The effect of feeding frequency on the economic efficiency of catfish (*Clarias gariepinus*) cultivation: a linear regression approach

[1]M. Amri, [2]Siti Aisyah

[1] Department of Agricultural Extension, Universitas Prima Nusantara Bukittinggi, Bukittinggi City, West Sumatra, Indonesia; [2] Department of Aquatic Resource Management, Faculty of Science, Nahdlatul Ulama University of West Sumatra, Padang City, Indonesia. Corresponding author: M. Amri, muhammadamri327@gmail.com

Abstract. Catfish (*Clarias gariepinus*) cultivation is one of the potential fisheries sectors, but economic efficiency is often influenced by various factors such as feeding frequency, feed quality, and pond environmental conditions. This research aimed to analyze the effect of feeding frequency on economic efficiency in catfish cultivation in Padang City, by considering feed quality and pond conditions as control variables. The research method used was multiple linear regression analysis with data from 85 respondents obtained through interviews and observations. The independent variable of this research was the frequency of feeding, while the control variables included feed quality and pond conditions, with economic efficiency as the dependent variable. The results showed that feeding frequency and feed quality had a significant effect on economic efficiency, while pond conditions had a smaller but still significant effect. These findings emphasize the importance of appropriate feeding strategies, investment in high-quality feed, and good pond condition management to improve economic efficiency in catfish cultivation.

Key Words: aquaculture economics, catfish farming, feeding management, feed quality, linear regression.

Introduction. Catfish (*Clarias gariepinus*) cultivation in Indonesia, particularly in Padang City, West Sumatra, has experienced rapid growth in recent years. According to the Padang City Fisheries Service (2022), the total production of catfish in Padang increased by 35% between 2018 and 2022, reaching 2,450 tons year^{-1}. Padang City, the capital of West Sumatra Province, holds significant potential for the development of aquaculture, including catfish, which is a leading commodity due to its adaptability to various environmental conditions and high market demand. However, this rapid growth has also led to several challenges related to economic efficiency, particularly because feed costs account for up to 60-70% of total production expenses (Dauda et al 2018). However, catfish farmers in Padang City face several challenges that impact their economic efficiency, with suboptimal feed management being one of the most critical issues. Feeding management plays a pivotal role in catfish cultivation. Inappropriate or excessive feeding frequencies can lead to significantly higher feed costs. Inefficient feeding practices result in waste, ultimately reducing farmers' profit margins. Conversely, inadequate feeding can negatively affect fish growth, leading to suboptimal production outcomes (Uzochukwu et al 2023; Mugo-Bundi et al 2024). In Padang City, most catfish farmers operate on a small to medium scale with pond sizes ranging from 200 to 500 m^2, average stocking densities of 80-100 fish per m^2, and feeding costs representing 60-70% of total operational expenses (Padang City Fisheries Service 2022). Previous studies have highlighted that feed quality and feeding frequency are crucial factors in improving the economic efficiency of catfish farming (Giri et al 2003; Dauda et al 2018). Therefore, to sustain the industrial growth of catfish farming in Padang City, it is essential to investigate how feeding frequency affects economic efficiency and identify feeding strategies that balance growth and cost-effectiveness.

In addition to feeding frequency, other factors that influence the efficiency of catfish farming include feed quality and pond environmental conditions. Low feed quality, for instance, can increase the feed conversion ratio (FCR), meaning that farmers require more feed to achieve the desired fish growth (Shi et al 2024). Pond environmental conditions, such as temperature, pH, and oxygen levels, also significantly impact fish health, which, in turn, affects productivity and economic efficiency (Allam et al 2020; Padang City Fisheries Service 2022).

This research aimed to analyze the effect of feeding frequency on economic efficiency in catfish farming in Padang City, while considering control variables such as feed quality and pond environmental conditions. The study adopts a quantitative approach with an explanatory design, which is commonly used in socio-economic research to examine relationships between specific variables (Gujarati 2004; Walpole et al 2012). Multiple linear regression analysis was employed to provide insights into how proper management of feeding frequency, high-quality feed, and well-maintained environmental conditions can enhance economic efficiency in catfish cultivation in Padang City.

Material and Method. This study adopted a quantitative approach with an explanatory design. The main objective was to determine the effect of feeding frequency on economic efficiency in catfish farming, while considering control variables such as feed quality and pond environmental conditions. The quantitative approach and explanatory design are widely utilized in studies that aim to examine relationships between variables in a socio-economic context (Gujarati 2004). Data were collected between March and July 2024 through a structured survey using both questionnaires and direct interviews with catfish farmers to ensure clarity and completeness of responses. To control the accuracy of the data, cross-verification was conducted by comparing farmer-reported information with records from the Padang City Fisheries Service and field observations. To achieve this objective, multiple linear regression analysis was employed to assess the impact of feeding frequency on economic efficiency, as well as the influence of control variables like feed quality and pond environmental conditions. Multiple linear regression is a widely recognized technique for analyzing relationships between several independent and dependent variables in socio-economic research (Walpole et al 2012). The model used in this study is as follows:

$$Y = \beta 0 + \beta 1X + \beta 2Z_1 + \beta 3Z_2 + \epsilon \quad (1)$$

where: Y = economic efficiency (income per kg of fish, feed cost per kg of fish;
X = feeding frequency (total of feeds per day);
Z_1 = feed quality (nutrient content in the feed);
Z_2 = pond environmental conditions (water temperature, pH, and dissolved oxygen content);
β_0 = constant;
β_1, β_2, β_3 = coefficients that show the effect of each variable on economic efficiency;
ε = error term representing unobserved factors not included in the model, assumed to have a mean value of zero and constant variance σ^2, with its significance tested through the classical assumption tests (normality, homoscedasticity, and independence).

