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Application of Synbiotics *Lactobacillus Casei* and Banana Peel Waste to Improve Growth Performance of African Catfish *Clarias Gariepinus* in Intensive Aquaculture Systems

Linuwih Aluh Prastiti, Qorie Astria, Nadisa Theresia Putri, Dian Febriani, Rio Yusufi Subhan

Politeknik Negeri Lampung, Jl. Soekarno Hatta No.10, Rajabasa Raya, Kec. Rajabasa, Kota Bandar Lampung, Lampung 35141, Indonesia

*Correspondence Author: linuwihaluh@polinela.ac.id

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ABSTRACT

Food security and malnutrition remain global challenges, requiring sustainable food production strategies such as the Blue Transformation concept promoted by FAO. African catfish (*Clarias gariepinus*) is an important aquaculture commodity for fulfilling nutritional needs, containing 19.03% protein, 8.1% fat, and high levels of essential amino acids. However, intensive farming systems often encounter constraints such as high feed conversion, reduced water quality, and suboptimal growth performance. Synbiotics, combining probiotics and natural prebiotics, offer a promising alternative to antibiotic use in aquaculture. In this context, the utilization of locally available banana peel waste as a prebiotic represents an eco-friendly approach that supports resource efficiency within the Blue Transformation framework. This study aimed to evaluate the effect of dietary synbiotics consisting of *Lactobacillus casei* and banana peel–based prebiotics on the growth performance and feed efficiency of African catfish. Four treatments were applied: a control diet (without synbiotics) and diets supplemented with 1%, 2%, and 3% (v/w) fermented banana peel prebiotics. Observed parameters included Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), feed efficiency, and survival rate. The results indicated that synbiotic supplementation positively influenced growth and feed utilization. The best performance was obtained at the 3% dose, with an SGR of 6.78%, FCR of 1.07, feed efficiency of 93,97%, and survival rate of 84%. These findings suggest that the application of synbiotics at an optimal dose can be practically implemented in intensive African catfish culture to reduce feed costs, improve production efficiency, and support more sustainable aquaculture practices.

INTRODUCTION

Fish play a critical role in supporting the sustainability of global food systems. African catfish (*Clarias gariepinus*) is an important aquatic resource with strong potential to meet community nutritional needs, as it contains 19.03% protein, 8.1% fat, and high levels of essential amino acids, notably oleic acid (36.35%) and linoleic acid (1.08%). In addition, *C. gariepinus* is recognized for its considerable micronutrient content, including iron (17.03 mg/100 g) and zinc (2.92 mg/100 g), which are essential for human health and often insufficient in the diets of vulnerable populations (Mobdy et al., 2021).

In Indonesia, *C. gariepinus* is one of the most widely cultivated freshwater fish species. Between 2020 and 2024, national catfish production increased by 1.61% (Directorate General of Aquaculture, 2025). The growing market demand requires adequate seed supply to ensure stable production. In response, the Ministry of Marine Affairs and Fisheries encouraged the adoption of intensive aquaculture technologies in 2024. However, intensified culture systems are commonly associated with several constraints, including elevated feed conversion ratios (FCR), deteriorating water quality, and increased disease prevalence resulting from high stocking densities and suboptimal feeding management (Difinubun et al., 2023).

Major challenges in catfish aquaculture include high FCR, uneven growth performance, accumulation of organic waste from uneaten feed and feces, and increased susceptibility to bacterial infections such as *Aeromonas* sp., *Pleisomonas* sp., and *Pseudomonas* sp. (Sarjito et al., 2018). To address these issues, antibiotics such as oxytetracycline and enrofloxacin are frequently used (Milijasević et al., 2024). Nevertheless, continued antibiotic use contributes to antimicrobial resistance, representing a serious threat to the sustainability of aquaculture (Suyamud et al., 2024), and raises concerns regarding chemical residues and food safety.

