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The Effect of Fish Meal Substitution with Mealworm Meal in Artificial Feed on the Growth and Survival of Siamese Catfish (*Pangasius hypophthalmus*)

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ABSTRACT

The Siamese catfish (*Pangasius hypophthalmus*) holds significant economic value, with increasing demand for its production. The quality of feed—particularly its nutrient content—plays a crucial role in catfish growth. Fish meal, a conventional protein source, often encounters supply challenges, making mealworm (*Tenebrio molitor*) flour a promising alternative, offering up to 45.88% protein content and 35% fat content. This study aimed to evaluate the effect of replacing fish meal with mealworm flour on the growth and survival of Siamese catfish. The experiment was conducted using a completely randomized design (CRD) with five treatments: A (0% mealworm flour, 100% fish meal), B (25% mealworm flour, 75% fish meal), C (50% mealworm flour, 50% fish meal), D (75% mealworm flour, 25% fish meal), and E (100% mealworm flour, 0% fish meal), each with three replications. The fish used in the study had an average length of 8.44 ± 0.575 cm and an average weight of 3.86 ± 0.72 grams, with a stocking density of one fish per 5 liters in 50×50×100 cm nets. The maintenance period lasted 49 days, with feeding provided twice daily to satiation. The findings indicated that substituting fish meal with mealworm flour had a significant effect ($P< 0.05$) on growth parameters. Treatment B (25% mealworm flour) produced the most favorable outcomes, with total feed consumption (TFC) of 215.70 ± 0.74g, feed efficiency (FE) of 79.51 ± 0.88%, feed conversion ratio (FCR) of 1.19 ± 0.05, specific growth rate (SGR) of 2.95 ± 0.02%/day, and absolute weight gain of 171.51 ± 1.66g.

INTRODUCTION

The Siamese catfish (*Pangasius hypophthalmus*) represents a freshwater fish commodity with substantial potential for commercial cultivation. It is increasingly popular in Indonesia and plays a key role in boosting aquaculture productivity. According to the Ministry of Marine Affairs and Fisheries (KKP), national catfish production reached

348,378.76 tons in 2023, marking an increase compared to the previous year. Furthermore, the KKP projected that national catfish production would reach 443,082 tons in 2024, highlighting the significant growth potential for catfish farming in Indonesia. Catfish has emerged as a preferred commodity among fish farmers. Nutritional data show that 100 grams of fresh catfish contains 135 kcal of energy, 17 grams of protein, 6.6 grams of fat, 1.1 grams of carbohydrates, and 1.6 mg of iron, classifying it as a high-protein, moderately fatty freshwater fish **(Kodriah & Hastuti, 2021)**.

Pangasius fish farmers often face challenges in selecting suitable feed for seedlings to promote growth and improve survival rates. Feed constitutes a critical component in *Pangasius* aquaculture, accounting for 50–60% of total production costs **(Hassan *et al.*, 2021)**. There are two main types of feed: natural feed and artificial feed (pellets). Pellet feed typically contains 33% protein, 5% fat, and 6% carbohydrates **(Irwanto & Lesti, 2021)**. Fish meal serves as the primary ingredient in high-protein feed and is commonly sourced from marine fish; however, its cost is rising, and its availability is becoming increasingly limited. Beyond the sustainability concerns regarding fish meal raw ingredient supplies, the use of wild-caught fish in fish meal production also presents a risk of microplastic contamination **(Wicaksono, 2022)**. Feed produced with microplastic-contaminated fish meal ingredients can contribute to the transfer of microplastics from aquatic environments into aquaculture systems. Commercial fish meal has been reported to contain up to 124 MPs/kg of microplastics, exhibiting a higher concentration compared to trash fish used as raw ingredients **(Thiele *et al.*, 2021)**.

To reduce the risk of microplastics entering aquaculture systems through feed, alternative protein sources should be considered. Mealworms offer a promising substitute for fish meal in feed formulations due to their favorable nutritional composition. Specifically, mealworms contain approximately 48% crude protein, 40% crude fat, 3% ash, 57% moisture, and 8% non-nitrogenous extract **(Marianty *et al.*, 2022)**. In terms of amino acid composition, mealworm flour exhibits a profile comparable to soybean meal, although it may be deficient in methionine, histidine, lysine, cystine, and threonine, while being rich in tyrosine and valine **(Iaconisi *et al.*, 2018)**.