The population for this research consisted of catfish farmers in Padang City, totaling 108 individuals. Using the Slovin formula (Ghozali 2011; Huberty & Petoskey 2020), $n = N / (1 + N(e)^2)$, where n = sample size, N = population size (108 farmers), and e = margin of error (0.05 or 5%), the required sample size was calculated to be approximately 85 catfish farmers. A simple random sampling technique was employed to ensure that the sample adequately represented the population. This technique was chosen because the population of catfish farmers in Padang City is relatively homogeneous in terms of farming practices, pond sizes, and feed management patterns. Therefore, each farmer had an equal probability of selection, minimizing sampling bias and providing a representative sample of the entire population. Stratified or purposive sampling methods were deemed unnecessary as there were no distinct subgroups or criteria requiring separate analysis. The definition of each variable used in the regression model, along with their respective indicators, is presented in Table 1 to provide clarity regarding variable measurement and operationalization.

Table 1

Research variables

No.	*Variables*	*Variable types*	*Indicators*
1	Economic efficiency	Dependent	• Income per kg of catfish (USD) • Feed cost per kg of fish (USD) • Feed conversion ratio (FCR)
2	Feeding frequency	Independent	• Amount of feeding per day used by farmers (frequency and total of feed in kg)
3	Feed quality	Control	• Nutritional content of feed (protein, fat, and carbohydrates in feed) • Type of feed used: pellets or natural feed (type/concentration)
4	Pool environmental conditions	Control	• Water temperature in pond (°C) • pH of pond water • Dissolved oxygen content in pond water (mg L^{-1})

Feed quality and pond environmental conditions were selected as control variables because previous studies have consistently shown them to be the most significant external factors influencing fish growth and production costs besides feeding frequency (Dauda et al 2018; Uzochukwu et al 2023). These variables directly affect feed conversion efficiency and fish health, which in turn determine economic outcomes. Other potential factors, such as market price fluctuations, farmer experience, and access to credit, were not included because they introduce high variability beyond the scope of this study's focus on biological and technical determinants of economic efficiency. By controlling feed quality and pond conditions, we ensured that the effect of feeding frequency on economic efficiency was not confounded by major environmental and nutritional factors.

Data analysis technique. Before performing the regression analysis, a classical assumption test was conducted to ensure that the data met the requirements for multiple linear regression. This test included a normality test to verify that the residuals followed a normal distribution, a multicollinearity test to check for high correlations between independent variables, and a heteroscedasticity test to ensure that the variance of residuals was consistent across different values of the independent variables. Once the data satisfied these assumptions, a multiple linear regression analysis was conducted to examine the relationship between feeding frequency and economic efficiency, with feed quality and pond environmental conditions serving as control variables.

The data analysis process involved several steps. First, a multicollinearity test was conducted to ensure the absence of strong correlations among the independent variables (Gujarati 2004). This was followed by a multiple linear regression analysis to examine the effect of feeding frequency on economic efficiency, with feed quality and pond environmental conditions included as control variables. Subsequently, a t-test was employed to assess the statistical significance of each independent variable, while an F-test was utilized to evaluate the overall significance of the regression model. The significance testing procedure encompasses three key stages: the t-test determines the individual significance of each variable on economic efficiency, the F-test assesses the collective significance of the regression model, and the coefficient of determination (R^2)

quantifies the proportion of variation in the dependent variable explained by the independent variables in the model. All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA), which is widely used for econometric and socio-economic research.

Results. Following the assessment of 85 catfish farmers in Padang City, the results are summarized in Table 2.

Table 2

Indicator assessment results

Variables	*Indicator*	*Assessment results*			
		Minimum	*Maximum*	*Mode*	*Mean*
Economic efficiency	Income per kg of catfish (USD)	0.95	1.52	1.52	1.35
	Feed cost per kg of fish (USD)	0.44	0.57	0.51	0.49
	Feed conversion ratio (FCR)	1	2	2	2
Feeding frequency	Feeding frequency (times/day)	2	5	2	3
	Total of feed per day (kg)	2	3	2	2
Feed quality	Protein (%)	28	36	30	32
	Fat (%)	6	10	8	8
	Carbohydrate (%)	12	18	16	15
	Type of feed used	Artificial feed	Natural feed	Artificial feed	Artificial feed
Environmental conditions	Pond water temperature (°C)	27	31	30	29
	Pond water pH	7	8	7	7
	Dissolved oxygen content (mg L^{-1})	5	7	6	6

The average income per kilogram of catfish was 1.35 USD, with a range of 0.95 USD to 1.52 USD, indicating stable profit potential. The most frequently observed income (mode) was 1.52 USD, suggesting a profitable sales level under optimal conditions. The average feed cost per kilogram of fish was 0.49 USD, with a range of 0.44 to 0.57 USD. The mode for feed cost was 0.51 USD, reflecting a relatively controlled level of operational cost efficiency. The average FCR was recorded at 2, indicating efficient feed utilization for fish weight gain. While this FCR value is already considered satisfactory, there is still potential for further improvements to optimize productivity and reduce production costs.

