Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8672
https://doi.org/10.4025/actascianimsci.v48i1.73647

AQUACULTURE

Growth performance and economic evaluation of *Leporinus lacustris* fed different levels of crude protein

Fúlvia Cristina Oliveira[1*], Fayane do Espírito Santo[2], Rubia Mara Acunha[1], André Luiz Julien Ferraz[2], Robson Andrade Rodrigues[3], André Rozemberg Peixoto Simões[2] and Cristiane Meldau de Campos[1,2]

[1]Universidade Federal de Mato Grosso do Sul, Av. Costa e Silva, s/n, 79070-900, Campo Grande, Mato Grosso do Sul, Brazil. [2]Universidade Estadual de Mato Grosso do Sul, Aquidauana, Mato Grosso do Sul, Brazil. [3]Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil. *Author for correspondence. E-mail: fulviacoliveira65@gmail.com

ABSTRACT. The determination of optimal crude protein levels in fish diets is crucial due to its essential role in growth and its high cost. This study evaluated the effect of crude protein levels in the diet of piau corró *Leporinus lacustris* on growth performance, as well as the maximum technical and economic efficiency of this species. Juveniles of *L. lacustris* were distributed in 20 tanks, 20 L volume, density of six fish, and fed three times daily with 7% biomass. The design was completely randomized with four levels of crude protein (CP): 30, 34, 38, and 42%, and five replicates each. After 60 days of cultivation, the Fulton's condition factor showed significant differences among treatments, fitting a quadratic regression model. Fish fed diets containing 34% CP exhibited better nutritional status. In contrast, the protein efficiency ratio (PER) followed a decreasing linear trend, with the best performance observed in fish fed 30% CP. Therefore, the diet with 30% crude protein can be recommended for *L. lacustris* juveniles at this stage of cultivation, as it is close to the optimal level for maximizing the species' technical and economic efficiency.

Keywords: feed cost; nutrition; piau; productivity.

Received on September 5, 2024.
Accepted on April 15, 2025.

Introduction

Sport and leisure fishing is practiced worldwide in many aquatic environments, such as rivers, dams, and lakes, as well as other marine environments and estuaries (Arlinghaus et al., 2017; Nyboer et al., 2022). Brazil, with the largest river basin in the world and a vast diversity of fish species, is a great attraction for fishing tourism. Sport or leisure fishing is practiced throughout the country, especially in the Amazon and Pantanal regions, which stand out for the high tourist demand and variety of fish species (Chiaravalloti et al., 2022; Ministério da Pesca e Aquicultura, 2023; Lubich et al., 2024). In 2019, sport fishing moved R$ 1 billion, benefiting many sectors such as hotels, gastronomy, fishing shops, guides, and producers/collectors of live bait (Sebrae, 2021).

Live baits traded for sport fishing are mostly purchased from collectors who catch them in rivers or from small producers. Among the main species used in fishing and produced in fish farms, the lambari (*Astyanax bimaculatus*), curimba (*Prochilodus lineatus*), and piavuçu (*Megaleporinus macrocephalus*) stand out. The latter belongs to the family *Anostomidae*, which encompasses different species popularly known as piaus.

Piaus have a distribution restricted to South America and represent an important source of income for fishermen in several regions of Brazil (Sidlauskas et al., 2022; Bandeira et al., 2024). In general, piaus are represented by the genus *Leporinus*, of which the *L. elongatus, L. friderice, L. obtusidens,* and *L. macrocephalus* (now belongs to the species *Megaleporinus macrocephalus*). These fish have high production potential, good meat quality, and excellent live bait options for sport fishing (Froese & Pauly, 2023; Sousa et al., 2024).

The piau corró *(Leporinus lacustris*) is a species with potential for production and trade as live bait. Although it has the potential to be produced in captivity, little is known about its biological characteristics and zootechnical attributes. This species has an omnivorous feeding behavior, a relative advantage because they can be fed with low protein diets (Copatti et al., 2022). Determining the level of crude protein supply to captive fish and the quality of this protein are the main factors affecting fish farms' performance and production cost. The feed cost can reach 50 to 60% of the total cost of fish production (Ye et al., 2020).

Protein digestion by fish is crucial for metabolic processes such as growth, tissue repair, and reproduction (National Research Council, 2011; Volkoff & London, 2018). Protein deficiency can delay the growth of animals, while its excess can increase production costs and the amount of nitrogen waste in water, impairing the environment (Portz & Furuya, 2013.

Although several previous studies have investigated protein levels and fish performance (Paula et al., 2020; Nguyen et al., 2021; Almeida et al., 2023), none focused on *Leporinus lacustris*. Therefore, with this work, the objective was to evaluate how different levels of crude protein in the diet influence growth performance, as well as the technical and economic efficiency of the production of juveniles of piau corró *(Leporinus lacustris)*.