A promising strategy to enhance fish health and disease resistance is the incorporation of synbiotics into feed. Synbiotics combine probiotics and prebiotics that work synergistically to improve gut microbial balance. Probiotics are live microorganisms that provide health benefits to the host (Tabassum et al., 2021; Ghori et al., 2022), whereas prebiotics are non-digestible dietary components that selectively stimulate the growth of beneficial gut microbes (Ringø et al., 2010). Hardi et al. (2022) reported that synbiotic supplementation improved growth and resistance to *Aeromonas hydrophila* in catfish. *Lactobacillus casei* is a promising probiotic strain due to its tolerance to bile salts and low pH, enabling it to survive in the gastrointestinal tract of fish (Siddik et al., 2022).

Lampung Province is one of Indonesia's largest banana chip production centers, producing approximately 11.2 million tons of bananas in 2021 (Central Bureau of Statistics, 2021). The banana-processing industry generates substantial peel waste, which contains soluble fibers such as oligosaccharides (Liang et al., 2022) and fructooligosaccharides (FOS) (Azam et al., 2020). These compounds are known to function as prebiotics that can selectively stimulate the growth of beneficial gut microbiota. Furthermore, fermentation of banana peel can enhance the availability of functional fibers and oligosaccharides, thereby supporting probiotic growth and metabolic activity (Moretti et al., 2025). Previous findings indicate that dietary FOS supplementation at 0.1–0.5% enhances growth and survival in pomfret fish challenged with Aeromonas hydrophila (Lima Paz et al., 2019).

Most synbiotic applications in aquaculture have primarily relied on commercial prebiotics, which are often costly and may limit their accessibility for small-scale farmers. In contrast, the exploration of locally available agro-industrial waste as alternative prebiotic sources remains limited. Banana peel waste, which is abundantly produced and underutilized, has the potential to be valorized as a low-cost and sustainable prebiotic ingredient. However, to date, there has been no published study evaluating the use of banana peel waste as a local prebiotic in synbiotic formulations for African catfish (*C. gariepinus*). This gap highlights the need to develop sustainable and cost-effective feeding strategies that align with circular economy principles by reducing agro-industrial waste and improving resource efficiency in aquaculture systems.

Therefore, the present study aims to evaluate the effects and determine the optimal dosage of synbiotic feed formulated with Lactobacillus casei and banana peel–derived prebiotics on growth performance and gut microflora modulation in African catfish (*C. gariepinus*) fry reared under intensive aquaculture conditions.present study aims to evaluate the effects and determine the optimal dosage of synbiotic feed formulated with Lactobacillus casei and banana peel–derived prebiotics on growth performance and gut microflora modulation in African catfish (*C. gariepinus*) fry reared under intensive aquaculture conditions

METHOD

This research was conducted from July to October 2025 at the Smart Food Security Laboratory and the Aquaculture Laboratory of Politeknik Negeri Lampung, Bandar Lampung. The experimental design used was a Completely Randomized Design (CRD). The study consisted of four treatments with three replications to determine the optimal concentration of synbiotic supplementation for improving the growth performance of African catfish in an intensive aquaculture system. The treatments followed Susanto and Agustina (2023) and were arranged as follows:

1. Treatment K: Control (feed without synbiotic addition)
2. Treatment A: Feed + *L. casei* + 1% (v/w) fermented prebiotic liquid
3. Treatment B: Feed + *L. casei* + 2% (v/w) fermented prebiotic liquid
4. Treatment C: Feed + *L. casei* + 3% (v/w) fermented prebiotic liquid

All treatments received a fixed probiotic dose of 1% (v/w) *L. casei* liquid culture, while the prebiotic dose was adjusted to 1%, 2%, and 3% (v/w).

