of the experiment, where the treatments consisted of the fish from each of the feeding regimes in Phase 1. In this second phase, which lasted 65 days, the fish were fed daily (DF) with a commercial extruded feed *ad libitum* twice per day (09h00 and 15h00). At the end, the fish from each treatment were captured with a trawl and anesthetized for biometric measurements (weight and body measurements), followed by blood collection. Subsequently, the fish were killed for removal of offal and filleting, in accordance with the procedures described in Phase I.

During the entire experimental period, the following water quality characteristics were evaluated: dissolved oxygen (Phase I: 5.64 ± 0.046 mg L^{-1}; Phase II: 6.56 ± 0.10 mg L^{-1}); temperature (Phase I: 29.57 ± 0.05 °C; Phase II: 24.45 ± 0.21 °C); pH (Phase I: 7.55 ± 0.01; Phase II: 8.22 ± 0.01); total alkalinity (Phase I: 327.06 ± 2.00 mg $CaCO_3$ L^{-1}; Phase II: 119.10 ± 1.11 mg $CaCO_3$ L^{-1}); non-ionized ammonia (NH_3), calculated as proposed by Emerson et al. (1975) (below 0.002 mg L^{-1} in both phases); and water transparency, which was determined only in Phase II, in the excavated pond (59.8 ± 0.67 cm). All parameters were within the adequate threshold for the cultivation of tropical fish as described by Moro et al. (2013).

Performance parameters

Weight and body-measurement data were used to determine the following growth parameters: Daily weight gain (g d^{-1}) = (average final weight – average initial weight)/period in days; Condition factor (K) = weight/(standard length)^3; Specific growth rate (SGR) (%) = [(Ln (average final weight) – Ln (average initial weight))/(period in days)] * 100; Apparent feed conversion (AFC) = feed intake (g)/weight gain (g). The collected offal were weighed to calculate the viscerosomatic index (VSI), using the following formula: VSI = 100 * [offal weight (g)/(body weight (g))].

Blood analyses

Blood was harvested with and without anticoagulant (ethylene diamine tetra acetic acid - EDTA). Hemoglobin (hemoglobin cyanide method, using a Labmax Flex® analyzer and Labtest® commercial kits) and hematocrit (centrifugation in a Spin100 microcentrifuge at 12,000 rpm for 5 min) were determined in the total collected blood. Afterwards, the blood was centrifuged for 10 min at 3000 rpm (Serological Centrifuge Model 80-2B) for separation of serum and plasma. In the blood plasma, glucose was measured by the enzymatic glucose oxidase method and Trinder's reagent (Labtest® commercial kit) and triglycerides were determined by Trinder's reagent enzyme method (Labtest® commercial kit), both using a Labmax Flex® analyzer.

Centesimal analysis

The filets obtained from the fish were used for triplicate analysis of moisture, crude protein, lipid and ash contents according to the Official Physical-Chemical Analytical Methods for the Control of Fish and Derivatives Brasil, 2011).

Economic indicators

As an economic indicator, the total operating cost (TOC) was calculated by following the method proposed by Martin et al. (1994), considering the sum of the effective operating cost—represented by items such as man labor, feeding, purchase of the fingerlings, general inputs, occasional expenses and maintenance of machinery and improvements—and the depreciation values. For the economic analysis of producing tambaqui subjected to short restricted-feeding cycles, we calculated the average TOC (R$ g^{-1}), which was determined as TOC (R$) divided by the obtained final biomass (g).

Statistical analysis

Phase 1 of the study was conducted as a completely randomized design with three treatments (control and two feeding regimes) and four replicates. In Phase II, fish originating from the same feeding regime in Phase 1 constituted one treatment, totaling three treatments with 60 replicates, since each fish individualized with a microchip was considered a replicate. The completely randomized design was also adopted in Phase II, since all replicates were subjected to the same non-perceptible variations. Data were tested for normality and homogeneity of variance and subjected to analysis of variance (ANOVA), and when the F values indicated significant differences, means were compared by Tukey's test (5%). Results were expressed as means ± standard error.