Materials and methods

Ethics approval

The study was approved by the Animal Ethics Committee (CEUA) of the Universidade do Estado de Mato Grosso do Sul – UEMS, Aquidauana, MS, Brazil, under Protocol No. 017/2022 and followed all ethical principles in animal experimentation.

Location and facilities

The experiment was conducted at the Universidade Estadual de Mato Grosso do Sul in the municipality of Aquidauana - MS. Piau juveniles (1.90 ± 0.19 g and 5.35 ± 0.18 cm) were obtained from induced reproduction in fish aged 90 days performed in the Fish farming sector. The fish went through 15 days of adaptation to laboratory conditions prior to the start of the experiment.

Experimental diets

The experimental diets were formulated to meet the nutritional requirements of the fish, except for crude protein (Table 1).

Table 1. Ingredients and nutritional composition of the experimental feeds for the four treatments.

Ingredients (%)	Diets			
	30%	34%	38%	42%
Soybean meal	46.75	57.26	67.77	78.27
Corn grain	33.88	23.39	12.89	2.39
Fish meal	11.89	12.11	12.32	12.54
Soybean oil	0.83	0.65	0.47	0.29
Dicalcium phosphate	5.13	5.09	5.04	5
Common salt	0.5	0.5	0.5	0.5
Premix vit-min[1]	1	1	1	1
BHT	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00
Calculated/analyzed composition				
Gross energy (kcal Kg^{-1})	3767.2	3786.7	3806.3	3825.82
Digestible energy (kcal Kg^{-1})	3500	3500	3500	3500
Crude Protein	30.14	32.63	37.63	44.15
Digestible Protein (%)	28.00	32.00	36.00	40.00
Dry matter (%)	92.04	91.95	91.97	91.59
Ash (%)	13.26	14.36	14.06	13.95
Ether extract (%)	4.25	3.45	2.55	2.52
NDF (%)	56.27	57.51	49.73	52.62
ADF (%)	34.82	36.05	34.77	39.34
Calcium (%)	2	2	2	2
Total phosphorus (%)	1.4	1.4	1.4	1.4
Fat (%)	3.88	3.55	3.23	2.91
Crude fiber (%)	3.02	3.32	3.63	3.93
Ratio DE:DP (kcal g^{-1})	12.50	10.90	9.70	8.88
Ratio GE:CP (kcal g^{-1})	12.53	11.07	9.91	8.99

[1]Premix vit-min guarantee levels: folic acid - 1,250 mg, niacin – 22.5 g, biotin-15 mg, vit. A – 2,500,000 IU, vit. D3 - 600,000 IU, vit. E - 37,500 IU, vit. B1 – 4,000 mg, vit. B2 – 4,000 mg, vit. B5 - 12 g, vit. B6 – 4,000 mg, vit. B12 – 4,000 mcg, vit K3 - 3,750 mg, vit. C – 50 g, copper – 2500 mg, iron – 15 g, manganese – 12.5 g, zinc – 12.5 mg, cobalt – 125 mg, iodine – 375 mg, selenium-87.5 mg.

The nutritional requirements for the genus *Leporinus* were used as a basis. The ingredients were ground in a mill fitted with a 1 mm sieve, weighed, mixed, and moistened with heated water (20%) to form a homogeneous mass. A manual meat grinder fitted with a 2 mm sieve was used to make the pellets. The pellets were dried in a forced air oven at 60°C for 24 hours. All feeds were identified and refrigerated throughout the experiment.

The feeds were analyzed for centesimal composition following the methodologies described by Silva and Queiroz (2002).

Experimental design

The experimental design was completely randomized, and the treatments consisted of four levels of crude protein (CP): 30, 32, 36, and 42%, with five tanks considered replicates. The fish (n= 120) were distributed in 20 rectangular tanks (40 x 20 x 25cm) with 20 L of useful volume each, coupled to a water recirculation system with filtration containing acrylic blanket and biofilter with bioballs. Six fish were allocated in each tank. Initially, they were fed three times daily (8:00 am, 1:00 pm, and 5:00 pm), with a total daily feed of 7% biomass of each tank. Biometrics were performed every 20 days to adjust the feed supply.

Water quality

Water quality parameters were monitored daily: dissolved oxygen (7.91 ± 0.84 mg L^{-1}), temperature (25.74 ± 1.21°C), Alphakit AT160 oximeter, and pH (7.48 ± 0.47) digital pHmeter, Chemis QA338. Toxic ammonia (0.006 ± 0.003) and nitrite (1.6 ± 0.84) were monitored every two days using colorimetric kits (Labcon®). Whenever necessary, the tanks were siphoned to remove feces and feed wastes. The water volume lost by evaporation and siphoning was replaced. The water quality parameters remained within the recommended range for tropical fish (Kubitza, 2013).