Preparation of fermented prebiotic

Banana peels were washed thoroughly and sun-dried for 2–3 days until the moisture content decreased. They were then dried again in an oven at 50–60°C for approximately 12 hours to ensure minimal moisture and subsequently ground into a fine powder. The banana peel powder was fermented by mixing it with distilled water at a ratio of 1:5 (w/v), followed by the addition of molasses at 5% of the total volume as a simple carbon source. Inoculation was carried out by adding *L. casei* culture at 10% (v/v) with a concentration of approximately 10^8 CFU/mL. The mixture was incubated in a closed container at room temperature (28–30°C) for 3–5 days. Fermentation was considered complete when a characteristic sour aroma developed and the pH consistently decreased. The fermented product (fermented prebiotic liquid) was then mixed into the feed according to the treatments.

Feed preparation

The feed used in this study was a commercial PF800 fish feed with a diameter of 0.8 mm and a protein content of 39–41%. Two types of feed were prepared: synbiotic-supplemented feed and non-synbiotic feed. Feed ingredients were mixed manually using egg white as a binder at 2% (v/v) and water at 6% (v/w) (Prastiti et al., 2018). After thorough mixing, the feed was left for 12–24 hours at room temperature to allow microorganisms to adapt to the feed substrate. If the feed was not used immediately, it was dried naturally or in a low-temperature oven (<40°C) until the moisture returned to its original level, then stored in airtight containers before being provided to the experimental fish.

Fish rearing and feeding application

African catfish were reared for 20 days in concrete tanks measuring 1 × 2 × 1 m^3. Four tanks were used with three replications. The tanks were equipped with aerators and sterilized using 30 ppm chlorine, dried, and filled with water to a depth of 70 cm. African catfish juveniles (3–5 cm) were stocked following SNI 6484.4:2014 at a density of 500 fish/m^2.

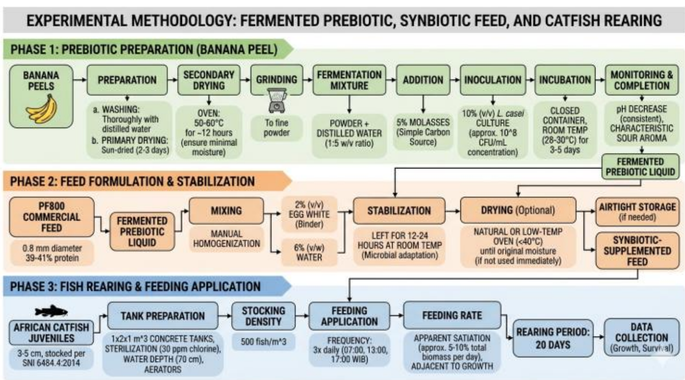

Figure 1. Schematic flow of the experimental methodology, including fermented prebiotic preparation, synbiotic feed formulation, and African catfish rearing application.

Feed was administered three times daily at 07:00, 13:00, and 17:00 WIB to apparent satiation or approximately 5–10% of total biomass per day, with adjustments according to growth.

Observed growth parameters

The observed parameters included specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency (FE), survival rate (SR), and water quality.

1. Absolute Growth Rate (Effendie, 1997):

$$\text{AGR (g)} = \text{Wt} - \text{W0}$$

AGR: Absolute Growth Rate
Wt = final average fish weight (g);
W0 = initial average fish weight (g);

2. Specific Growth Rate (SGR) (Weatherley & Gill, 1987):

$$\text{SGR } (\%days^{-1}) = \frac{\text{Ln(Wt)} - \text{Ln(W0)}}{\text{t}} \text{ x } 100$$

Wt = final average fish weight (g);
W0 = initial average fish weight (g);
t = rearing period (days).

3. Feed Conversion Ratio (FCR) (Haetami et al., 2024):

$$\text{FCR } = \frac{\text{F}}{(\text{Bt+Bm})-\text{B0}}$$

F = total feed given (g);
Bt = final biomass (g);
Bm = biomass of dead fish (g);
B0 = initial biomass (g).

4. Feed Efficiency (Effendie, 1997):

$$\text{EP } = \frac{(\text{Bt+Bm})-\text{B0}}{\text{F}} \text{ x } 100\%$$

F = total feed given (g);
Bt = final biomass (g);
Bm = biomass of dead fish (g);
B0 = initial biomass (g).