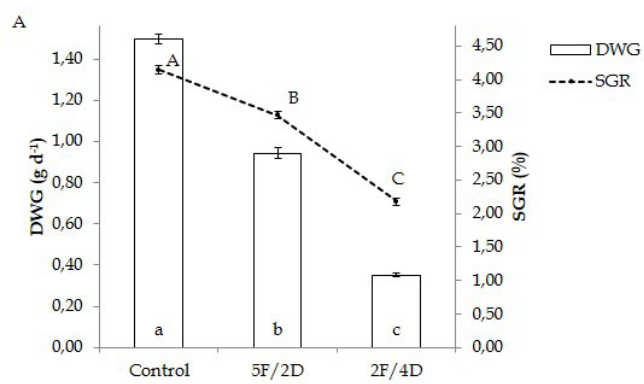
RESULTS

Production performance

The fish subjected to restricted-feeding periods (Phase I) had a lower daily weight gain (DWG) than control group (Figure 1). These effects consequently influenced the final weight of the animals and their viscerosomatic index (VSI), which were significantly lower (Table 1). Restricted feeding in this phase also led to a lower specific growth rate (SGR) (Figure 1A), while apparent feed conversion (AFC) did not differ across the treatments. The condition factor (K) was significantly lower in the fish subjected to the more intense deprivation period (2F/4D) (Table 1).

When the tambaqui were fed continuously for 65 days (Phase II), DWG did not differ across the treatments (Figure 1B), but those subjected to the more intense feed restriction (2F/4D+DF) showed a significantly higher SGR (Figure 1B) and a significantly lower AFC (Table 1). In spite of their higher SGR, final weight was significantly lower when compared with that of the other treatments (Table 1).

Short restricted-feeding cycles (Phase I) affected the morphometric measurements of the juveniles, whose values were lower than those of control group (Table 2). This difference remained even after continuous daily feeding for 65 days (Phase II) (Table 2).



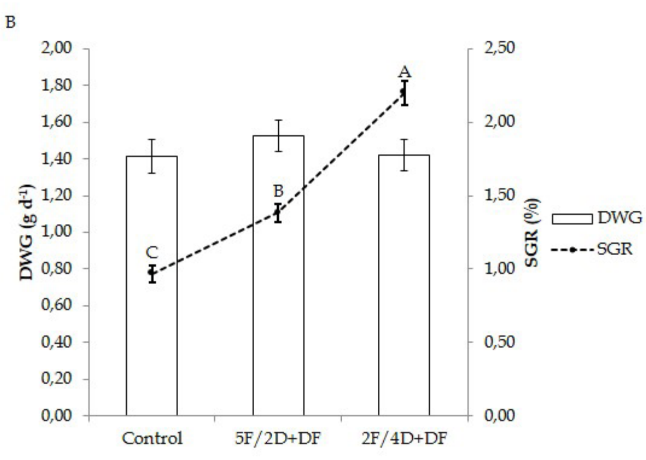


Figure 1. Daily weight gain (DWG) and specific growth rate (SGR) of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (A - Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (B - Phase II). Different lowercase letters indicate significant differences for DWG and different uppercase letters denote differences for SGR, according to Tukey's test (5%). Control: daily feeding (DF); 5F/2D = five days of feeding/two days of fasting; and 2F/4D = two days of feeding/four days of fasting'.

Blood parameters

Short restricted-feeding cycles (Phase I) did not affect blood glucose levels in the fish. The fish that underwent the longer period of feed restriction (2F/4D) showed lower a hematocrit percentage and a lower hemoglobin concentration (Table 3). The feed-deprived fish exhibited lower triglyceride values than those of control group (Table 3). After being fed continuously for 65 days (Phase II), the blood parameters *glucose*, *triglycerides*, *hematocrit* and *hemoglobin* did not differ across the treatments (Table 3).

Centesimal composition

The tambaqui juveniles subjected to short restricted-feeding cycles (Phase I) exhibited a lower concentration of lipids in their muscle (Table 4), although no significant differences were seen in moisture, ash and protein across the treatments. This difference in lipid concentration in the filet in relation to control treatment remained even after the fish were fed continuously for 65 days (Phase II) (Table 4).