Growth *performance*

After 60 days of feeding, the fish were fasted for 24 hours and sampled for total biometrics (weight and total length). The growth performance variables evaluated were: weight gain - WG (g): final weight – initial weight; Length gain - LG (cm): final length – initial length; Biomass gain - BG (g): final biomass – initial biomass; specific growth rate - SGR (g): 100 x (ln FW – In IW) / days of experiment; Protein efficiency rate - PER (%): (WG / % feed protein) x 100; Apparent feed conversion - AFC: total feed intake /WG; Survival rate – S (%): (final amount of fish / initial amount of fish) x 100.

The weight/length ratio was observed by the scatter plot and the equation $Y=a * C^b$, where Y is the total weight; a is a regression constant related to the degree and fish growth; c is total length; and b is the angular coefficient that characterizes the type of population growth, which can be isometric (b equal to 3), positive allometric (when b is less than 3), or negative allometric (b greater than 3) (Le Cren, 1951). The relative condition factor (Kn) was calculated using the equation Kn= (observed weight / expected weight), as described by Le Cren (1951) and Vazzoler (1996).

We also evaluated the uniformity of fish - U (%): ($N_{\pm 20}$ / Nt) x 100, where Nt is the number of animals in the tank, $N_{\pm 20}$ is the total number of animals with a weight or length 20% higher or lower than the average live weight in each experimental unit.

Hepatosomatic index and intestinal quotient

Two fish from each tank were euthanized by anesthetic overdose (400 mg L^{-1}) to remove the liver and intestine in order to calculate the hepatosomatic index (HSI) and intestinal quotient (IQ). The recorded liver and intestine weight was measured for each fish, providing the necessary data for calculations. HSI was determined by the formula (liver weight / live weight) x 100, while IQ was calculated as gut length / total fish length.

Statistical analysis

The data were assessed for normality (Shapiro-Wilk test) and homogeneity (Bartlett test). Subsequently, an analysis of variance (ANOVA) was performed; in case of difference, the Tukey test was applied and a regression analysis was performed at a 5% significance level. All the analyses were carried out using the statistical software R (R Core Team, 2024).

Maximum technical efficiency and maximum economic efficiency

The methodology of Nicholson and Snyder (2016) was used to find the values of maximum technical efficiency (MTE) and maximum economic efficiency (MEE). The amount of CP that generated MTE was calculated by equating the first derivative of the production function regarding the amount of protein to zero:

Y= a+bx+cx²

MTE= dy/dx=0

Where y is the production; and x is the amount of CP in the feed.

The MEE was obtained by equating the first derivative of profit regarding the amount of feed on feed and fish prices, according to the equation:

$\pi = p_y y - p_x x$

$\pi = p_y f(x) - p_x x$;

To find the point of maximum profit (π max):

$$\pi\ max => \frac{d\pi}{dx} = p_y \frac{df}{dx} - p_x = 0$$

$$\pi\ max => \frac{df}{dx} = \frac{p_x}{p_y}$$

where π is the profit; p_y is the price of fish; y is the quantity of fish; p_x is the feed price; and *x* is the amount of feed.

The price used for the sale per juvenile unit was R$ 3.00 based on the quotation of the piavuçu species in the local market.

Results

The Fulton condition factor showed a quadratic effect, with fish fed 34% PB presenting significantly better nutritional status and body condition. However, the protein efficiency ratio (PER) showed a decreasing linear effect, with fish fed diets containing 30% CP having significantly better values (Table 2). The weight-length ratio, as indicated by the values of the angular coefficient (b) (Figure 1), falls within the range of 2.5 to 3.5, which is typical for many fish species, indicating good hygiene and welfare (Froese, 2006).

Table 2. Means and standard deviation of productive performance parameters of juveniles of *L. lacustris* fed diets with different levels of crude protein.

Parameters	Crude protein levels (%)				CV
	30	34	38	42	
Total length gain (cm)	2.35 ± 0.21	2.33 ± 0.31	2.08 ± 0.57	2.13 ± 0.27	15.91
Weight gain (g)	4.52 ± 0.36	4.64 ± 1.01	4.12 ± 1.17	3.72 ± 0.74	21.64
Specific growth rate (%)	3.05 ± 0.07	3.07 ± 0.28	3.02 ± 0.37	2.83 ± 0.22	9.25
Protein efficiency rate (%) [1]	15.04 ± 1.20[a]	13.71 ± 2.57[a]	10.84± 2.94[ab]	8.92 ± 1.70[b]	20.44
K Fulton [2]	2.58[b]	2.67[a]	2.52[c]	2.55[bc]	2.44
Relative K	0.99 ± 0.06	1.00 ± 0.04	1.00 ± 0.05	0.99 ± 0.05	3.24
Feed conversion	3.20 ± 0.28	2.77 ± 0.55	3.18 ± 1.03	3.66 ± 1.00	26.50
Uniformity (%)	76.6 ± 13.33	63.33 ± 16.33	73.33 ± 20	76.6 ± 29.05	31.64
Survival (%)	100	100	100	100	0
Hepatosomatic index	0.60 ± 0.12	0.55 ± 0.07	0.65 ± 0.19	0.46 ± 0.09	25.29
Intestinal quotient	0.91 ± 0.08	0.88 ± 0.11	0.91 ± 0.09	0.81 ± 0.06	11.52

*Regression analysis of significant parameters ($p<0.05$) of the productive performance of juveniles of L. lacustris. [1] Protein efficiency rate: 30.1645 – 538.0301x, R^2: 0.9825, (p = 0.0053). [2] K Fulton: -0.1002 + 16.6532x – 25.1063 x2, R^2: 0.8907, (p=0.0175).