The primary challenge in catfish aquaculture is reduced productivity due to high feed costs, which account for 50–60% of total production expenses. This issue is further compounded by the limited availability and rising price of fish meal, as well as concerns about microplastic contamination, which can negatively impact the health of both fish and consumers. The reliance on fish meal as the main feed component, the lack of cost-effective alternative feeds, and dependence on imported feed—subject to global price fluctuations—further contribute to the problem. As a potential solution, this study explores the use of mealworm (*Tenebrio molitor*) flour as a replacement for fish meal, given its high nutritional value. The objective of the research was to determine the optimal substitution level of mealworm flour in catfish feed, evaluate its effects on growth and feed efficiency, and offer recommendations for more economical and sustainable feed formulation to enhance the productivity of catfish farming.

Research hypotheses

H_0: Substituting fish meal with mealworm flour in formulated feed at varying inclusion levels has no effect on the growth, survival, feed utilization efficiency, and total feed consumption of Siamese catfish fingerlings.

H_1: Substituting fish meal with mealworm flour in formulated feed at varying inclusion levels affects the growth, survival, feed utilization efficiency, and total feed consumption of Siamese catfish fingerlings.

MATERIALS AND METHODS

This study utilized a feed pellet machine, oven, and drying trays for the feed processing phase. A digital scale and a millimeter block were used to measure fish weight and length. Additional equipment included hoses, an aerator, a siphon hose, a hand net, plastic buckets, and jars for feed storage. A thermometer and a Water Quality Checker (WQC) were used to monitor environmental conditions throughout the experiment.

The feed ingredients included various flours such as fish meal, independently produced mealworm flour, and fish oil. The mealworm flour was prepared through a controlled drying process. The test animals were the striped catfish (*Pangasius hypophthalmus*) of specific sizes and weights, sourced from fish farmers in Demak Regency, Indonesia. The rearing system consisted of 17 cages, each measuring 50 × 50 × 100 cm, placed in a cleaned pond filled with uncontaminated freshwater.

Treatments

The experimental treatments were as follows:

- **Control**: Commercial catfish feed.
- **Treatment A**: Artificial feed with 0% mealworm flour and 100% fish meal (FM).
- **Treatment B**: Artificial feed with 25% mealworm flour and 75% FM.
- **Treatment C**: Artificial feed with 50% mealworm flour and 50% FM.
- **Treatment D**: Artificial feed with 75% mealworm flour and 25% FM.
- **Treatment E**: Artificial feed with 100% mealworm flour and 0% FM.

Research procedures

The production of mealworm flour began with thoroughly cleaning the worms to remove dirt, followed by roasting without oil for 10–15 minutes to reduce moisture content. The roasted worms were then ground into a fine powder and stored in airtight containers.

Test feed pellets were prepared by replacing fish meal with mealworm flour according to the treatment formulation. The ingredients were mixed, shaped using an extruder machine, and dried. Once dried, the pellets were coated with fish oil and mixed with corn, then stored in airtight jars.

Preparation of the test containers involved cleaning the pond of plant residue and debris, checking for leaks, filling it with clean freshwater, and assessing water quality to ensure it met the optimal conditions for fish health.

The fish arrived at the experimental site in plastic bags and underwent acclimatization before being released into the rearing containers. Acclimatization lasted approximately 15–20 minutes, during which the fish remained in the bags. The bags were then gradually tilted at a 90° angle for 5–10 minutes to allow the fish to swim out on their own.

The Siamese catfish were reared for 49 days and fed twice daily—at 08:00 a.m. and 04:00 p.m. Western Indonesian Time. Water changes were performed as needed, with 50% of the water being replaced weekly.