5. Survival Rate (Takeuchi, 1988):

$$SR(\%) = \frac{Nt}{No} \text{ x } 100$$

Nt = number of surviving fish at the end;
N0 = number of fish at the beginning.

6. Water Quality Measurement

Water quality was measured every two days using a water quality checker, recording dissolved oxygen (DO), pH, temperature, and ammonia.

Data Analysis

The data were tabulated using Microsoft Excel and analyzed using SPSS. Prior to analysis, the assumptions of ANOVA were tested, including normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test). Analysis of variance (ANOVA) was then performed at a 95% confidence level. If treatments showed significant effects, Duncan's multiple range test was conducted to determine the best treatment. If no significant effect was observed, data were analyzed descriptively.

RESULT AND DISCUSSION

Absolute Growth Rate

The improvement in Absolute Growth Rate observed in fish fed synbiotic supplemented diets demonstrates that the combination of *L. casei* and fermented banana peel prebiotic contributed positively to biomass accumulation over the rearing period. The highest dose treatment showed significantly greater absolute weight gain compared to control and lower synbiotic doses (based on ANOVA and Duncan results provided), confirming a dose-dependent effect (Figure 1.)

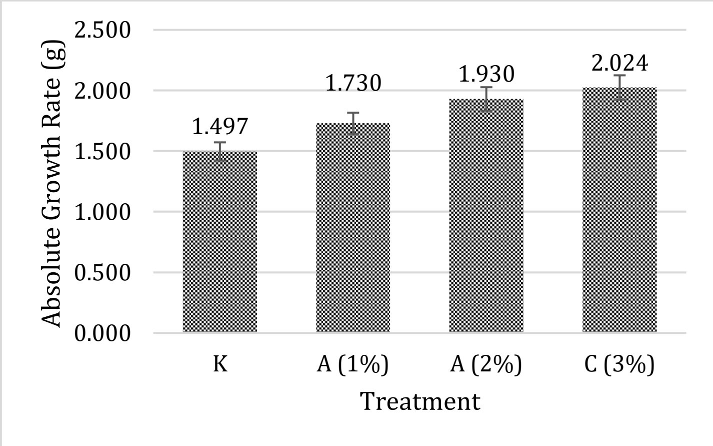

Figure 2. Absolute Growth Rate of African Catfish (*C. gariepinus*)
Source: Processed Data (2025)

Fish provided with a non-supplemented basal diet exhibited the lowest AGR values. This suggests that under intensive culture conditions, a conventional diet alone may not adequately support optimal nutrient utilization. Intensive systems typically increase stress and reduce feed efficiency when functional feed additives are absent (Onomu and Okuthe, 2024). Thus, the control treatment reflects the baseline growth potential without synbiotic intervention

Fish that received low to medium synbiotic supplementation demonstrated moderate improvements in AGR relative to the control group. Such improvement aligns with reports where *Lactobacillus* spp. enhanced nutrient assimilation and facilitated weight gain in catfish (Aini et al., 2025). The fermentable fibers contained in banana peel support the growth and metabolic activity of lactic acid bacteria, contributing to improved intestinal processes and energy utilization (Moretti et al. 2025). These results suggest that synbiotic efficacy becomes evident even before reaching the optimal supplementation level. Overall, the AGR results of this study confirm that the tested synbiotic composition is effective in enhancing growth efficiency, particularly when applied at the highest dose.