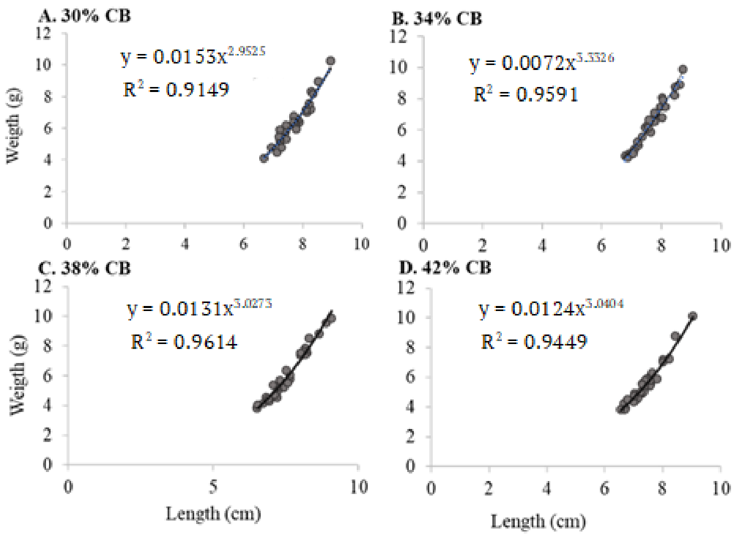

Figure 1. Weight-to-length ratio of *L. lacustris* fed diets with different levels of crude protein (CP).

No significant differences were observed for the variables of final length, weight gain, specific growth rate, relative condition factor, feed conversion, uniformity, survival rate, hepatosomatic index, and intestinal quotient (Table 2). The weight during the 60 days of cultivation is shown in Figure 2 and an feed intake in each treatment and per fish is shown in Figure 3.

The morphometric rates of HSI and IQ of the animals indicated no significant differences, suggesting that the diets did not lead to undesirable fat accumulation in the liver and viscera.

The feed values varied for each amount of crude protein used in each treatment. The prices for 30, 34, 38, and 42% CP were R$ 3.52, R$ 3.76, R$ 4.48, and R$ 6.16, respectively. The quadratic equation yielded an MTE of 31.18% (Figure 4). The mean MEE values for diets containing 30, 34, 38, and 42% CP were calculated to be 31.54, 31.53, 31.52, and 31.48%, respectively, which were lower than the MTE during the experimental period.

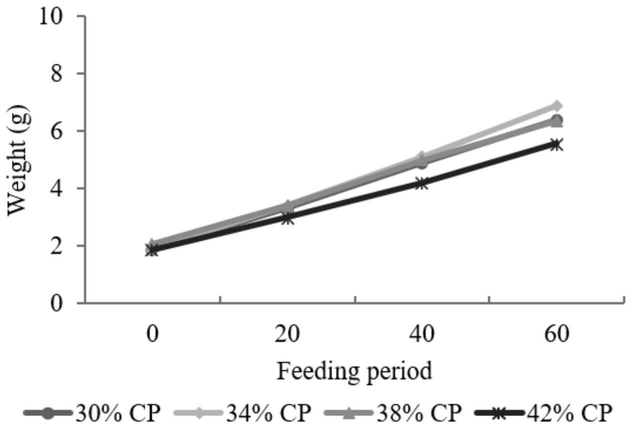

Figure 2. Final weight during the growing days of *L. lacustris* fed different % CP diets.

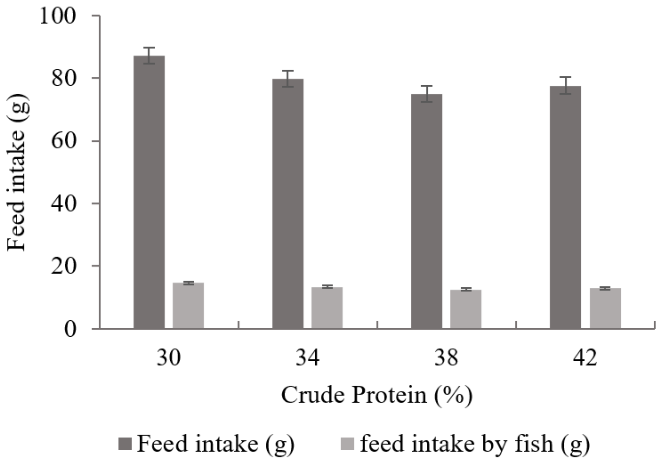

Figure 3. Feed intake during the experiment and feed intake by fish *L. lacustris* fed diets with different levels of crude protein (CP).

