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ORIGINAL ARTICLE

Performance and carcass yield of silver catfish raised in monosex and mixed-sex systems

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Abstract - An experiment lasting 180 days was carried out to evaluate the influence of sex on the performance and production of silver catfish (*Rhamdia quelen*) when reared in closed recirculation systems using only males, only females, or with both genders. A total of 300 fish (41.49 ± 6.82 g and 16.53 ± 0.95 cm) were used, comprising 150 females and 150 males distributed in an experimental structure consisting of three closed water recirculation systems coupled to a 20,000 L culture tank and a 20,000 L biofiltration tank connected by a $3,500 \text{ L h}^{-1}$ water pump. The first system contained 100 females, the second, 100 males, and the third, 50 females and 50 males. High fish weight variations were observed regardless of sex. Female weight gains and specific growth rates were 41.51 % and 28.94 % higher compared to males, respectively, exhibiting greater growth than males raised monosexually or in mixed rearing systems, with no effect on chemical composition or trunk yield. The findings thus indicate that both male and female silver catfish exhibit wide weight variations and females that gain more biomass than males reared monosexually or in mixed-sex systems.

Keywords: Aquaculture. Fish weight gain. Native fish. *Rhamdia quelen*. Specific growth rates.

Desempenho e rendimento de carcaça de jundiás criados em sistemas monossexuais e mistos

Resumo - Um experimento de 180 dias foi conduzido para avaliar a influência do gênero sobre o desempenho e produção de jundiás (*Rhamdia quelen*) criados em um sistema de recirculação fechada monossexo e misto. Foram utilizados 300 peixes ($41,49 \pm 6,82$ g e $16,53 \pm 0,95$ cm) sendo 150 fêmeas e 150 machos distribuídos na estrutura experimental, que constava de três sistemas fechados de recirculação de água, com um tanque de cultivo e um tanque de biofiltração, ambos de 20.000 L de capacidade e ligados por uma bomba d'água de 3.500 L h^{-1} . O primeiro sistema foi composto por 100 fêmeas, o segundo por 100 machos e o terceiro por 50 fêmeas e 50 machos. Os peixes, independente do gênero, apresentaram uma grande variação de peso. O ganho de peso e a taxa de crescimento específico das fêmeas foram, respectivamente, 41,51 % e 28,94 % superiores aos machos. Fêmeas de jundiá apresentam um crescimento superior a machos criados de maneira monossexual ou mista, sem efeito sobre a composição química ou rendimento do tronco. Esta espécie apresenta ampla variação de peso, independente do sexo, a criação de fêmeas pode apresentar um melhor ganho de biomassa que a criação de indivíduos machos ou mista.

Palavras-chave: Aquicultura. Ganho de peso dos peixes. Peixes nativos. *Rhamdia quelen*. Taxa de crescimento específico.

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Introduction

Aquaculture activities in Brazil have increased rapidly since the 1990s, due to the reduction of natural fish stocks, caused by fishing activities of native species (VIDAL; XIMENES, 2019). Therefore, aquaculture, through the cultivation of species for harvest, promotes a decrease in the pressures of commercial fishing, comprising a significant positive aspect of aquaculture in relation to biodiversity conservation (FROEHLICHA; GENTRYB; HALPERNA, 2017).

According to the Brazilian Association of Fish Farming (PEIXE BR), Brazilian fish farms increased by 5.93 % in 2020, producing 802,930 t of fish products. However, although native fish continue to represent a significant segment of Brazilian fish farming, over 60 % of the total production comprises exotic species (PEIXE BR, 2021).

To encourage the production of native fish species, new technologies following modern propositions are required (IGARASHI, 2020), with the combined management of fish production within market needs or requirements. In this regard, meat quality and growth parameters in many species displaying economic interest are influenced by sex, due to metabolism and hormone production differences that reflect on meat performance and characteristics (ADORIAN *et al.*, 2018). This is also observed for fish, where differences in growth rate, behavioral patterns, breeding season, body-color, shape, and size may occur between males and females (YAMAZAKI, 1983).