Economic analysis

During Phases I and II, general expenses and depreciation were the equal for all treatments. Differences were only found for feeding and man-labor expenses in Phase I, in which the regimes of restricted feeding for 2 days (5F/2D) and 4 days (2F/4D) provided savings in feeding (33.0% and 76.2%, respectively) and labor (33.3% and 66.7%, respectively) costs. Consequently, the TOC of production in the respective treatments were lower (by 17.9% and 37.5%, respectively) than in the daily-feeding strategy (control treatment) (Table 5). However, the feed-deprived fish (5F/2D and 2F/4D) exhibited a lower weight gain and consequently lower final biomass production (by 30.9% and 69.2%, respectively) than those fed continuously (control) (Table 5). In Phase II, the only expense that differed across the treatments was feeding, but, as in Phase I, TOC was reduced in the treatments involving feed restriction (Table 5).

Table 1. Performance of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (Phase II).

		Control	5F/2D	2F/4D
Phase I	Final weight (g)	94.18 ± 2.54[a]	65.05 ± 1.53[b]	29.01 ± 0.63[c]
	K factor	3.19 ± 0.02[a]	3.15 ± 0.02[a]	2.97 ± 0.02[b]
	VSI (%)	7.07 ± 0.19[a]	6.27 ± 0.24[b]	5.48 ± 0.26[c]
	AFC	0.90 ± 0.02	0.91 ± 0.01	0.87 ± 0.02
		Control	5F/2D + DF	2F/4D + DF
Phase II	Final weight (g)	195.26 ± 8.07[a]	162.46 ± 6.01[b]	116.04 ± 5.73[c]
	K factor	3.36 ± 0.03	3.44 ± 0.04	3.35 ± 0.04
	VSI (%)	5.73 ± 0.13	5.97 ± 0.14	6.12 ± 0.37
	AFC	1.05 ± 0.06[a]	1.07 ± 0.06[a]	0.78 ± 0.05[b]

Mean ± standard error. Different letters in the same row indicate significant differences by Tukey's test (5%). K factor = condition factor; VSI = viscerosomatic index; AFC = apparent feed conversion; Control = daily feeding (DF); 5F/2D = five days of feeding/two days of deprivation; and 2F/4D = two days of feeding/four days of deprivation.

Table 2. Morphometric measurements of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (Phase II).

		Control	5F/2D	2F/4D
Phase I	Total length (cm)	17.59 ± 0.16[a]	15.58 ± 0.12[b]	12.18 ± 0.10[c]
	Standard length (cm)	14.42 ± 0.14[a]	12.67 ± 0.10[b]	9.91 ± 0.08[c]
	Width (cm)	1.86 ± 0.03[a]	1.62 ± 0.03[b]	1.20 ± 0.02[c]
	Height (cm)	6.96 ± 0.08[a]	6.06 ± 0.05[b]	4.46 ± 0.04[c]
	Head (cm)	4.95 ± 0.06[a]	4.47 ± 0.06[b]	3.57 ± 0.05[c]
		Control	5F/2D + DF	2F/4D + DF
Phase II	Total length (cm)	20.43 ± 0.24[a]	19.21 ± 0.21[b]	17.31 ± 0.27[c]
	Standard length (cm)	17.90 ± 0.23[a]	16.74 ± 0.20[b]	15.10 ± 0.26[c]
	Width (cm)	2.65 ± 0.06[a]	2.45 ± 0.04[b]	2.16 ± 0.06[c]
	Height (cm)	8.57 ± 0.12[a]	7.97 ± 0.11[b]	7.03 ± 0.14[c]
	Head (cm)	5.55 ± 0.09[a]	5.17 ± 0.08[b]	4.53 ± 0.10[c]

Mean ± standard error followed by different letters in the same row indicate significant differences by Tukey's test (5%). Control = daily feeding (DF); 5F/2D = five days of feeding/two days of deprivation; and 2F/4D = two days of feeding/four days of deprivation.

Table 3. Metabolic and hematological parameters of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (Phase II).