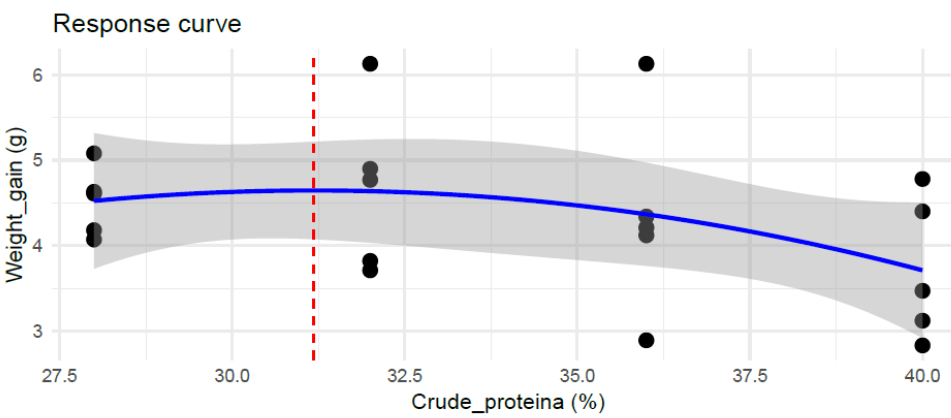

Figure 4. Response curve of the weight gain ratio and crude protein levels in the diet of *L. lacustris*. ---- MET point 31.18%

Discussion

In this study, we investigated the effects of varying levels of crude protein in the diet of juvenile *Leporinus lacustris*. We found that crude protein levels of 30 and 34% were effective in optimizing the growth performance of the juveniles, as they showed improved protein efficiency rates. However, by quadratic regression model fitting the maximum final weight would be achieved with a diet containing 31.18% CP, as indicated by the trend equation of the MTE analysis of the experimental data. This result contrasts with the findings of Feiden et al. (2009), who studied the protein requirements for piavuçu fry (average weight of 0.63 g) and concluded that 38% crude protein resulted in better growth performance.

Dietary protein is crucial for fish nutrition as it is necessary for achieving fast growth and improved feed efficiency (Wang et al., 2016). Proper growth relies on meeting the amino acid requirements for muscle formation and enzymatic function, which vary depending on the fish species under study (Portz & Furuya, 2013; Hua et al., 2019). Fishmeal has been used in diets formulated for *L. lacustris*. According to Han et. al. (2018), fishmeal offers high biological value, balanced amino acids, and significant levels of vitamins, fatty acids, and minerals, making it an excellent ingredient for feed formulation. However, the high cost of fishmeal makes its use economically unfeasible.

In our study, we observed that fish fed with the highest percentage of protein (42%) were less efficient in utilizing dietary protein based on their values of PER. According to Ahmed and Ahmad (2020), diets with high protein levels can decrease the growth rate of fish, as there is greater energy expenditure in metabolizing excess protein instead of using it for growth. This reduced energy availability for muscle growth may have contributed to the lower weight gain observed in fish that received the diet with the highest protein concentration. The requirement for crude protein is also linked to the rate of feed intake, feeding frequency, and the ability of the animal to consume large amounts of feed, as eating behavior directly influences the speed of feed transit in the fish's digestive tract (Signor et al., 2020).

The protein efficiency rate decreased as the protein levels increased. It went from 16.16 g in the diet containing 30% CP to 9.37 g with 42% CP. This suggests that diets with low CP levels were more effective than those rich in protein, a finding consistent with Bicudo et al, (2010). The decrease of PER in diets with higher CP content may have led to increased protein utilization as an energy source (Fracalossi & Cyrino, 2013).

Feiden et al. (2009) investigated the nutritional requirements of crude protein in the diet of piavuçu fry *Leporinus macrocephalus* and found that fish fed with 34% CP showed a better growth performance. Values of 28 and 35% crude protein resulted in good performance without compromising the chemical composition of the *Leporinus* (Pezzato et al., 2000; Bittencourt et al., 2010). The protein requirements may differ based on the fish's feeding behavior and can change as the fish develops. In our study, juveniles of *L. lacrustris* growth performed better with low CP diets, likely due to their omnivorous habit.

The condition factor indicates an animal's welfare based on its feeding condition. A relative condition factor value equal to or greater than 1.00 indicates good growth conditions for the fish, while values less than 1.00 indicate reduced growth (Le Cren, 1951). According to Jisr et al. (2018), this parameter may change due to intrinsic factors, such as organic reserves, gonadal development, and animal size, and extrinsic factors, such as feed availability, temperature, and photoperiod, among others.