Specific Growth Rate

In this study, synbiotic supplementation with *L. casei* plus banana peel fermented prebiotic resulted in a significantly higher SGR in the highest dose treatment compared to control (no synbiotic) and lower-dose synbiotic (Figure 2.). This suggests a dose response effect, consistent with the hypothesis that increasing the availability of beneficial microbes (probiotic) and fermentable substrates (prebiotic) enhances digestive efficiency and nutrient assimilation (Thakur et al. 2025)

The enhancement of growth performance (including SGR) in aquaculture by synbiotic or combined probiotic–prebiotic supplementation has been widely documented. More specially, a study using *L. casei* in catfish demonstrated improved growth parameters, immune response, and overall health when fish were fed probiotic-supplemented diets under stress or infection challenge (Aini et al. 2025)

The significantly elevated SGR in the highest synbiotic dose may reflect enhanced colonization or activity of *L. casei* in the gut, supported by banana-derived substrates that encourage lactic acid bacteria proliferation. This likely improves digestive enzyme activity and absorption efficiency, resulting in faster growth. The dose response pattern suggests that there is a threshold of prebiotic/probiotic availability needed to maximize benefits. Other study also observed in other synbiotic (e.g., chitosan probiotic supplementation in catfish) where optimal doses improved growth performance over control and lower doses (Say et al. 2023). Moreover, using agro-industrial waste (banana peel) as prebiotic makes the approach more sustainable and locally relevant, especially considering waste valorization and circular economy, which aligns with recent calls for sustainable aquaculture innovations.

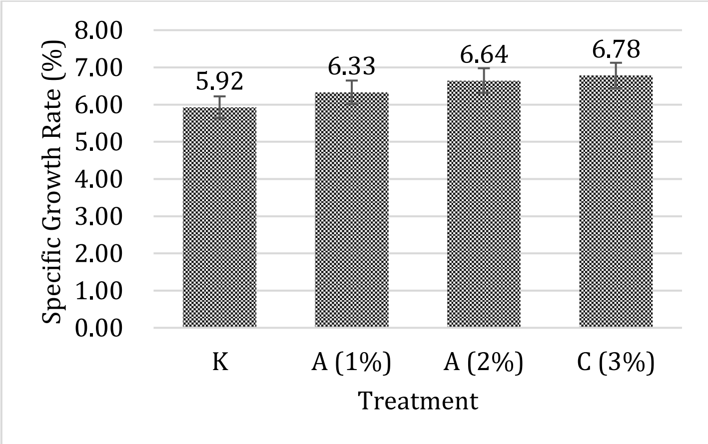

Figure 3. Specific Growth Rate of African Catfish (*C. gariepinus*)
Source: Processed Data (2025)

Feed Conversion Ratio

FCR reflects the efficiency of converting feed into fish biomass, where a lower value indicates better efficiency. In this study, synbiotic supplementation significantly decreased FCR, with the lowest FCR found in the highest synbiotic dose (Figure 3.). This demonstrates that combining *L. casei* with fermented banana peel prebiotic improved feed utilization efficiency in a dose-dependent manner. Fish without synbiotic supplementation exhibited the highest FCR. This suggests that under intensive rearing, digestion and nutrient assimilation are less efficient without microbial support.

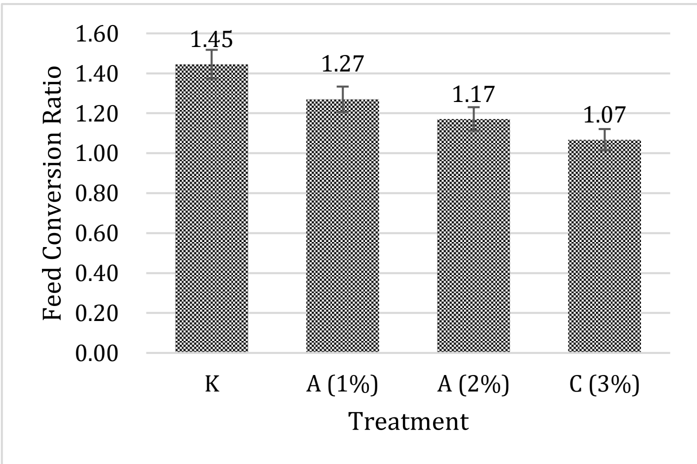

Figure 4. Feed Conversion Ratio of African Catfish (*C. gariepinus*)
Source: Processed Data (2025)