		Control	5F/2D	2F/4D
Phase I	Glucose (mg dL^{-1})	55.21 ± 2.81	58.69 ± 4.63	50.29 ± 4.70
	Triglycerides (mg dL^{-1})	142.53 ± 4.32[a]	104.33 ± 13.50[b]	108.63 ± 9.34[b]
	Hematocrit (%)	33.00 ± 1.66[a]	26.47 ± 1.71[ab]	17.00 ± 3.03[b]
	Hemoglobin (g dL^{-1})	7.60 ± 0.62[a]	7.60 ± 0.58[a]	3.79 ± 0.82[b]
		Control	5F/2D + DF	2F/4D + DF
Phase II	Glucose (mg dL^{-1})	81.00 ± 6.33	92.50 ± 7.51	99.71 ± 12.38
	Triglycerides (mg dL^{-1})	253.15 ± 16.4	219.35 ± 18.98	227.90 ± 15.15
	Hematocrit (%)	41.94 ± 1.01	42.00 ± 0.77	41.29 ± 1.56
	Hemoglobin (g dL^{-1})	12.91 ± 0.76	11.79 ± 0.85	10.24 ± 1.13

Mean ± standard error followed by different letters in the same row indicate significant differences by Tukey's test (5%). Control = daily feeding (DF); 5F/2D = five days of feeding/two days of deprivation; and 2F/4D = two days of feeding/four days of deprivation.

Table 4. Centesimal composition of the filet of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (Phase II).

		Control	5F/2D	2F/4D
Phase I	% Moisture	75.40 ± 0.70	76.96 ± 0.13	77.48 ± 0.35
	% Dry matter	24.60 ± 0.70	23.04 ± 0.13	22.52 ± 0.35
	% Ash*	1.61 ± 0.05	1.65 ± 0.04	1.70 ± 0.03
	% Lipids*	4.65 ± 0.21[a]	2.34 ± 0.13[b]	1.77 ± 0.15[b]
	% Protein*	15.19 ± 0.46	15.84 ± 0.33	16.38 ± 0.20
		Control	5F/2D + DF	2F/4D + DF
Phase II	% Moisture	77.53 ± 0.24	78.18 ± 0.15	77.66 ± 0.25
	% Dry matter	22.47 ± 0.24	21.82 ± 0.15	22.34 ± 0.25
	% Ash*	1.51 ± 0.03	1.50 ± 0.03	1.47 ± 0.04
	% Lipids*	2.25 ± 0.07[a]	1.70 ± 0.12[b]	1.81 ± 0.14[b]
	% Protein*	15.55 ± 0.16	15.17 ± 0.09	15.27 ± 0.09

*Percentage on a wet basis. Mean ± standard error followed by different letters in the same row indicate significant differences by Tukey's test (5%). Control = daily feeding (DF); 5F/2D = five days of feeding/two days of deprivation; and 2F/4D = two days of feeding/four days of deprivation.

Table 5. Production cost of tambaqui (*C. macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days (Phase I) and continuous feeding during rearing in a semi-intensive system for 65 days (Phase II).

Performance indicator	Control		5F/2D		2F/4D	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Number of fish (N)	60	60	60	60	60	60
Weight gain (kg)	5.16	6.06	3.42	5.84	1.27	5.22
Feed intake (kg)	4.64	6.37	3.11	6.25	1.10	4.07
Final biomass (kg)	5.65	11.72	3.90	9.75	1.74	6.96
Feeding period (days)	60	65	40	65	20	65
Economic indicator	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
General expenses* and depreciation (R$)	37.13	16.36	37.13	16.36	37.13	16.36
Feeding expenses (R$)	12.88	17.66	8.63	17.34	3.06	11.30
Man labor expenses (R$)	30.73	30.73	20.49	30.73	10.24	30.73
Total operating cost (R$)	80.74	64.75	66.25	64.44	50.44	58.39
Average total operating cost (R$ g^{-1})	0.012		0.013		0.016	

*Inputs, maintenance and fees. Purchase of fingerlings considered only in Phase I. Control = daily feeding (DF); 5F/2D = five days of feeding/two days of deprivation; and 2F/4D = two days of feeding/four days of deprivation.

Despite the reduction observed in the total operating costs of both phases, the TOC per gram of juvenile produced during short periods of restricted feeding followed by refeeding became 8% (R$0.013) and 25.9% (R$0.016) higher than that of control group (R$0.012), due to the lower biomass produced (Table 5).

DISCUSSION

The restricted-feeding cycles (Phase I) did not interfere with the efficiency of utilization of the supplied feed for transformation into live weight, since no significant difference was found in apparent feed conversion in the restricted and continuously fed fish (control). Nevertheless, the results indicate that performance was affected by the offer of feed, with restriction leading the fish to consume less, which resulted in lower DWG, final weight, VSI, morphometric measurements and SGR. Similar findings were reported by Takahashi et al. (2011), who observed lower weight gain, feed intake and SGR in pacu (*Piaractus mesopotamicus*) (initial weight of 36 g) subjected to short periods of restricted feeding (3 days of feeding / 3 days of fasting) for 36 days. Rodriguez and Landines (2011), in turn, did not find significant differences in the productive parameters of pirapitinga (*Piaractus brachypomus*) (initial weight of 54 g) subjected to short deprivation periods (3 days of feeding / 2 days of fasting) for eight weeks.