The diets tested in this experiment did not negatively impact the fish's development, as the relative condition factor ranged from 0.99 to 1.0. The weight-length ratio of *L. lacustris* fed different percentages of crude protein was similar, indicating that their protein nutritional requirements were met. It is important to conduct studies that investigate different levels of crude protein in fish feed, along with economic analyses, to help choose diets that provide the best cost-benefit (Santos et al., 2018; Bussons et al., 2021). Findings show an optimal point of technical efficiency between the 30 and 34% CP levels, with the best efficiency at 31.18 % CP. Even though no specific data is available in the literature for this species, a study by Feiden et al. (2009) with *Leporinus macrocephalus* found that maximum economic efficiency was achieved with a diet containing 34% CP.

Different diets with varying levels of crude protein were created to meet the requirements of the *L. Lacustris* species. However, it is crucial to consider these diets' optimization and economic efficiency. The practical result indicated that the technical efficiency was similar to the economic efficiency. This result implies that diets with protein levels between 30 and 34% may have been more economical in relation to feed costs while maximizing production and and performance.

Economic efficiency in aquaculture is essential for production to be economically viable and attractive, with feed cost being a crucial factor for the farmer. In the study by Acunha et al. (2023), feed was identified as the third most impactful factor on the effective operational costs in lambari farming, ranking only behind labor and the purchase of juveniles. Similarly, Pires et al. (2025), in evaluating the economic and financial viability of curimba farming, observed that feed costs ranked just below the pro-labore and labor expenses. These studies highlight that, although feed has a significant weight, the production costs of live baits are also strongly influenced by other factors, such as hiring employees and implementing the chosen production system. Furthermore, both works emphasize that the proper selection of feed can improve the species feed efficiency, leading to better productive performance and, consequently, making the activity more economically viable and attractive.

However, the cost of the product should not be the sole consideration when deciding which feed to use. Instead, it should be viewed as part of a set of factors that demonstrate the impact of feed cost on the overall economic outcome of the operation. It involves combining production and economic indicators. In other words, the choice of feed should take into account not only the cost of the product itself but also how this cost affects the overall productive efficiency and financial results of the operation.

Conclusion

Therefore, the diet with 30% crude protein can be recommended for *L. lacustris* juveniles at this stage of cultivation, as it is close to the optimal level for maximizing the species' technical and economic efficiency.

Acknowledgments

The Coordination for the Improvement of Higher Education Personnel (CAPES) for granting a PhD scholarships to Oliveira, F.C and Acunha, R.M. The authors also thank the financial support received through the Notice: Foundation of Support for the Development of Education, Science and Technology of the State of Mato Grosso do Sul—FUNDECT/ MS 19/2021 - Process: 71/049.087/2021.

Data availability

Not applicable.

References

Acunha, R. M. G., Barros, A. F., Ferraz, A. L. J., & Campos, C. M. (2023). Avaliação econômica da lambaricultura em Aquidauana, MS, a partir de um estudo de caso. *Agrarian, 16*(56), 17244-17244. https://doi.org/10.30612/agrarian.v16i56.17244

Almeida, V. N. S. A., Carli, G. C., Satiro, T. M., Nascimento, T. M. T., & Takashashi, L. S. (2023). Digestible protein levels and metabolic responses in juvenile piapara (*Megaleporinus obtusidens*). *Boletim do Instituto de Pesca, 49*, 1-11. https://doi.org/10.20950/1678-2305/bip.2023.49.e754

Ahmed, I., & Ahmad, I. (2020). Effect of dietary protein levels on growth performance, hematological profile and biochemical composition of fingerlings rainbow trout, *Oncorhynchus mykiss* reared in Indian himalayan region. *Aquaculture Research, 16*, 100268. https://doi.org/10.1016/j.aqrep.2019.100268

Arlinghaus, R., Alós, J., Pieterek, T., & Klefoth, T. (2017). Determinants of angling catch of northern pike (*Esox lucius*) as revealed by a controlled whole-lake catch-and-release angling experiment—The role of abiotic and biotic factors, spatial encounters and lure type. *Fisheries Research, 186*(Part 3), 648-657. https://doi.org/10.1016/j.fishres.2016.09.009.

Bandeira, A. M., Leite, G. A., & Soares, L.S. (2024). Pesca artesanal no rio Turiaçu, Santa Helena–MA: registro de uma prática etnocultural. *Revista Sapiência*, *13*(5), 319-338. https://doi.org/10.31668/5nbajg52

Bicudo, A. J. A., Sado, R. Y., & Cyrino, J. E. P. (2010). Growth performance and body composition of pacu *Piaractus mesopotamicus* (Holmberg 1887) in response to dietary protein and energy levels. *Aquaculture Nutrition, 16*(2), 213-222. https://doi.org/10.1111/j.1365-2095.2009.00653.x