The average feeding frequency was three times per day, with a range of two to five times per day, reflecting flexibility in feeding practices based on the needs of the fish. The average amount of feed given per day was 2 kg, with the most frequently observed amount (mode) being 2 kg. This feeding amount can be adjusted further to align with the requirements of fish growth and environmental conditions, ensuring efficient feed utilization while maintaining optimal fish growth.

The feed used in catfish farm contains adequate nutritional content to support fish growth, with an average composition of 32% protein, 8% fat, and 15% carbohydrates. High protein content is particularly beneficial for accelerating catfish growth, while fat and carbohydrates provide essential energy. The most commonly used type of feed is artificial feed, reflecting farmers' preference for easily accessible feed with consistent nutritional quality to enhance farm productivity (Obirikorang et al 2015; Eriza et al 2022; Stone et al 2024). Previous studies have shown that feed with protein content above 30% can significantly increase growth rates and feed efficiency in catfish farming, while maintaining optimal feed conversion ratios (Giri et al 2003; Dauda et al 2018). Moreover, the use of artificial feed with balanced nutrients has been linked to improved fish health and reduced mortality rates, which directly contributes to higher economic efficiency (Uzochukwu et al 2023; Hildebrand et al 2024).

The average pond water temperature was recorded at 29°C, with a range of 27 to 31°C. This temperature falls within the optimal range for supporting catfish growth, indicating stable environmental conditions in the ponds (Setyawan et al 2019; Hlordzi et al 2020). Additionally, the average water pH was measured at 7, representing a neutral condition that is ideal for fish health (Sinha et al 2022). The average dissolved oxygen content was 6 mg L^{-1}, which is sufficient to meet the needs of catfish (Wambua et al 2021; Araujo et al 2025). However, the DO content occasionally reaching a minimum value of 5 mg L^{-1} highlights the importance of maintaining water quality, particularly in ponds with high fish densities, to prevent fish stress and ensure consistent growth (Toko et al 2007; Yildiz et al 2017).

The results of the statistical tests confirm that all assumptions required for linear regression analysis are satisfied. The normality test (Shapiro-Wilk) yielded a p-value > 0.05, indicating that the data is normally distributed and the assumption of normality is met. The multicollinearity test, assessed using variance inflation factor (VIF), revealed no indication of multicollinearity among the independent variables, thus satisfying the assumption of independent predictors. Furthermore, the heteroskedasticity test (Breusch-Pagan) showed no evidence of heteroskedasticity in the model, with a p-value > 0.05, thereby fulfilling the assumption of homoscedasticity. As the assumptions of normality, absence of multicollinearity, and homoscedasticity are met, the regression results are considered valid and can be reliably interpreted for subsequent analysis.

The classical assumption tests presented in Table 3 indicate that the data met all necessary requirements for multiple linear regression analysis. The Shapiro-Wilk test confirmed normality ($p = 0.623 > 0.05$), the VIF values below 10 showed no multicollinearity (VIF = 1.053–1.034), and the Breusch-Pagan test confirmed the absence of heteroskedasticity ($p = 0.778 > 0.05$).

Table 3

Classic assumption test results

Test	*Statistic*	*Conclusion*
Normality (Shapiro-Wilk)	Statistic: 0.988 p-value: 0.623	Data is normally distributed
Multicollinearity (VIF)	const: 41463.060 Feed frequency (X): 1.053 Feed quality (Z_1): 1.026 Pond condition (Z_2): 1.034	No multicollinearity detected
Heteroskedasticity (Breusch-Pagan)	LM statistic: 1.095 p-value: 0.778 f-stat: 0.352 f p-value: 0.788	No heteroskedasticity detected

The results of the regression analysis presented in Table 4 show that feeding frequency (X) had the highest positive and significant effect on economic efficiency ($\beta = 18.460$, $p < 0.001$), followed by feed quality (Z_1) ($\beta = 8.471$, $p < 0.001$) and pond environmental conditions (Z_2) ($\beta = 1.483$, $p = 0.048$).

Table 4

Results of regression analysis

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*p-value*	*Significance*
Const	-792.825	146.538	-5.41	0.000	Yes
Feed frequency (X)	18.460	4.873	3.788	0.000	Yes
Feed quality (Z_1)	8.471	1.481	5.718	0.000	Yes
Pond condition (Z_2)	1.483	0.74	2.004	0.048	Yes

Relationship between independent and dependent variables. The regression analysis identified the following relationships between the independent variables and the dependent variable, economic efficiency:

- Feeding frequency (X): the coefficient of 18.460 indicates a strong positive relationship. Each additional unit increase in feeding frequency results in an 18.460-unit increase in economic efficiency. This effect is highly significant ($p < 0.001$).

- Feed quality (Z_1): a coefficient of 8.471 shows a substantial positive impact. Improving feed quality by one unit increases economic efficiency by 8.471 units. This relationship is statistically significant ($p < 0.001$).
- Pond conditions (Z_2): The coefficient of 1.483 implies a slight positive effect. Improved pond conditions enhance economic efficiency by 1.483 units, with a marginally significant relationship ($p = 0.048$).

Model performance. The performance of the regression model is as follows:

- R-squared: 0.745, indicating that 74.5% of the variability in economic efficiency is explained by the independent variables;

- adjusted R-squared: 0.321, accounting for the number of predictors in the model;

- F-statistic: 14.23 ($p < 0.001$), demonstrating that the model is statistically significant;

- Durbin-Watson statistic: 1.716, suggesting no significant autocorrelation in the residuals.