Synbiotic supplementation at low to moderate levels led to moderate reductions in FCR. These enhancements indicate that the synbiotic began to improve digestive function and enhance nutrient absorption efficiency. Probiotics such as *L. casei* stimulate digestive enzyme activity, while prebiotics promote growth of lactic acid bacteria, resulting in improved feed conversion. The proteolytic and cellulolytic enzymes produced by probiotics help enhance the digestion of feed. With improved enzyme activity driven by probiotic supplementation, catfish can use nutrients more efficiently, resulting in a reduced feed conversion ratio (FCR) (Aini et al. 2025).

The most efficient FCR was recorded in the fish fed the highest synbiotic dose, indicating that an adequate level of *L. casei* and fermentable substrate is necessary to fully enhance feed conversion. Although this value is higher than those reported in previous studies, such as Aini et al. (2025), who obtained FCR values ranging from 0.51 to 0.83 using L. casei, and Liling et al. (2026), who reported FCR values of 0.76–0.80 using synbiotics based on sweet potato prebiotics, it remains lower than the typical FCR range of 1.2–1.5 observed in intensive African catfish culture.

The relatively higher FCR observed in the present study compared to those studies may be attributed to differences in culture conditions, particularly the higher stocking density applied, which can increase competition for feed and reduce feeding efficiency. In addition, previous studies often implemented more frequent water exchange, which may have contributed to improved water quality and feed utilization efficiency.

Feed Efficiency

Feed efficiency reflects the proportion of consumed feed that is successfully converted into fish biomass. In this study, feed efficiency increased significantly with synbiotic supplementation, with the highest efficiency achieved at the highest synbiotic dose (Figure 4.). These results further reinforce the dose-dependent improvements observed in the growth-related parameters (AGR and SGR). The control group, receiving no synbiotic supplementation, displayed the lowest feed efficiency. This suggests that the basal diet alone was less effectively digested and utilized under intensive aquaculture conditions.

This outcome is consistent with findings from other aquaculture studies employing synbiotics or probiotics. For example, in a feeding trial with marine fish Golden Rabbitfish (*Siganus guttatus*), a synbiotic consisting of *Pediococcus pentosaceus* and fructooligosaccharide significantly increased feed efficiency, growth rate, and digestive enzyme activity compared to control diets (Chat et al. 2024). Similarly, a general review on the use of synbiotics in aquaculture highlights that feed cost comprises > 50% of variable production costs, and that synbiotic supplementation often improves feed utilization, growth performance, and survival compared to non-supplemented diets (Cerezuela et al. 2011).

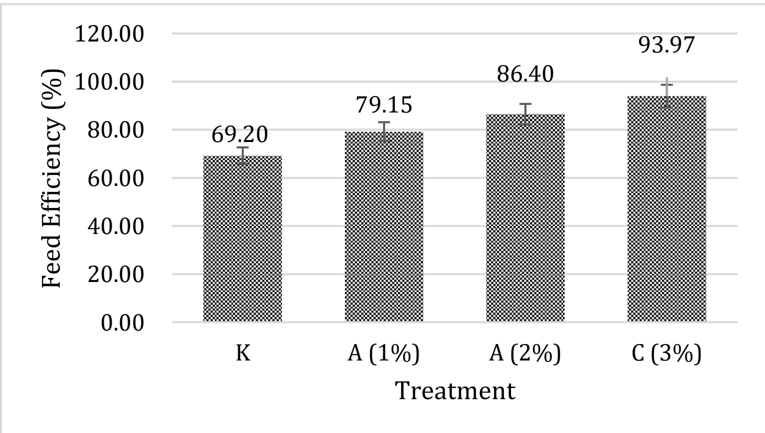

Figure 5. Feed Efficiency of African Catfish (*C. gariepinus*)
Source: Processed Data (2025)