In this regard, about 95 % of teleosts exhibit phenotypic differences between males and females of the same species (gonochoric), mainly in the adult stage (REIS; ALMEIDA; PIFERRER, 2016). This has been documented for silver catfish (*Rhamdia quelen*), a native South American catfish belonging to the Siluriform order and Heptapteridae family, where records indicate that females grow from 20 % to 30 % more than males (REIDEL *et al.*, 2010), although no studies on the effect of sex on silver catfish growth are available.

The rearing of gonochoric species can justify monosex systems, which depends on either individual sexing or sexual reversal techniques. However, according to Reis, Almeida and Piferrer (2016), few fish species are produced in commercial monosex populations in Brazil, mainly Nile tilapia (*Oreochromis niloticus*) and beta (*Betta splendens*). The authors attribute this to a lack of correct and methodical identification of phenotypic differences between males and females, indicating a greater economic potential for one or the other.

With the need for more intensive silver catfish production in Brazil in order to cope with species such as Nile tilapia, knowledge concerning the effect of sex on silver catfish growth to the adult stage is paramount for production chain structuring. In this sense, the growth of commercially farmed fish is associated to factors strictly intrinsic to sex, such as genetic, physiological, and behavioral elements, or even interactions between these factors. Therefore, evaluations on single-sex and mixedrearing systems should be carried out, as interaction among sexes can affect fish growth.

In this context, this study aimed to evaluate the influence of sex on silver catfish (*Rhamdia quelen*) specimens reared in closed monosex and mixed recirculation systems on productive performance and production.





Material and methods

The experiment was carried out at the Aquaculture Technology Laboratory (LATAq), at the advanced Jandaia do Sul Federal Paraná University campus from September to February, following the Ethical Principles in Animal Experimentation adopted by the Brazilian National Council of Animal Experimentation Control (CONCEA) and approved by the Ethics Committee on the Use of Animals (CEUA - UFPR), under protocol No. 22/2017-CEUA.

The rearing structure consisted of three experimental units arranged sequentially, separated by 120 cm, where each experimental unit comprised two 20,000 L (useful volume) surface tanks, manufactured in plastic canvas (height: 1.20 m; diameter: 4.61 m and radius: 2.30 m), connected by an electro-hydraulic pump with a flow rate of 3,500 L h⁻¹ turned on during the entire 180-day trial period.

Each experimental unit comprised one tank containing the fish and the other, the biofilter, which received *Eichhornia crassipes* macrophytes to remove nitrogen and phosphorus (HENRY-SILVA; CAMARGO, 2008) and nets used as an adhesion surface for nitrifying bacteria. The tanks did not have any type of cover or aerator, and their water came from the artesian well. As all water quality parameters were similar between the three production systems, the three fish-rearing environments were assumed as the same.

Daily oxygen and water temperature determinations using an Alfa kit A150 oximeter were performed twice a day (8:00 and 18:00 h). pH, ammonia nitrogen, and transparency were monitored weekly at 3 pm. pH was measured using a benchtop pH meter (Tecnopon Equip Esp Ltda, model LUCA 210), and ammoniacal nitrogen was determined with a Labcon analysis kit, and transparency was measured with a Secchi disk.

Dissolved oxygen values ranged between 1.43 mg L⁻¹ and 15.87 mg L⁻¹, averaging 7.93 mg L⁻¹. The minimum dissolved oxygen value was recorded during a power outage of a few hours, with a pause in water recirculation between the tanks, resulting in a lack of system oxygenation.

Temperatures ranged between 16.8 °C and 29.8 °C, averaging 23.55 °C, in agreement with normal temperature variations in the study area. pH ranged between 6.95 and 9.87, averaging 8.29. These high pH values are explained by the artesian well water source employed in the experiment.