The metabolic response in fasting may be influenced by several factors such as species, age, photoperiod, energy reserves, reproductive period, temperature, among others (Navarro and Gutiérrez, 1995). The difference in the above-mentioned results may be related to the fact that these are different species in distinct development phases, which lead to differences in energy reserves at the beginning of feed restriction.

Ali et al. (2003) stated that when fish are subjected to feed deprivation and have a decline in growth, its compensation after the normalization of feeding may be total, when they attain the same weight at the same age as those fed continuously; or partial, when they show a rapid growth rate and better feed conversion, but do not reach the same weight as those that were not restricted at the same age. Short restriction cycles lead to partial compensatory growth in pacu and pirapitinga, since the final weight of restricted animals was lower than that of the continuously fed fish (Rodriguez and Landines, 2011; Takahashi et al., 2011). This phenomenon was also observed in the present study in the tambaqui juveniles subjected to restricted-feeding periods, after feeding was normalized (daily feeding for 65 days).

The magnitude and duration of compensatory growth depend on the duration of restricted feeding. Longer restriction periods may result in higher growth rates, leading to total compensatory growth (Navarro and Gutiérrez, 1995). However, long deprivation periods may cause damage to the animals and compromise their growth. Ituassú et al. (2004) observed total compensatory growth when tambaqui juveniles were restricted for longer periods (14 days of deprivation), but when restriction was extended for more than 21 days, the fish showed partial growth.

In the present study, tambaqui juveniles subjected to restricted-feeding cycles showed a lower condition factor (K), and those subjected to the more intense restriction regime (2F/4D) exhibited hematological changes such as decreased hematocrit and hemoglobin concentration. In spite of those alterations, the blood glucose level in the restricted fish did not differ from that recorded in the animals fed continuously (control), which means that the fish under restriction used triglycerides as an energy source, maintaining their blood glucose values constant. The present results agree with the reports of Pérez-Jiménez et al. (2007), who observed a reduction in the plasma triglyceride levels of *Dicentrarchus labrax* subjected to restricted feeding.

According to Navarro and Gutiérrez (1995), when fish are subjected to feed-deprivation periods, their blood glucose concentrations are kept at a stable level, which is majorly due to the use of hepatic glycogen, and the mobilization of intramuscular lipids in some species is initiated as soon as fasting starts. As stated by those authors, proteolysis occurs when the reserves of easily accessed energy such as liver glycogen and lipids have been used.

In the current study, no proteolysis was observed in the tambaqui juveniles under short restriction cycles. However, these fish showed a lower concentration of lipids in the muscle (filet), demonstrating that there was lipid mobilization at the muscle level to be used as a source of energy during feed deprivation, as described in other fish species (Takahashi et al., 2011; Urbinati et al., 2014). Additionally, in the feed-restricted fish, the energy from the feed was used for the maintenance of metabolism rather than for muscle deposition. This finding corroborates Navarro and Gutiérrez (1995), who reported that lipogenic activity seems to be reduced during the entire feed-deprivation period.

After being fed daily for 65 days (Phase II), the tambaqui juveniles that had undergone short restriction cycles showed similar metabolic and hematological parameters and condition factor to the fish fed continuously (control), indicating recovery of these parameters after feeding was reestablished. As for the productive parameters, after being fed daily (DF), the fish subjected to restriction periods in Phase I showed a higher specific growth rate, which suggests compensatory growth. However, this growth was partial, since neither the final weight nor the morphometric measurements equaled those of the unrestricted fish.

When fed continuously, the fish which had been subjected to the more intense feeding restriction (2F/4D) showed the lowest apparent feed conversion (AFC), indicating their greater ability to convert the ingested feed. This is likely due to the sensitivity of biochemical mechanisms which is exacerbated during feed deprivation (Jobling, 2010). The fact that natural feed was available in the rearing environment may explain the observed AFC lower than 1.0 for the fish in that treatment group, since tambaqui has large filtering capacity despite being an omnivorous species.