Measurement method

Control parameters measured during the study included:

- Absolute growth
- Total feed consumption (TFC)
- Feed utilization efficiency (FUE)
- Feed conversion ratio (FCR)
- Specific growth rate (SGR)
- Water quality parameters

The total feed consumption was calculated according to **Tacon (1983)** using the following formula:

$$TFC = F_1 + F_2 + \cdots + F_n$$

Description;
TFC = Total feed consumption
F_1 = Amount of feed on day 1 (g)
F_2 = Amount of feed on day 2 (g)
F_n = Amount of feed on day n (g)

The feed utilization efficiency (FUE) was calculated according to **Tacon (1987)** using the following formula:

$$FUE = \frac{W_t - W_0}{F} \times 100\%$$

Description:
FUE = Feed Utilization Efficiency
W_t = Final weight
W_0 = Initial weight
F = Feed consumption

The absolute weight (W) was calculated using the following formula according to **Zonneveld *et al*. (1991)**:

$$W = W_t - W_0$$

Description:
W = Absolute growth (g)
W_t = Final weight (g)
W_0 = Initial weight (g)

The feed conversion ratio (FCR) was calculated using the following formula according to **Tacon (1997)**:

$$FCR = \frac{F}{(W_t - W_0) + D}$$

Description:
FCR = Feed Conversion Ratio
F = Amount of feed given
W_t = Final Weight
W_0 = Initial Weight
D = Weight of dead fish

The specific growth rate (SGR) was calculated using the following formula according to **Zonneveld *et al.* (1991)**:

$$SGR\,(\%) = \frac{Ln\,W_t \; - \; Ln\,W_0}{t} \times \; 100\%$$

Description;
SGR = Specific growth rate (%)
W_t = Average fish weight at the end of maintenance (g)
W_0 = Average fish weight at the beginning of maintenance (g)
t = Maintenance time (days)

The survival rate was calculated calculated using the following formula according to **Tacon (1987)**:

$$SR = \frac{N_t}{N_0} \times \; 100\%$$

Description:
SR = Survival rate (%),
N_t = Number of test fish at the end of the study (individuals)
N_0 = Number of test fish at the beginning of the study (individuals)

The water quality parameters assessed in this study included temperature, acidity (pH), and dissolved oxygen (DO). These parameters significantly influence fish survival and growth. The optimal conditions for catfish cultivation are a temperature range of 25–33°C, DO levels between 2– 7ppm, and a pH of 6.5–9.0 **(Suriyadin *et al.*, 2023)**. Water quality measurements were conducted twice daily—prior to feeding in the morning and afternoon—to ensure a stable and healthy rearing environment throughout the 49-day experimental period.

Data analysis

The collected data were analyzed using Analysis of Variance (ANOVA) to identify statistically significant differences among treatments at a confidence level of $P \leq 0.05$. When significant differences were detected, Dunnett's test was applied to compare each treatment group against the control group, which received commercial feed.

RESULTS AND DISCUSSIONS

Results

The analysis of growth parameters and feed efficiency in Siamese catfish fed experimental diets containing varying concentrations of mealworm flour (0, 25, 50, 75, and 100%) was conducted in comparison with a control treatment. The evaluated parameters included absolute weight gain (g), total feed consumption (TFC, g), protein utilization efficiency (PUE, %), feed conversion ratio (FCR), specific growth rate (SGR, %/day), and survival rate (SR, %).

The highest total feed consumption (TFC) was recorded in Treatment B (25% mealworm flour and 75% fish meal), with a value of 215.70 ± 0.74 g. In contrast, the lowest TFC was observed in Treatment A (0% mealworm flour and 100% fish meal), which resulted in a TFC of 190.42 ± 2.63 g. The TFC values for all treatments are illustrated in Fig. (1).