The enhanced FE in synbiotic-fed fish likely results from improved gut microbial balance and digestive processes: the probiotic supports beneficial bacteria that produce digestive enzymes or modulate gut physiology, while the prebiotic substrate sustains those bacteria, facilitating more efficient breakdown and absorption of nutrients. Such synergistic effects reduce nutrient losses through feces or metabolic inefficiencies, leading to greater biomass yield per unit feed was a critical advantage in intensive culture systems where feed input is a large portion of production cost and where wasted feed contributes to water pollution. This rationale aligns with evidence from studies on freshwater fish aquaculture, where probiotic or synbiotic supplementation improved feed utilization metrics under intensive rearing regimes. (Sumartini et al. 2019).

In the present study, the highest FE value (93.97%) was observed in the synbiotic treatment, which is substantially higher than the control (69.20%), indicating a marked improvement in feed utilization efficiency. This value is comparable to or higher than those reported in other studies using probiotic or synbiotic approaches in catfish culture, although variations may occur depending on feed composition, microbial strains, and culture conditions. In line with the FCR results discussed earlier, the relatively high FE achieved in this study under high stocking density conditions further highlights the effectiveness of banana peel–based synbiotics in enhancing feed utilization efficiency in intensive systems.

From a practical perspective, increasing feed efficiency via synbiotics provides dual benefits: enhancing production yield and reducing feed waste. This is particularly valuable for intensive aquaculture operations where feed efficiency and cost-effectiveness are key determinants of profitability and sustainability. From a practical perspective, increasing feed efficiency via synbiotics provides dual benefits: enhancing production yield and reducing feed waste. This is particularly valuable for intensive aquaculture operations where feed efficiency and cost-effectiveness are key to profitability and sustainability.

Survival Rate

Survival Rate (SR) reflects the ability of fish to maintain health and withstand environmental and physiological stress during culture. In this study, SR did not show significant differences among treatments, even though synbiotic-supplemented groups tended to have slightly higher survival percentages than the control (Figure 5.).

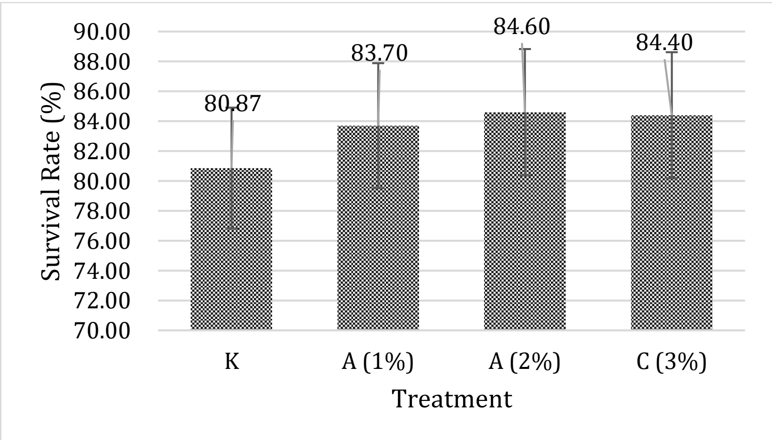

Figure 6. Survival Rate of African Catfish (*C. gariepinus*)
Source: Processed Data (2025)

The control group exhibited the lowest SR, although still within acceptable tolerance limits for Clarias gariepinus. High stocking density and intensive culture conditions may predispose fish to stress and digestive inefficiency, which in turn affects survival performance (Refaey et al 2018). The lower SR in the control indicates that fish without synbiotic supplementation may be less resilient to intensive farming conditions.