During growth, a larger portion of the acquired volume in the fish is white muscle, which implies accumulation of myofibrillar proteins (Mommsen, 2001). Considering that the protein synthesis requires ATP, the growth process requires use of energy (Bombardelli et al., 2004). Even after feeding was reestablished, the feed-restricted fish showed a lower lipid concentration in the filet than those fed continuously (control), suggesting utilization of the energy from the feed for the maintenance of metabolism and somatic growth rather than for lipid deposition in the muscle. Results obtained in laboratory conditions with short restricted-feeding cycles indicate that tambaqui juveniles have the capacity to mobilize their energy stock to go through fasting periods, but this physiological adaptation was not sufficient to elicit total compensatory growth.

The economic analysis of Phase I indicated that the operating expenses were lower in the regimes of feed deprivation for 2 and 4 days (5F/2D and 2F/4D). In Phase II, when all fish started to be fed daily, a 36.6% lower feeding cost was obtained in the group that was fasted for 4 days in comparison with control group, which was due to the significantly lower produced biomass and AFC. However, the average total operating cost (R$ g^{-1}) of this treatment was 25.9% lower than that of control, suggesting lesser participation of feeding in the production costs during this phase. This can be verified in other studies (Sanches et al., 2013; Brabo et al., 2015) in which the authors reported that, unlike the fattening stage, in the fingerling production stage, feeding is not the greatest expense. Rather, man labor and the purchase of juveniles are the costliest items, which contrasts with the present findings obtained during the pre-fattening stage.

Although feed deprivation allowed for decreased spending on man labor and feeding, the fish under such conditions did not develop equally to those fed continuously, resulting in less biomass produced. This explains the higher total operating cost per gram (R$ g^{-1}) of fish produced in those treatments (8.0% for 5F/2D and 25.9% for 2F/4D) in relation to control. In this way, the feeding management protocols in which the fish were fasted for a period resulted in a reduction of operating costs. Nevertheless, production in live weight was also lower, which means that despite the decreased expenses, the average total operating cost per gram of produced fish increases due to the lower productivity. Therefore, this practice is not indicated for tambaqui (*C. macropomum*) during this development phase.

CONCLUSION

Tambaqui (*Colossoma macropomum*) juveniles subjected to short restricted-feeding cycles for 60 days exhibited metabolic and hematological alterations and lower productive performance and used endogenous energy reserves to maintain their blood glucose level.

Continuously feeding for 65 days prompted partial compensatory growth and reestablishment of the metabolic and hematological parameters of tambaqui juveniles subjected to restricted-feeding cycles, though no muscle lipid deposition occurred. However, restricted feeding for short periods followed by refeeding did not prove to be economically viable for rearing tambaqui (*Colossoma macropomum*) fingerlings.

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REFERENCES

Ali, M.; Nicieza, A.; Wootton, R.J. 2003. Compensatory growth in fishes: a response to growth depression. Fish and Fisheries, 4(2): 147-190. **http://dx.doi.org/10.1046/j.1467-2979.2003.00120.x**.

Barros, A.F.; Martins, M.I.E.G. 2012. Performance and economic indicators of a large scale fish farming in Mato Grosso, Brazil. Revista Brasileira de Zootecnia, 41(6): 1325-1331. **http://dx.doi.org/10.1590/S1516-35982012000600001**.

Bombardelli, R.A.; Meurer, F.; Syperreck, M.A. 2004. Metabolismo protéico em peixes. Arquivos de Ciências Veterinárias e Zoologia da UNIPAR, 7(1): 69-79. **http://dx.doi.org/10.25110/arqvet.v7i1.2004.546**.

Brabo, M.F.; Natividade Júnior, L.S.; Dias, C.L.; Barbosa, J.; Campelo, D.A.V.; Veras, G.C. 2017. Viabilidade econômica da produção familiar de tambaqui em gaiolas flutuantes no Oeste paraense, Amazônia, Brasil. Custos e Agronegócio, 13(1): 275-293. Available from: <www.custoseagronegocioonline.com.br> Access on: 7 feb 2019.