All values, including R-squared, adjusted R-squared, F-statistic, and the Durbin-Watson statistic, were automatically generated by the regression output in SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The Durbin-Watson statistic specifically was used to test for the presence of autocorrelation in the residuals, with values between 1.5 and 2.5 generally indicating no serious autocorrelation (Gujarati 2004).

Regression equation. The regression equation derived from the analysis is:

$$Y = -792.826 + (18.460 \cdot X) + (8.471 \cdot Z1) + (1.483 \cdot Z2) \quad (2)$$

where: Y = economic efficiency;
X = feeding frequency;
Z_1 = feed quality;
Z_2 = pond conditions.

The regression model indicated that feeding frequency and feed quality exerted the most significant and substantial positive effects on economic efficiency, while pond environmental conditions contributed a smaller yet positive impact. The model is statistically robust, with all assumptions normality, absence of multicollinearity, and homoskedasticity satisfactorily met. These findings suggest actionable strategies to enhance economic efficiency, emphasizing the optimization of feeding practices and improvements in feed quality as key priorities.

Discussion

Economic efficiency. The results of the analysis indicate that catfish farming has a relatively high profit potential. The average income per kilogram of catfish is 1.35 USD, while the average feed cost is 0.49 USD per kilogram of fish, suggesting a relatively large profit margin. The most frequent income (mode), at 1.52 USD, indicates that under optimal conditions, this farm method can generate higher income. However, the average FCR of 2, although considered quite efficient, still leaves room for improvement. Optimizing feed management to reduce the FCR value could significantly enhance overall profitability.

Research by Koagne et al (2025) indicated that technical efficiency in catfish farming has not yet reached its maximum potential, with an average technical efficiency of 0.935. This suggests that there is room for improvement in the management of production factors. Similar findings were reported by Shalih & Hayati (2021), who employed the Cobb-Douglas production function model. Their study recorded the technical efficiency of catfish farming in Nigeria District at 0.91, further indicating the potential for efficiency improvements. Meanwhile, the technical efficiency of catfish farming in Nigeria averaged 0.85, with economic efficiency at only 0.66, highlighting that catfish farming in the region is not yet economically efficient (Olagunju et al 2024). To enhance efficiency, several technologies can be applied. For example, the use of a biofloc system with a higher carbon-to-nitrogen (C/N) ratio has been shown to improve fish growth and reduce the FCR, achieving a minimum FCR value of 1.06 (Limbu 2020). Additionally, Shahariar et al (2024) demonstrated that using black soldier fly maggots as an alternative to commercial pellets can lower FCR and enhance catfish growth. The application of biofloc technology in dumbo catfish farm has also been proven to reduce FCR to as low as 0.64 while significantly decreasing feed costs (Huang et al 2025). Overall, these studies highlight that economic efficiency in catfish farming can be significantly improved through better management practices, the adoption of innovative technologies, and the use of alternative feed sources. Implementing these strategies not only reduces production costs and increases profitability but also promotes the long-term sustainability of catfish farming.

Feeding frequency*.* The average feeding frequency was three times per day, with a range of two to five times. This practice aligns with the nutritional needs of the fish, as an ideal feeding frequency supports optimal growth while minimizing waste. The average amount of feed provided daily was 2 kg, with a mode of 2 kg, indicating that the majority of farmers adopt an efficient approach to feed management. Nevertheless, further adjustments based on fish growth rates and activity levels could enhance feed efficiency.

The results of the analysis reveal a strong positive relationship between feeding frequency and economic efficiency, with a coefficient of 18.460. This coefficient represents the change in economic efficiency measured as net income (in USD) per kilogram of catfish produced. Specifically, each additional feeding session per day increases the net income by 18.460 USD per metric ton of production, holding feed quality and pond conditions constant. This indicates that each additional feeding session per day increases economic efficiency by 18,460 units. The significance of this variable ($p < 0.001$) underscores the critical role of feeding frequency in enhancing catfish farm outcomes. However, excessive feeding should be avoided, as it can lead to resource wastage and deterioration of water quality. Therefore, a well-planned feeding schedule is essential to optimize efficiency while preserving environmental quality.

Research by Hildebrand et al (2024) showed that a feeding frequency of 6 times per day provided the best length growth in catfish compared to frequencies of 2 and 4 times per day. Okomoda et al (2019) and Wu et al (2021) emphasized the importance of the right feeding frequency in catfish farm. They found that feeding 5 times a day provided the best growth in dumbo catfish kept in bucket media. Efficient feeding management can reduce production costs and increase sales results in catfish farming (Almazán-Rueda et al 2004; Abdel-Aziz et al 2021; Elesho et al 2021).

Higher feeding frequency can increase the daily growth rate and absolute growth of Sangkuriang catfish (*Clarias* sp.) seeds (Salhi et al 2004). Rodjaroen et al (2024) stated that good feeding management, including the right frequency, can increase feed efficiency and growth of pearl catfish. Thus, optimal feeding frequency management is very important in catfish farm to achieve maximum growth and feed efficiency, while maintaining water quality and the farm environment.

Feed quality*.* The nutritional content of the feed used, with an average protein of 32%, fat of 8%, and carbohydrate of 15%, indicates a fairly high feed quality. Significant protein content contributes to faster fish growth, while fat and carbohydrates provide adequate energy. The selection of artificial feeds most often used by farmers shows a preference for consistent and easily accessible feed sources. However, testing alternative feeds, such as natural feeds, can be an option to improve cost efficiency and nutritional quality.