Ammoniacal nitrogen was not detected during the experimental period, demonstrating the efficiency of the employed biofiltration system. Transparency ranged between 29 and 60 cm, averaging 40.65 cm, due to the presence of phytoplankton in the tanks. The means of the physicochemical variables were all within conditions considered ideal for silver catfish, according to Gomes *et al.* (2000).

A total of 300 fish (16.53 ± 0.95 cm and 41.49 ± 6.82 g), acquired from a commercial breeding site in the Municipality of Maringá, PR, Brazil, were anesthetized, measured, weighed and separated into three culture tanks. Treatments comprised a rearing system containing only 100 females (16.50 ± 0.93 cm and 40.70 ± 6.28 g), one containing only 100 males (16.60 ± 0.98 cm and 42.80 ± 7.05 g), and another containing 50 females (16.51 ± 0.90 cm and 40.08 ± 6.29 g) and 50 males (16.47 ± 0.98 cm and 41.85 ± 7.38 g).

Fish were fed a commercial extruded feed containing 32 % crude protein twice a day (8:00 and 18:00 h) until apparent satiety.

At the end of the experiment, all fish were counted, weighed, and measured to assess final weight, total





weight gain, daily weight gain, total length, specific growth rate, condition factor, feed conversion, and survival. They were then sacrificed in water through excess anesthetic (250 mg L⁻¹ of eugenol) and carcass yield, clean trunk yield, viscera percentage, and chemical composition of the clean trunk were assessed.

Following the final measurements, the silver catfish trunks were tagged and stored in a freezer for chemical composition evaluations. To this end, the samples were thawed and crude protein, ether extract, moisture, and ash analyses were carried out, according to the AOAC (2019).

Thus, each fish in each treatment was used as a repetition. The results were submitted to an Analysis of Variance (ANOVA) at a significance level of 5 %, and then submitted to the Tukey test, employing the Past statistical software.

Results and discussion

The final mean weight, total weight gain, daily weight gain, total length, specific growth rate, condition factor, feed conversion, and survival values of the single-sex and mixed silver catfish rearing systems are presented in Table 1.

Table 1. Performance parameters of silver catfish (*Rhamdia quelen*) reared in a single-sex and mixed-sex closed recirculation system.

Evaluated parameters	Single-sex		Mixed-sex	
	Female	Male	Female	Male
FW (g) ¹	161.43 ± 45.07 ^a	113.41 ± 32.92 ^b	159.63 ± 43.81 ^a	112.29 ± 31.75 ^b
FWG (g) ²	120.72 ± 6.94	70.60 ± 11.16	118.93 ± 7.15	69.49 ± 7.84
DWG (g) ³	0.67 ± 0.04	0.39 ± 0.06	0.66 ± 0.04	0.38 ± 0.04
TL (cm) ⁴	24.92 ± 2.45 ^a	22.52 ± 2.04 ^b	25.21 ± 2.01 ^a	22.65 ± 1.99 ^b
SGR ⁵	0.76 ± 0.01	0.54 ± 0.01	0.76 ± 0.01	0.54 ± 0.01
RCF ⁶	1.04 ± 0.08 ^a	0.99 ± 0.12 ^b	0.99 ± 0.07 ^b	0.96 ± 0.11 ^b
FC ⁷	1.05 ± 0.2	1.33 ± 0.33	1.04 ± 0.2	
S (%) ⁸	93.42	94.73	94.73	

^{a, b}Means in the same line with different superscript letters are significantly different ($p < 0.05$). ¹Final weight; ²final weight gain; ³daily weight gain; ⁴total length; ⁵specific growth rate; ⁶relative condition factor; ⁷food conversion; ⁸survival.

Weight and length were influenced by sex, regardless of single-sex or mixed-rearing conditions ($p < 0.05$). Silver catfish condition factor, on the other hand, was influenced by the rearing system ($p < 0.05$), where females reared alone presented a higher condition factor than males (regardless of rearing system), as well as females reared alongside with males. No other parameters were influenced ($p > 0.05$) by the rearing system.