Brabo, M.F.; Reis, M.H.D.; Veras, G.C.; Silva, M.J.M.; Souza, A.S.L.; Souza, R.A.L. 2015. Viabilidade econômica da produção de alevinos de espécies reofílicas em uma piscicultura na Amazônia oriental. Boletim do Instituto de Pesca, 41(3): 677-685.

Brasil, 2011. Instrução Normativa n. 25, de 2 de junho de 2011: Anexo I: Métodos Analíticos Oficiais Físico-Químicos para Controle de Pescado e seus Derivados. Diário Oficial da União, Brasília, 03 de março de 2011, Seção 1, p. 34-39.

Costa, J.; Freitas, R.; Gomes, A.L.; Bernadino, G.; Carneiro, D.; Martins, M.I. 2016. Effect of stocking density on economic performance for *Colossoma macropomum* (Cuvier, 1816), juvenile in earthen ponds. Latin American Journal of Aquatic Research, 44(1): 165-170. **http://dx.doi.org/10.3856/vol44-issue1-fulltext-18**.

Dar, S.A.; Srivastava, P.P.; Varghese, T.; Gupta, S.; Gireesh-Babu, P.; Krishna, G. 2018. Effects of starvation and refeeding on expression of ghrelin and leptin gene with variations in metabolic parameters in Labeo rohita fingerlings. Aquaculture, 484: 219-227. **http://dx.doi.org/10.1016/j.aquaculture.2017.11.032**.

Emerson, K.; Russo, R.C.; Lund, R.E.; Thurston, R.V. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Research Board of Canada, 32(12): 2379-2383. **http://dx.doi.org/10.1139/f75-274**.

Inoue, L.A.K.A.; Moraes, G. 2007. Óleo de cravo: um anestésico alternativo para o manejo de peixes. Brasília: Embrapa Amazônia Ocidental. p. 9-24. (Documentos, 51).

Ituassú, D.R.; Santos, G.R.S.; Roubach, R.; Pereira-Filho, M. 2004. Desenvolvimento de tambaqui submetido a períodos de privação alimentar. Pesquisa Agropecuária Brasileira, 39(12): 1199-1203. **http://dx.doi.org/10.1590/S0100-204X2004001200006**.

Jobling, M. 2010. Are compensatory growth and catch-up growth two sides of the same coin? Aquaculture International, 18(4): 501-510. **http://dx.doi.org/10.1007/s10499-009-9260-8**.

Martin, N.B.; Serra, R.; Oliveira, M.D.M.; Ângelo, J.A.; Okawa, H. 1994. Custos: sistema de custo de produção agrícola. Informações Econômicas, 24(9): 97-122.

Mommsen, T.P. 2001. Paradigms of growth in fish. Comparative Biochemistry and Physiology, 129(2-3): 207-219. **http://dx.doi.org/10.1016/S1096-4959(01)00312-8**. PMid:11399452.

Moro, G.V.; Torati, L.S.; Luiz, D.B.; Matos, F.T. 2013. Monitoramento e manejo da qualidade da água em pisciculturas. In: Rodrigues, A.P.O.; Lima, A.F.; Alves, A.L.; Rosa, D.K.; Torati, L.S.; Santos, V.R.V. Piscicultura de água doce: multiplicando conhecimentos. Brasília: Embrapa Pesca e Aquicultura. p. 141-170.

Morshedi, V.; Kochanian, P.; Bahmani, M.; Yazdani, M.A.; Pourali, H.R.; Ashouri, G.H.; Pasha-Zanoosi, H. 2017. Cyclical short-term starvation and refeeding provokes compensatory growth in sub-yearling Siberian sturgeon, *Acipenser baerii* Brandt, 1869. Animal Feed Science and Technology, 232: 207-214. **http://dx.doi.org/10.1016/j.anifeedsci.2016.10.005**.

Navarro, I.; Gutiérrez, J. 1995. Fasting and starvation. In: Hochachka, P.W.; Mommsen, T.P. Biochemistry and molecular biology of fishes. New York: Elsevier. v. 4, p. 393-434.

Nikki, J.; Pirhonen, J.; Jobling, M.; Karjalainen, J. 2004. Compensatory growth in juvenile rainbow trout, *Oncorhynchus mykiss* (Walbaum), held individually. Aquaculture, 235(1-4): 285-296. **http://dx.doi.org/10.1016/j.aquaculture.2003.10.017**.