Feed quality also has a major influence, with a coefficient of 8.471. High-quality feed provides the nutrients needed for fish growth, which ultimately increases economic efficiency. The significance of this variable ($p < 0.001$) indicates that investment in high-quality feed is essential to increase productivity and economic output. These results are in line with previous studies that emphasize the importance of feed in supporting farm productivity. Therefore, catfish farm managers must prioritize access to high-quality feed as part of an efficiency-increasing strategy.

Research by Eriza et al (2022) and Stone et al (2024) confirmed that high-quality feed, which has complete nutritional content and economical price, can increase catfish productivity. Obirikorang et al (2015) and Arisa et al (2018) showed that the use of local raw materials as catfish feed can increase farm productivity, with absolute weight and length growth of 9.94 g and 3.83 cm, respectively, and feed efficiency of 103.24%. Utomo et al (2013) found that fish meal from various raw materials plays a role in the growth of Sangkuriang catfish, showing the importance of feed quality in supporting farm productivity.

High cost and low quality of feed are obstacles in the farm process, so that additional ingredients (feed additives) are needed to be added to the feed to obtain better fish growth and feed efficiency (Hasan & Shipton 2021; Kaleem & Sabi 2021; Amri et al 2023; Kumar et al 2023; Roslan et al 2024). Natural and artificial feed affects the growth and survival of African catfish seeds, emphasizing the importance of feed quality in catfish cultivation (Ferosekhan et al 2020; Limbu 2020; Rahman et al 2020; Ilmi et al 2023; Hildebrand et al 2024).

Thus, catfish farming managers must prioritize access to high-quality feed as an integral part of the efficiency improvement strategy. This effort can be done by choosing a trusted feed brand, evaluating the nutritional content of the feed, and ensuring consistent feed availability. Investment in high-quality feed can be considered a strategic step to increase the profitability and sustainability of catfish farming businesses.

Pond condition*.* Stable pond environmental conditions also support the success of catfish cultivation. The average temperature of 29°C with a range of 27 to 31°C is within the optimal range for fish growth. The average water pH of 7 indicates neutral water conditions and supports fish health. The average dissolved oxygen content of 6 mg L^{-1} is also sufficient for fish respiration needs. However, the minimum dissolved oxygen value of 5 mg L^{-1} needs to be watched out for, especially in ponds with high fish density. Routine water quality monitoring and the use of aerators can be a solution to maintain dissolved oxygen stability.

Although the influence of pond condition is smaller (coefficient = 1.483), this variable is still statistically significant (p = 0.048). Well-maintained pond conditions, including water quality and physical infrastructure, create a healthy environment for catfish growth. This suggests that efforts to improve pond conditions, although not the main factor, can still provide significant benefits. For example, practices such as regular pond cleaning, aeration, and water quality monitoring can help optimize economic outcomes.

Water quality parameters such as dissolved oxygen, pH, temperature, and ammonia concentration must be managed effectively to ensure maximum catfish growth (Hlordzi et al 2020; Saha et al 2022; Sinha et al 2022). Polluted water can cause stress to fish, reduce feed efficiency, and increase mortality rates (Wambua et al 2021; Uzochukwu et al 2023; Araujo et al 2025). In addition, practices such as regular pond cleaning, aeration, and periodic water quality monitoring are also important elements in pond management. Adequate aeration can increase dissolved oxygen levels in ponds, which have a positive impact on catfish growth rates and feed efficiency (Toko et al 2007; Yildiz et al 2017; Calone et al 2019). Cleaning the bottom of the pond from leftover feed and organic waste prevents the accumulation of organic matter that can reduce water quality. Periodic water quality monitoring, such as measuring pH, temperature, and ammonia levels, helps maintain stable pond conditions. In this study, ammonia concentration was not included as a control variable because most sampled farms reported relatively homogeneous ammonia levels resulting from similar water management practices. Additionally, field measurements of ammonia were not consistently available across all farms during the study period. As a result, dissolved oxygen, pH, and temperature were prioritized as control variables due to their more direct and consistent influence on fish health and economic efficiency. Future studies should integrate ammonia data to provide a more comprehensive analysis of water quality impacts.

Ponds with good management can increase fish growth rates by up to 20% compared to poorly maintained ponds (Setyawan et al 2019). These results indicate that although pond conditions are not the main factor such as feed quality or feeding frequency, well-maintained ponds still provide real benefits both biologically and economically. Therefore, catfish farming managers must integrate best practices into pond management to support sustainable productivity. Investing in pond maintenance that includes aeration, regular cleaning, and water quality monitoring is a strategic step to ensure optimal results and cost efficiency in catfish farming.

Practical implications. The results of this research provide several practical recommendations for fish farmers to improve the economic efficiency and productivity of catfish farming businesses.

Feeding strategy. Adjusting the frequency of feeding has been shown to have a significant impact on economic efficiency. By increasing or adjusting the amount of feed given according to the needs of the fish, farmers can maximize growth and yields. However, excessive feeding should be avoided because it can waste resources, increase production costs, and reduce pond water quality. A feeding frequency of five times a day gives the best results in African catfish farming (Okomoda et al 2019; Komariyah et al 2024).

Investment in feed quality. Allocating resources to purchase high-quality feed provides substantial economic benefits. High-quality feed increases feed efficiency, accelerates fish growth rates, and reduces unused feed waste. The use of quality feed with additional feed additives can increase feed efficiency and catfish growth (Chris et al 2018; Essa et al 2011; Roslan et al 2024).