Females grew more than males in both the single and mixed-sex rearing systems, with greater lengths and weights than males. Female weight gain and specific growth rate were 41.51 % and 28.94 % higher compared to males, respectively. This corroborates previous reports by Gomes *et al.* (2000), Fracalossi *et al.*





(2004), Amaral Júnior, Nunes and Garcia (2008), and Adorian *et al.* (2018), who all demonstrated the zootechnical superiority of silver catfish females. Gomes *et al.* (2000) stated that this is due to early male investment in reproduction. Most female fish in aquaculture activities, with the exception of a few, represent the most profitable sex (BEARDMORE; MAIR; LEWIS, 2001), usually due to a later puberty stage compared to males (REIS; ALMEIDA; PIFERRER, 2016), owing to early energy diversion for reproduction in males, while females display later maturation and invest longer in growth.

In this sense, Adorian *et al.* (2018) evaluated the influence of separate silver catfish sex rearing on intermediate fish metabolism (blood and liver metabolites) and performance parameters, reporting metabolic differences between sexes.

The silver catfish reared herein exhibited good apparent feed conversion when adults, corroborating previous reports by Adorian *et al.* (2018) and Santos *et al.* (2021) for fingerlings, although, higher than that determined by Grigio and Meurer (2020). Meyer and Fracalossi (2004) state that good feed conversion is the result of silver catfish ability to save protein under adequate dietary energy concentration conditions, reaffirming the species adaptability to artificial feeding reported in other assessments, such as Gomes *et al.* (2000).

The weight variation of single-sex and mixed silver catfish rearing are presented in Table 2. Of the 13 considered weight classes, most fish, regardless of sex, were distributed between the 3rd and 11th classes. The most frequent weight class in the female-only rearing system was composed of fish from 140 g to 160 g, at 21.21 % of all individuals, while the weight class from 100 g to 120 g was more expressive in the male-only system, observed for 34.24 % of all individuals.

Table 2. Distribution of the weights of silver catfish (*Rhamdia quelen*), reared in a single-sex and mixed-sex closed recirculation system.

Weight classes (g)	Single-sex		Mixed-sex	
	Female*	Male*	Female*	Male*
20 – 40	0.00	1.37	0.00	0.00
40 – 60	1.52	0.00	0.00	2.27
60 – 80	3.03	10.96	3.57	18.18
80 – 100	0.00	23.28	3.57	25.00
100 – 120	6.06	34.24	10.71	11.36
120 – 140	12.12	12.32	17.86	18.18
140 – 160	21.21	8.22	17.86	18.18
160 – 180	19.69	6.84	17.86	6.81
180 – 200	13.63	0.00	17.86	0.00
200 – 220	10.60	1.37	3.57	0.00
220 – 240	6.06	1.37	3.57	0.00
240 – 260	4.54	0.00	0.00	0.00
260 – 280	1.52	0.00	3.57	0.00

*Percentage values.

Weight classes were distributed differently in the mixed-sex system compared to the male- and female-only rearing systems. In this case, females displayed an even distribution in the four weight classes ranging



between 120 g and 200 g, at 17.86 % each. Regarding males, the most frequent weight class ranged between 80 g and 100 g, observed for 25.00 % of all individuals.

High weight variability regardless of sex or rearing system was observed in the present study. Females mostly belonged to higher weight classes compared to males, although a higher number of classes was observed for this sex, indicating lower growth homogeneity. Males, on the other hand, despite occupying lower weight classes, exhibited greater growth homogeneity. This difference may be due to genetic variability (SANTOS *et al.*, 2021). Virmond *et al.* (2017) observed high genetic variability (98.06 %) within captive silver catfish populations when employing microsatellite-type molecular markers, indicating the possibility of applying mass selection to search for better weight averages. Genetic improvement through selection is highly effective, as it modifies genetic frequencies in the desired direction, establishing cumulative changes in each generation (BESSON *et al.*, 2014).