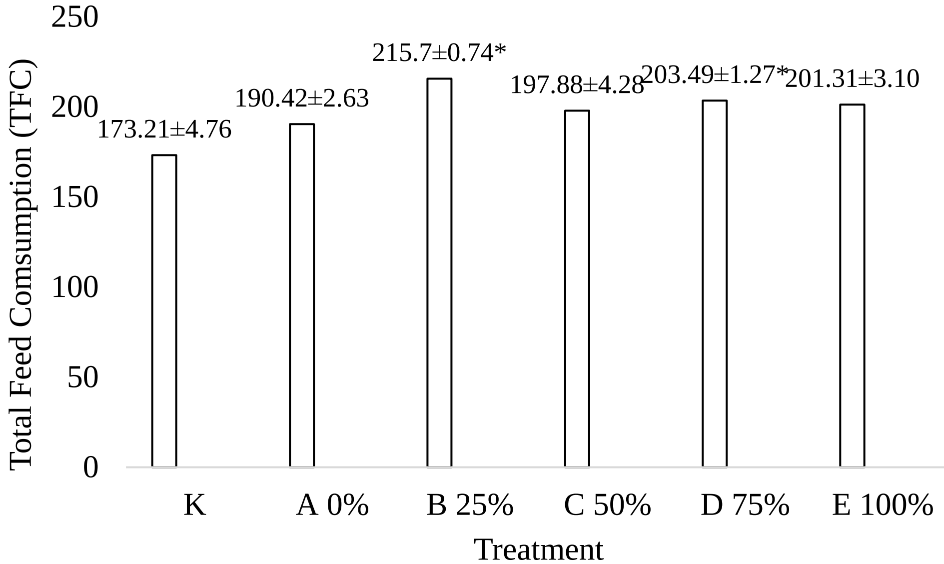

Fig. 1. Total feed consumption (TFC) of Siamese catfish

Note: Asterisk (*) indicates a significant effect on the control treatment.

The highest feed utilization efficiency (FUE) was observed in Treatment B, which incorporated 25% mealworm flour and 75% fish meal, yielding a value of 79.51 ± 0.88%. In contrast, the lowest FUE was recorded in Treatment E, which used 100% mealworm flour with no fish meal, resulting in a value of 63.06 ± 0.74%. The complete Feed Utilization Efficiency (FUE) values for all treatments are presented in Fig. (2).

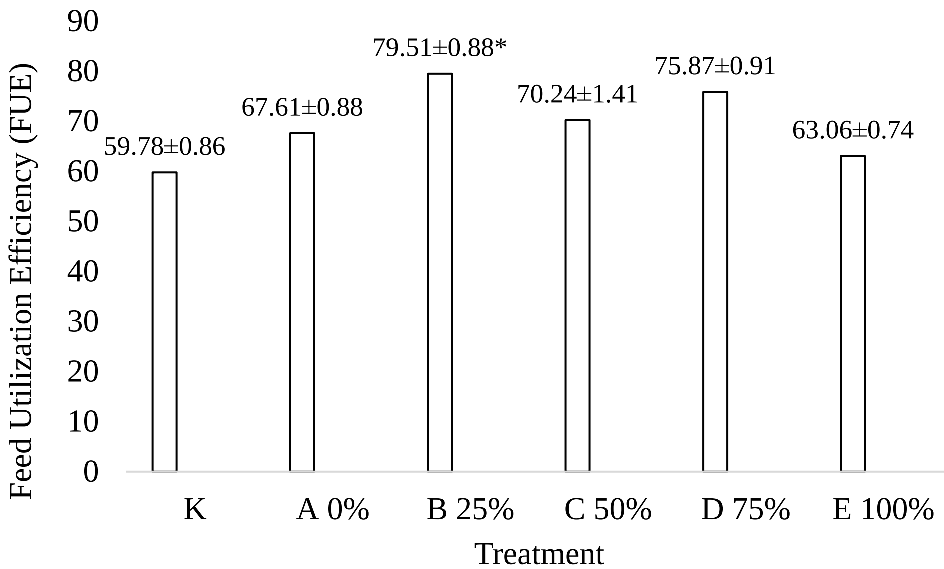

Fig. 2. Feed utilization efficiency (FUE) of Siamese catfish
Note: Asterisk (*) indicates a significant effect on the control treatment.

The most favorable feed conversion ratio (FCR) was observed in Treatment B, which included 25% mealworm flour and 75% fish meal, resulting in an FCR of 1.19 ± 0.05. In contrast, the highest (least efficient) FCR was recorded in Treatment E, which used 100% mealworm flour without any fish meal, yielding a value of 1.49 ± 0.00. The complete FCR values for all treatments are presented in Fig. (3).