Pond maintenance. Although its impact on economic efficiency is not as great as the frequency or quality of feed, maintaining optimal pond conditions is an important part of an integrated approach to cultivation. Practices such as regular pond cleaning, aeration, and water quality monitoring help maintain fish health, prevent the accumulation of organic waste, and increase feed efficiency. Good pond management can increase fish growth and reduce the risk of disease (Kautsky et al 2000; Bosma & Verdegem 2011; Opiyo et al 2018; Elesho et al 2021).

Conclusions. Based on the results of the analysis, the frequency of feeding has a significant positive relationship with economic efficiency. Every increase in the frequency of feeding tends to increase economic efficiency, as long as the quality of the feed is maintained and the pond conditions are supportive. Feed quality as a control variable also shows a significant effect, where feed with high nutritional content contributes to optimal fish growth and feed use efficiency. In addition, pond environmental conditions, although their impact is smaller, still provide real benefits in supporting economic efficiency, especially through maintaining stable water quality and implementing good pond management practices. The results of this research indicate that the right feeding strategy, coupled with management of feed quality and pond conditions, are the keys to increasing economic efficiency in catfish farming.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Abdel-Aziz M. F. A., Hassan H. U., Yones A. M., Abdel-Tawwab Y. A., Metwalli A. A. A. T., 2021 Assessing the effect of different feeding frequencies combined with stocking density, initial weight, and dietary protein ratio on the growth performance of tilapia, catfish and carp. Scientific African 12:e00806.

Allam B. W., Khalil H. S., Mansour A. T., Srour T. M., Omar E. A., Nour A. A., 2020 Impact of substitution of fish meal by high protein distillers dried grains on growth performance, plasma protein and economic benefit of striped catfish (*Pangasianodon hypophthalmus*). Aquaculture 517:734792.

Almazán-Rueda P., Schrama J. W., Verreth J. A., 2004 Behavioral responses under different feeding methods and light regimes of the African catfish (*Clarias gariepinus*) juveniles. Aquaculture 231(1-4):347-359.

Amri M., Aisyah S., Husni E., 2023 [Feed adaptation by using *Leucaena leucocephala* as a replacement of soybean flour for *Osphronemus gourami* feed]. Berkala Perikanan Terubuk 51(3):2042-2049. [in Indonesian]

Araujo A. N., San Andres C. F., Nguyen K. Q., Corby T. L., Rhodes M. A., García J., Roy L. A., Davis D. A., 2025 Effects of minimum dissolved oxygen setpoints for aeration in semi-intensive pond production of Pacific white shrimp (*Litopenaeus vannamei*). Aquaculture 594:741376.

Arisa I. K., Fadil N., Anwar A., Nizamuddin N., Parmakope P., 2018 Utilization of organic waste as raw material of fish feed production for African catfish *Clarias gariepinus*. IOP Conference Series: Earth and Environmental Science 216:012035.

Bosma R. H., Verdegem M. C. J., 2011 Sustainable aquaculture in ponds: principles, practices and limits. Livestock Science 139:58-68.

Calone R., Pennisi G., Morgenstern R., Sanyé-Mengual E., Lorleberg W., Dapprich P., Wincler P., Orsini F., Gianquinto G., 2019 Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics. Science of the Total Environment 687:759-767.

Chris U. O., Singh N. B., Agarwal A., 2018 Nanoparticles as feed supplement on growth behaviour of cultured catfish (*Clarias gariepinus*) fingerlings. Materials Today: Proceedings 5(3):9076-9081.

Dauda A. B., Romano N., Chen W. W., Natrah I., Kamarudin M. S., 2018 Differences in feeding habits influence the growth performance and feeding efficiencies of African catfish (*Clarias gariepinus*) and lemon fin barb hybrid (*Hypsibarbus wetmorei* ♂ × *Barboides gonionotus* ♀) in a glycerol-based biofloc technology system versus a recirculating system. Aquacultural Engineering 82:31-37.

Elesho F. E., Kröckel S., Ciavoni E., Sutter D. A. H., Verreth J. A. J., Schrama J. W., 2021 Effect of feeding frequency on performance, nutrient digestibility, energy and nitrogen balances in juvenile African catfish (*Clarias gariepinus*) fed diets with two levels of crystalline methionine. Animal Feed Science and Technology 281:115098.

Eriza M., Lubis A. S., Amri M., Arlius A., Elfrida E., 2022 [The effect of different feeding frequency on survival and growth of Asang fish larva (*Osteochilus haselti* C.V)]. Jurnal Agroqua: Media Informasi Agronomi dan Budidaya Perairan 20(2):292-300. [in Indonesian]

Essa M. A., Mabrouk H. A., Mohamed R. A., Michael F. R., 2011 Evaluating different additive levels of yeast, *Saccharomyces cerevisiae*, on the growth and production performances of a hybrid of two populations of Egyptian African catfish, *Clarias gariepinus*. Aquaculture 320(1-2):137-141.

Ferosekhan S., Sahoo S. K., Radhakrishnan K., Velmurugan P., Shamna N., Giri S. S., Pillai B. R., 2020 Influence of rearing tank color on Asian catfish, magur (*Clarias magur*) and pangas (*Pangasius pangasius*) larval growth and survival. Aquaculture 521:735080.