Slight increases in SR were observed in low–medium synbiotic treatments, indicating that supplementation of *L. casei* and banana peel derived prebiotics may support immune health and stress tolerance, even if not statistically significant. Probiotic intervention has been shown to strengthen mucosal immunity and improve fish resilience against opportunistic pathogens (Srirengaraj et al. 2023)

Synbiotic supplementation in this study did not significantly affect the survival rate of *C. gariepinus*, although the treated groups exhibited slightly higher values than the control This result may be attributed to the absence of significant environmental stress or pathogen challenge during the experimental period, as the immunomodulatory effects of synbiotics are generally more pronounced under conditions of disease exposure or physiological stress. In such conditions, synbiotics can enhance host resistance by improving immune responses and gut microbial balance. Therefore, the non-significant effect on survival rate observed in this study does not necessarily indicate a lack of synbiotic efficacy, but rather reflects the optimal rearing conditions without infection pressure. Further studies incorporating pathogen challenge tests are required to better evaluate the protective role of synbiotics in improving fish survival.

This indicates that the culture conditions in this study were sufficiently optimal to minimize mortality, thereby limiting the detectable immunological benefits of the synbiotic. Similar observations have been made in freshwater fish where improved growth performance was not necessarily accompanied by significant differences in survival under non-stress conditions. The potential health-protective effects of synbiotics may become more evident when fish are exposed to pathogen challenges or environmental stressors. Therefore, further studies evaluating immune response indicators and survival under challenge conditions are recommended to better determine the contribution of synbiotics to fish health resilience.

Water Quality

Throughout the culture period, the measured water quality remained within the acceptable range for African catfish (*C. gariepinus*) intensive production. The average temperature of 28.3°C, dissolved oxygen of 5.09 mg L^{-1}, pH of 7.41, and ammonia concentration of 0.012 mg L^{-1} supported optimal physiological functioning and minimized environmental stress on fish. These conditions are consistent with recommended optimal ranges for C. gariepinus: (temperature 27-32^{o}C, DO 3,09-4,16 mg L^{-1}, pH 6,7-7,1 and NH_3 0,07-0,09 mg L^{-1}) (Taharudin et al. 2017).

Because the water parameters were well controlled across all treatments, differences in growth performance and feed utilization can be confidently attributed to synbiotic supplementation rather than environmental fluctuation. Adequate dissolved oxygen is essential for aerobic metabolism, enabling efficient energy production for growth, feed digestion, and nutrient assimilation. Higher DO levels also reduce physiological stress and prevent the shift to anaerobic metabolism, which can impair growth performance. Meanwhile, low ammonia concentrations minimize the toxic effects of unionized ammonia (NH_3), which can disrupt gill function, reduce oxygen transport capacity, and impair protein metabolism. Maintaining low ammonia levels therefore supports better metabolic efficiency and overall fish health.

Furthermore, the low ammonia level suggests efficient nitrogen utilization and reduced organic waste production, which may be linked to improved digestive efficiency in synbiotic-fed fish. Similar findings have been reported where probiotics enhanced nutrient assimilation and contributed to better water quality in intensive freshwater aquaculture (Srirengaraj et al. 2023). Overall, maintaining water quality within optimal thresholds strengthened the internal validity of this study and ensured that the synbiotic effect on growth and feed efficiency was the primary driver of performance differences observed.

CONCLUSION

This study demonstrated that synbiotic supplementation consisting of Lactobacillus casei and fermented banana peel prebiotic effectively improved the growth performance of African catfish (Clarias gariepinus) reared under intensive aquaculture conditions. Synbiotic addition significantly enhanced growth performance compared to the control treatment, with the highest performance obtained at a 3% inclusion level. Although survival rate did not differ significantly among treatments, synbiotic-fed fish showed a numerically higher survival tendency. These findings indicate that fermented banana peel, when used as a prebiotic component in combination with L. casei, can serve as a practical and sustainable feed additive to support improved nutrient utilization and biomass production in intensive catfish farming. An optimal dose of 3% banana peel–based synbiotic can be used as a reference for functional feed formulation and as a standard in intensive catfish feeding strategies to enhance production efficiency. Further research incorporating pathogen challenge trials, digestive enzyme assays, and gut microbiota analyses is required to fully validate the physiological mechanisms underlying the observed improvements.

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