Table 3 presents the carcass yield, clean trunk yield and viscera percentages for the single-sex and mixed silver catfish rearing systems. No influence ($p > 0.05$) of the rearing system on body yield parameters and clean trunk chemical composition was observed. Furthermore, the chemical composition of the clean trunks was not different between rearing systems ($p > 0.05$), with average values of 73.56 % for moisture, 1.23 % for ash, 19.17 % for crude protein and 2.85 % for ether extract.

Table 3. Body yields of *Rhamdia quelen* reared in a single-sex and mixed-sex closed recirculation system.

Tanks		Yield (%)		
		Carcass	Clean trunk	Viscera
Single-sex	Female	82.80 ± 5.61	59.19 ± 9.19	20.71 ± 4.46
	Male	87.32 ± 1.85	52.23 ± 0.88	17.38 ± 1.06
Mixed-sex	Female	88.94 ± 0.50	60.28 ± 8.34	23.26 ± 1.83
	Male	86.58 ± 0.31	53.57 ± 1.00	16.20 ± 2.64

Values are means ± standard deviation.

The body yields observed herein corroborate other silver catfish assessments (LAZZARI *et al.*, 2008; LOSEKANN *et al.*, 2008; PEDRON *et al.*, 2008; GRÍGIO *et al.*, 2020), as well as other native species, such as pacu *Piaractus mesopotamicus* (BITTENCOURT *et al.*, 2010) and *Colossoma macropomum*, (LOPES *et al.*, 2010). Carcass yield values were higher than those reported by Silva *et al.* (2009) for Nile tilapia.

Chemical fish composition assessments are used to evaluate the nutritional importance of fish meat (LIMA *et al.*, 2018). The protein values observed herein in clean silver catfish trunks were similar to those reported by Grígio *et al.* (2020) and higher than those calculated for other native species, such as barbado (*Pterodoras granulosus*) (BOMBARDELLI; SANCHES, 2008) and tambaqui (LIMA *et al.*, 2018).

Although greater growth was noted for females, the chemical trunk composition and body yields reported herein did not vary between sex. Thus, choosing the sex that results in the greatest productive performance is paramount.





Baldisserotto (2004) reported that no effect of sex on silver catfish growth is observed for about 150 days after hatching under rearing conditions. Similarly, Santos *et al.* (2021) reported that sex does not influence this species, growth during a grow-out period of 180 days from the fingerling stage. This seems to indicate that the effect of sex on silver catfish growth species is associated to with gonadal maturation, which takes place during the adult stage.

Two factors may explain this difference, mainly a genetic predisposition towards greater weight gains and greater energy expenditure among males fighting for territory, since silver catfish present strong agonistic behavior (PIAIA; BALDISSEROTTO, 2000), or the fact that males begin the reproductive maturation process earlier than females (GHIRALDELLI *et al.*, 2007; AMARAL JUNIOR; NUNES; GARCIA, 2008).

In the present study, sex was also proven to influence final silver catfish weight. Therefore, considering the total biomass of each treatment, single-sex female rearing may be more profitable, as a higher production was noted in this rearing system compared to the other treatments. In fact, according to Reis, Almeida and Piferrer (2016), single-sex rearing may result in significant economic gains, as only individuals displaying zootechnical superiority are maintained. Techniques for single-sex breeding include sexing, as in the present study, or sexual reversal. Thus, further studies should be carried out to support the use or non-use of single-sex silver catfish rearing, as well as to verify whether the use of reversed individuals would provide the same performance pattern observed herein.

In sum on the findings reported herein, female silver catfish (*R. quelen*) display higher growth rates than males reared monosexually or in mixed-systems, with no sex effect on chemical composition or trunk yield. Furthermore, this species exhibits a wide weight variation, regardless of sex, and breeding females exhibit better biomass gains than males reared alone or in mixed-systems.

Conflict of interest

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

The experiment was carried out following the Ethical Principles in Animal Experimentation adopted by the Brazilian National Council of Animal Experimentation Control (CONCEA) and approved by the Ethics Committee on the Use of Animals (CEUA - UFPR), under protocol No. 22/2017-CEUA.

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