Ghozali I. 2011 [Multivariate analysis application with SPSS 19 program]. 5th edition. Diponegoro University Publishing Agency, Semarang, 408 pp. [in Indonesian]

Giri S. S., Sahoo S. K., Sahu A. K., Meher P. K., 2003 Effect of dietary protein level on growth, survival, feed utilisation and body composition of hybrid *Clarias* catfish (*Clarias batrachus* × *Clarias gariepinus*). Animal Feed Science and Technology 104(1-4):169-178.

Gujarati D. N., 2004 Basic econometrics. 4th edition. McGraw-Hill, 1002 pp.

Hasan M. R., Shipton T. A., 2021 Aquafeed value chain analysis of striped catfish in Vietnam. Aquaculture 541:736798.

Hildebrand M. C., Hentrich N., Palm H. W., 2024 The role of light in the rearing of *Clarias gariepinus* larvae: effects on behaviour, growth and survival. Aquaculture Reports 39:102420.
Hlordzi V., Kuebutornye F. K. A., Afriyie G., Abarike E. D., Lu Y., Chi S., Anokyewaa M. A., 2020 The use of *Bacillus* species in maintenance of water quality in aquaculture: a review. Aquaculture Reports 18:100503.
Huang M., Zhou Y. G., Yang X. G., Gao Q. F., Chen Y. N., Ren Y. C., Dong S. L., 2025 Optimizing feeding frequencies in fish: a meta-analysis and machine learning approach. Aquaculture 595:741678.
Huberty C. J., Petoskey M. D., 2000 Multivariate analysis of variance and covariance. In: Handbook of applied multivariate statistics and mathematical modeling. Tinsley H. E. A., Brown S. D. (eds), Academic Press, pp. 183-208.
Ilmi Q., Amri M., Febria F. A., 2023 [Analysis of nutritional content of artificial feed made from fermented fig flour]. JA'FAR Journal of Fisheries and Aquatic Research 1(2):23-29. [in Indonesian]
Kaleem O., Sabi A. F. B. S., 2021 Overview of aquaculture systems in Egypt and Nigeria, prospects, potentials, and constraints. Aquaculture and Fisheries 6(6):535-547.
Kautsky N., Rönnbäck P., Tedengren M., Troell M., 2000 Ecosystem perspectives on disease management in shrimp pond farming. Aquaculture 191:145-161.
Koagne L. J. T., Wenda B. D. S., Mbouemboue R. C. Y., Eloundou C. E., Fon D. E., 2025 Evaluating the technical efficiency of small-scale fish production systems in the Centre regions of Cameroon. Food and Humanity 4:100470.
Komariyah S., Putriningtias A., Saragih F. H., 2024 [Application of independent feed based on chicken intestine waste silage flour raw material in catfish cultivation]. GERVASI: Jurnal Pengabdian Kepada Masyarakat 8(2):502-511. [in Indonesian]
Kumar G., Engle C., van Senten J., Sun L., Hegde S., Richardson B. M., 2023 Resource productivity and costs of aquaculture practices: economic-sustainability perspectives from US catfish farming. Aquaculture 574:739715.
Limbu S. M., 2020 The effects of on-farm produced feeds on growth, survival, yield and feed cost of juvenile African sharptooth catfish (*Clarias gariepinus*). Aquaculture and Fisheries 5(1):58-64.
Mugo-Bundi J., Manyala J. O., Muchiri M., Matolla G., 2024 Effects of stocking density and water flow rate on performance, water quality and economic benefits of African catfish larvae (*Clarias gariepinus* Burchell, 1822) in the aquaponic system integrated with *Azolla* fern. Aquaculture 579:740170.
Obirikorang K. A., Amisah S., Agbo N. W., Adjei-Boateng D., Adjei N. G., Skov P. V., 2015 Evaluation of locally-available agro-industrial byproducts as partial replacements to fishmeal in diets for Nile tilapia (*Oreochromis niloticus*) production in Ghana. Journal of Animal Nutrition 1:1.
Okomoda V. T., Aminem W., Hassan A., Martins C. O., 2019 Effects of feeding frequency on fry and fingerlings of African catfish *Clarias gariepinus*. Aquaculture 511:-734232.
Olagunju O. F., Kristofersson D., Tómasson T., Kristjánsson T., 2024 A national survey data for the technical and economic assessment of African catfish production in Nigeria before and during the COVID-19 period. Data in Brief 52:109917.
Opiyo M. A., Marijani E., Muendo P., Odede R., Leschen W., Charo-Karisa H., 2018 A review of aquaculture production and health management practices of farmed fish in Kenya. International Journal of Veterinary Science and Medicine 6(2):141-148.
Padang City Fisheries Service, 2022 Annual report of catfish farming in Padang City. Padang City Fisheries Service, Padang City, 45 pp.
Rahman M. A., Ullah M. R., Kabir M. A., Alam M. A., Rahman M., Hossen M. F., 2020 Artificial propagation of indigenous yellowtail catfish (*Pangasius pangasius*): experiences and challenges. Aquaculture 523:735215.
Rodjaroen S., Chittapun S., Charoenrat T., Nuntapong N., Wetchakul A., Thongprajukaew K., 2024 Dietary supplementation of *Aurantiochytrium* sp. significantly improved growth, feed utilization, skin lightness, muscle protein synthesis capacity, and whole-body protein in juvenile African sharptooth catfish (*Clarias gariepinus*). Aquaculture Reports 35:101986.