Bittencourt, F., Feiden, A., Signor, A. A., Boscolo, W. R., & Freitas, J. M. A. (2010). Proteína e energia em rações para alevinos de piavuçu. *Revista Brasileira de Zootecnia, 39*(12), 2553-2559. https://doi.org/10.1590/S1516-35982010001200001

Bussons, I. N. B., Sousa, E., Aride, P. H. R., Duncan, W. L. P., Pantoja-Lima, J., Furuya, W. M., Oliveira, A. T., Bussons, M. R. F. M., & Faggio, C. (2021). Growth performance, hematological responses and economic indexes of *Colossoma macropomum* (Cuvier, 1818) fed graded levels of glycerol. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 249*, 109122. https://doi.org/10.1016/j.cbpc.2021.109122

Chiaravalloti, R. M., Catella, A., & Siqueira, A. L. (2022). Pesca profissional artesanal no Pantanal sul: histórico, manejo dos recursos e recomendações para a sustentabilidade. *Biodiversidade Brasileira, 12*(2), 1-15. https://doi.org/10.37002/biobrasil.v12i2.1987

Copatti, C. E., Souza, E. M., & Souza, R. C. (2022). Piau-verdadeiro *Megaleporinus obstusidens* (Valenciennes, 1837). In E. M. Souza, & D. F. Amaral (Eds.), *Peixes do rio São Francisco: nativos, endêmicos e exóticos* (pp. 66-72). Editora IFSertãoPE.

Feiden, A., Signor, A. A., Boscolo, W. R., Signor, A., & Reidel, A. (2009). Exigência de proteína de alevinos de piavuçú. *Ciência Rural, 39*(3), 859-865. https://doi.org/10.1590/S0103-84782008005000102

Fracalossi, D. M., & Cyrino, J. E. P. (2015). *Nutriaqua: nutrição e alimentação de espécies de interesse para a aquicultura brasileira*. Aquabio.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology, 22*(4), 241-253. https://doi.org/10.1111/j.1439-0426.2006.00805.x

Froese, R., & Pauly, D. (2023). *FishBase*. https://www.fishbase.org

Han, D., Shan, X., Zhang, W., Chen, Y., Wang, Q., Li, Z., Zhang, G., Xu, P., Li, J., Xie, S., Mai, K., Tang, Q., & Silva, S. S. (2018). A revisit to fishmeal usage and associated consequences in Chinese aquaculture. *Reviews in Aquaculture, 10*(2), 493-507. https://doi.org/10.1111/raq.12183

Hua, K., Suwendi, E., & Bureau, D. P. (2019). Effect of body weight on lysine utilization efficiency in Nile Tilapia (*Oreochromis niloticus*). *Aquaculture, 505*, 47-53. https://doi.org/10.1016/j.aquaculture.2019.02.030

Jisr, N., Younes, G., Sukhn, C., & El-Dakdouki, M. H. (2018). Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. *Egyptian Journal of Aquatic Research, 44*(4), 299-305. https://doi.org/10.1016/j.ejar.2018.11.004

Kubitza, F. (2013). *Qualidade da água no cultivo de peixes e camarões*. Kubitza

Le Cren, E. D. (1951). The length-weight relationship and seasonal cycle in gonadal weight and condition in the perch, *Perca luviatilus. Journal of Animal Ecology, London*, 20(2), 201-219. http://dx.doi.org/10.2307/1540.

Lubich, C., Siqueira-Souza, F., Batista, G., & Freitas, C. (2024). Spatial distribution of the sport fishing in the state of Amazonas, northern Brazil. *Brazilian Journal of Biology, 84*, e282905. https://doi.org/10.1590/1519-6984.282905

Ministério da Pesca e Aquicultura (2023). *Cartilha da pesca amadora e esportiva*. Ministério da Pesca e Aquicultura. https://www.gov.br/mpa/pt-br/assuntos/pesca/pesca-amadora-e-esportiva/cartilha-arte-1.pdf.

National Research Council. (2011). *Nutrient requirements of fish and shrimp.* National Academies Press.

Nicholson, W., & Snyder, C. M. (2016). *Microeconomic theory: basic principles and extensions*. Cengage Learning.

Nguyen, H.Y. N., Trinh, T. L., Baruah, K., Lundh, T., & Kiessling, A. (2021). Growth and feed utilisation of Nile tilapia (*Oreochromis niloticus*) fed different protein levels in a clear-water or biofloc-RAS system. *Aquaculture, 536*, 736404. https://doi.org/10.1016/j.aquaculture.2021.736404

Nyboer, E. A., Embke, H. S., Robertson, A. M., Arlinghaus, R., Bower, S., Baigun, C., Beard, D., Cooke, S. J., Cowx, I. G., Koehn, J. D., Lyach, R., Milardi, M., Potts, W., & Lynch, A. J. (2022). Overturning Stereotypes: The Fuzzy Boundary Between Recreational and Subsistence Inland Fisheries. *Fish and Fisheries, 23*(6), 1282-298. https://doi.org/10.1111/faf.12688