Ortiz, J.C.; Sánchez, S.; Roux, J.P.; González, A.O. 2008. Crecimiento compensatorio de juveniles de pacu (*Piaractus mesopotamicus* Holmberg, 1887) en diferentes sistemas de alimentación. Boletim do Instituto de Pesca, 34(2): 251-258.

Palma, E.H.; Takahashi, L.S.; Dias, L.T.S.; Gimbo, R.Y.; Kojima, J.T.; Nicodemo, D. 2010. Estratégia alimentar com ciclos de restrição e realimentação no desempenho produtivo de juvenis de tilápia do Nilo da linhagem GIFT. Ciência Rural, 40(2): 391-396. **http://dx.doi.org/10.1590/S0103-84782010000200026**.

Pedroza Filho, M.X.; Rodrigues, A.P.O.; Rezende, F.P. 2016. Dinâmica da produção de tambaqui e demais peixes redondos no Brasil. Boletim Ativos da Aquicultura, 7:1-5. Available from: <www.infoteca.cnptia.

embrapa.br/infoteca/bitstream/doc/1041302/1/CNPASA2015aa7.pdf> Access on: 7 feb 2019.

Peixe BR, 2018. Anuário Peixe BR da Piscicultura. São Paulo. Available from: <https://www.peixebr.com.br/anuario2018> Access on: 7 feb 2019.

Pérez-Jiménez, A.; Guedes, M.J.; Morales, A.E.; Oliva-Teles, A. 2007. Metabolic responses to short starvation and refeeding in *Dicentrarchus labrax*. Effect of dietary composition. Aquaculture, 265(1-4): 325-335. **http://dx.doi.org/10.1016/j.aquaculture.2007.01.021**.

Rodriguez, L.; Landines, M.A. 2011. Evaluación de la restricción alimenticia sobre el desempeño productivo y fisiológico en juveniles de cachama blanca, *Piaractus brachypomus*, en condiciones de laboratorio. Revista de la Facultad de Medicina Veterinaria y Zootecnia, 58(3): 141-151.

Sabaini, D.S.; Casagrande, L.P.; Barros, A.F. 2015. Viabilidade econômica da criação do pintado da Amazônia (*Pseudoplatystoma* spp.) em tanques-rede no estado de Rondônia, Brasil. Boletim do Instituto de Pesca, 41(4): 825-835.

Sanches, E.G.; Tosta, G.A.M.; Souza-Filho, J.J. 2013. Viabilidade econômica da produção de formas jovens de bijupirá (*Rachycentron canadum*). Boletim do Instituto de Pesca, 39(1): 15-26.

Santos, L.; Pereira Filho, M.; Sobreira, C.; Ituassú, D.; Fonseca, F.A.L. 2010. Exigência protéica de juvenis de tambaqui (*Colossoma macropomum*) após privação alimentar. Acta Amazonica, 40(3): 597-604. **http://dx.doi.org/10.1590/S0044-59672010000300021**.

Santos, M.Q.D.C.; Lima, M.A.C.; Santos, L.; Pereira-Filho, M.; Ono, E.A.; Affonso, E.G. 2013. Feeding strategies and energy to protein ratio on tambaqui performance and physiology. Pesquisa Agropecuária Brasileira, 48(8): 955-961. **http://dx.doi.org/10.1590/S0100-204X2013000800021**.

Takahashi, L.S.; Biller, J.D.; Criscuolo Urbinati, E.; Urbinati, E.C. 2011. Feeding strategy with alternate fasting and refeeding: effects on farmed pacu production. Journal of Animal Physiology and Animal Nutrition, 95(2): 259-266. **http://dx.doi.org/10.1111/j.1439-0396.2010.01050.x**. PMid:20880282.

Urbinati, E.C.; Sarmiento, S.J.; Takahashi, L.S. 2014. Short-term cycles of feed deprivation and refeeding promote full compensatory growth in the Amazon fish matrinxã (*Brycon amazonicus*). Aquaculture, 433: 430-433. **http://dx.doi.org/10.1016/j.aquaculture.2014.06.030**.

Won, E.; Borski, R.J. 2013. Endocrine regulation of compensatory growth in fish. Frontiers in Endocrinology, 4(73): 74. **http://dx.doi.org/10.3389/fendo.2013.00074**. PMid:23847591.