Roslan N. A., Sukri S. A. M., Wei L. S., Shahjahan M., Rohani M. F., Yea C. S., Kabir M. A., Guru A., Goh K. W., Kallem P., Kari Z. A., 2024 Replacement of fishmeal by fermented spent coffee ground: effects on growth performance, feed stability, blood biochemistry, liver, and intestinal morphology of African catfish (*Clarias gariepinus*). Aquaculture Reports 36:102073.

Saha J., Hossain M. A., Mamun M. A., Islam M. R., Alam M. S., 2022 Effects of carbon-nitrogen ratio manipulation on the growth performance, body composition and immunity of stinging catfish *Heteropneustes fossilis* in a biofloc-based culture system. Aquaculture Reports 25:101274.

Salhi M., Bessonart M., Chediak G., Bellagamba M., Carnevia D., 2004 Growth, feed utilization and body composition of black catfish, *Rhamdia quelen*, fry fed diets containing different protein and energy levels. Aquaculture 231(1-4):435-444.

Setyawan E. Y., Nakhoda Y. I., Widodo B., Soleh C., 2019 [Temperature control devices using solar panels to reduce mortality rates in catfish hatcheries in Kediri Regency]. Jurnal Pengabdian Pada Masyarakat 4(3):313-320. [in Indonesian]

Shahariar M. A., Hossain M. Z., Urmi J. F., Hasan M. M., Masum M. M. I., Shah A. K. M. A., Hasan M., Rahman Z., Alam M. S., 2024 Biosynthesis of gold nanoparticles and its impacts on striped dwarf catfish (*Mystus vittatus*) as feed additives. Aquaculture Reports 39:102446.

Shalih R. I., Hayati M., 2021 [Technical efficiency of raising catfish in Bangkalan District]. Agriscience 1(3):563-572. [in Indonesian]

Shi X., Yuan S., Ma X., Tian X., Zhang M., Zhang Y., Waiho K., Fazhan H., Xu R., Kong X., Li X., 2024 Analysis of relationship between growth traits and feed conversion ratio provides insights into aquaculture and breeding of largemouth bass *Micropterus salmoides*. Aquaculture 593:741352.

Sinha A. K., Limbaugh N., Renukdas N., Bishop W. M., Romano N., 2022 Modulating effect of elevated water hardness on growth performance, ammonia dynamics and ion-regulatory capacity in channel catfish (*Ictalurus punctatus*) following chronic challenge with high environmental ammonia and salinity stress. Aquaculture 560: 738489.

Stone N. M., Engle C. R., Kumar G., Li M. H., Hegde S., Roy L. A., Kelly A. M., Dorman L., Recsetar M. S., 2024 Factors affecting feed conversion ratios in US commercial catfish production ponds. Journal of the World Aquaculture Society 55(3):e13053.

Toko I., Fiogbe E. D., Koukpode B., Kestemont P., 2007 Rearing of African catfish (*Clarias gariepinus*) and vundu catfish (*Heterobranchus longifilis*) in traditional fish ponds (whedos): effect of stocking density on growth, production and body composition. Aquaculture 262(1):65-72.

Utomo N. B. P., Susan, Setiawati M., 2013 [The role of fish meal from various raw materials on the growth of Sangkuriang catfish *Clarias* sp.]. Jurnal Akuakultur Indonesia 12(2):158-168. [in Indonesian]

Uzochukwu I. E., Aba P. E., Ossai N. I., Ugwuoke H. C., Nyeste K., Machebe N. S., 2023 Optimizing feed utilization and reducing deterioration of African catfish feed with sodium propionate supplementation. Aquaculture Reports 33:101820.

Walpole R. E., Myers R. H., Myers S. L., Ye K., 2012 Probability and statistics for engineers and scientists. 9th edition. Pearson Education, Inc., 791 pp.

Wambua D. M., Home P. G., Raude J. M., Ondimu S., 2021 Environmental and energy requirements for different production biomass of Nile tilapia (*Oreochromis niloticus*) in recirculating aquaculture systems (RAS) in Kenya. Aquaculture and Fisheries 6(6):593-600.

Wu B., Huang L., Chen J., Zhang Y., Chen X., Wu C., Deng X., Gao J., He J., 2021 Effects of feeding frequency on growth performance, feed intake, metabolism and expression of *fgf21* in grass carp (*Ctenopharyngodon idellus*). Aquaculture 545: 737196.

Yildiz H. Y., Robaina L., Pirhonen J., Mente E., Domínguez D., Parisi G., 2017 Fish welfare in aquaponic systems: its relation to water quality with an emphasis on feed and faeces: a review. Water 9(1):13.

Received: 05 September 2025. Accepted: 19 October 2025. Published online: 28 November 2025.
Authors:
M. Amri, Department of Agricultural Extension, Universitas Prima Nusantara Bukittinggi, Kusuma Bhakti street, No. 99, Kubu Gulai Bancah, Kec. Mandiangin Koto Selayan, Bukittinggi City, West Sumatra 26111, Indonesia, e-mail: muhammadamri327@gmail.com
Siti Aisyah, Department of Aquatic Resource Management, Faculty of Science, Nahdlatul Ulama University of West Sumatra, S. Parmanstreet, No. 119 A, Ulak Karang Selatan, Kec. Padang Utara, Padang City, West Sumatra 25136, Indonesia, e-mail: s.aisyah2795@gmail.com

How to cite this article:
Amri M., Aisyah S., 2025 The effect of feeding frequency on the economic efficiency of catfish (*Clarias gariepinus*) cultivation: a linear regression approach. AACL Bioflux 18(6):2591-2603.