Paula, G. H., Calabresi, G. E., Boff, J. E. D., Figueiredo, L. P., Fonseca, C., Coldebella, A., Reidel, A., & Signor, A. A. (2020). Manejo alimentar de piavuçu (*Leporinus macrocephalus*) na fase inicial de cultivo. *Brazilian Journal of Development, 6*(7), 53053-53065. https://doi.org/10.34117/bjdv6n7-813

Pezzato, L. E., Barros, M. M., Pezzato, A. C., Miranda, E. C., Quintero, P. G. L., & Furuya, W. M. (2000). Relación energía: proteína en la nutrición de alevinos de piacu (*Leporinus macrocephalus*). *Revista de la Facultad de Medicina Veterinaria y de Zootecnia, 47*(2), 2-6.

Portz, L., & Furuya, W. M. (2013). Energia, proteína e aminoácidos. In D. Fracalossi, J. E. Cyrino (Eds.), *Nutriaqua:nutrição e alimentação de espécies de interesse para a aquicultura brasileira* (1. ed., pp. 65-77). Aquabio.

Pires, D. C., Bezerra, G. A., Souza, E. G. C., Castro, P. L., Acunha, R. M. G., & Campos, C. M. (2025). Economic and financial analysis of live bait production of curimba: a case study. *Ciência Animal Brasileira, 26*, 80319E. https://doi.org/10.1590/1809-6891v26e-80319E

R Core Team. (2024). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Santos, E. L., Oliveira, W. D. S., Soares, E. C., Lima, M. R., Silva, L. L. A., Machado, S. S., Silva, J. M., Silva, C. F., & Silva, F. F. (2018). Exigência de proteína bruta para juvenis de curimatã-pacu. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 70*(3), 921-930. https://doi.org/10.1590/1678-4162-9872

Sebrae. (2021). *Planejamento pode contribuir para o aumento da pesca esportiva.* https://sebrae.com.br/sites/PortalSebrae/conteudos/posts/planejamento-pode-contribuir-para-o-aumento-da-pescaesportiva

Sidlauskas, B. L., Assega, F. M., Melo, B. F., Oliveira, C., & Birindelli, J. L. (2022). Total evidence phylogenetic analysis reveals polyphyly of Anostomoides and uncovers an unexpectedly ancient genus of *Anostomidae* fishes (Characiformes). *Zoological Journal of the Linnean Society, 194*(2), 626-669. https://doi.org/10.1093/zoolinnean/zlab016

Silva, D. J., & Queiroz, A. C. (2002). *Análise de alimentos: métodos químicos e biológicos*. Editora UFV.

Signor, A. A., Buglione Neto, C. C., Figueiredo, E. F., Signor, F. R. P., Watanabe, A. W., Ferreira, H. K. A., & Reidel, A. (2020). Manejo alimentar de juvenis de jundia (*Rhamdia quelen*) cultivado em tanques-rede: tipos de rações, taxas de arraçoamento e estratégia alimentar. *Brazilian Journal of Development, 6*(7), 48531-48546. https://doi.org/10.34117/bjdv6n7-483

Sousa, W. B. B., Diniz, M. B. G., Souza, E. A., & Soares, C. B. D. (2024). Levantamento das espécies de peixes da família Anostomidae na região Nordeste do Brasil. In W. B. B. Sousa, M. F. B. G. Diniz, A. C. Sousa, A. T. S. Lima, A. J. F. Lopes, J. R. L. Silva, C. B. D. Soares, D. F. Antunes, B. M. Alcântara, T. S. D. Viração, A. J. M. Bento, S. M. Santos, J. C. X. Nunes, M. D. C. Martins, & J. A. O. Borges (Orgs.), *Explorando a biodiversidade e desafios epidemiológicos no Nordeste brasileiro* (pp. 76-85). Editora Omnis Scientia.

Vazzoler, A. E. A. M. (1996). *Biologia da reprodução de peixes teleósteos: teoria e prática.* Nupélia.

Volkoff, H., & London, S. (2018). Nutrition and reproduction in fish. *Encyclopedia of Reproduction, 6*, 743-748. https://doi.org/10.1016/B978-0-12-809633-8.20624-9

Ye, G., Dong, X., Yang, Q., Chi, S., Liu, H., Zhang, H., Tan, B., & Zhang, S. (2020). Low-gossypol cottonseed protein concentrate used as a replacement for fishmeal for juvenile hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *Epinephelus lanceolatus* ♂): effects on growth performance, immune responses, and intestinal microbiota. *Aquaculture, 524*,735309. https://doi.org/10.1016/j.aquaculture.2020.735309

Wang, J., Jiang, Y., Li, X., Han, T., Yang, Y., Hu, S., & Yang, M. (2016). Dietary protein requirement of juvenile red spotted grouper (Epinephelus akaara). *Aquaculture*, *450*, 289-294.