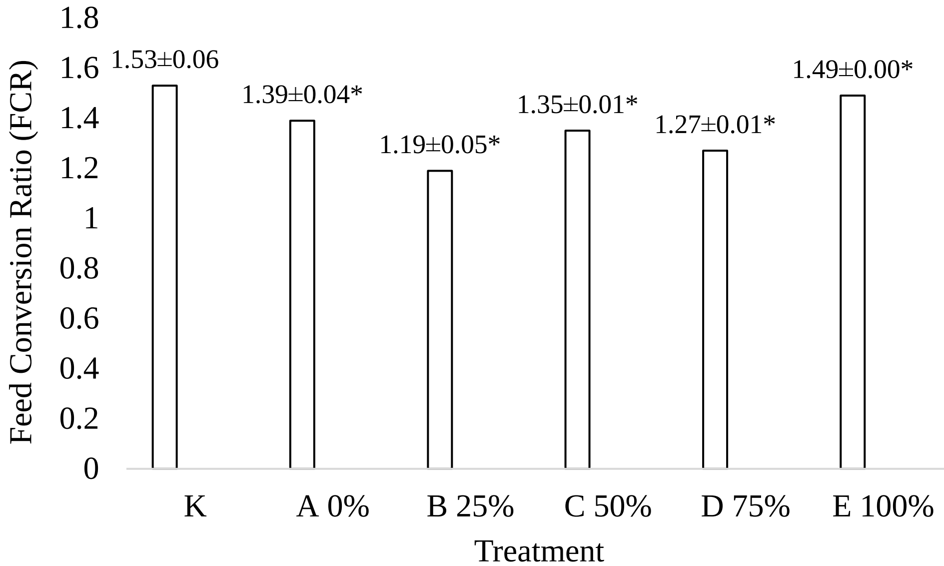

Fig. 3. Feed conversion ratio (FCR) of Siamese catfish

Note: Asterisk (*) indicates a significant effect on the control treatment.

The highest absolute weight gain (W) was observed in Treatment B, which used 25% mealworm flour and 75% fish meal, resulting in a final weight of 171.51 ± 1.46 g. Conversely, the lowest absolute weight was recorded in Treatment E, which contained 100% mealworm flour without any fish meal, yielding a weight of 126.93 ± 0.52 g. The absolute weight results across all treatments are presented in Fig. (4).

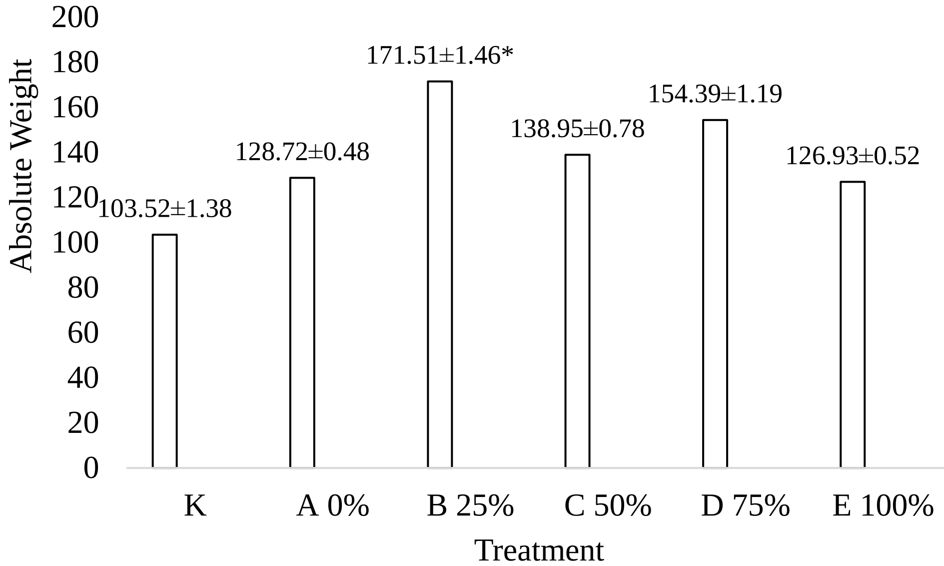

Fig. 4. Absolute weight results of Siamese catfish
Note: Asterisk (*) indicates a significant effect on the control treatment.

The optimal specific growth rate (SGR) was observed in Treatment B, where 25% mealworm flour and 75% of the fish meal were used, resulting in an SGR of 3.95 ± 0.02%/day. In contrast, the lowest SGR was found in Treatment E, with 100% mealworm flour and without using fish meal, resulting an SGR of 2.48 ± 0.01%/day. The SGR values throughout the study are shown in Fig. (5).

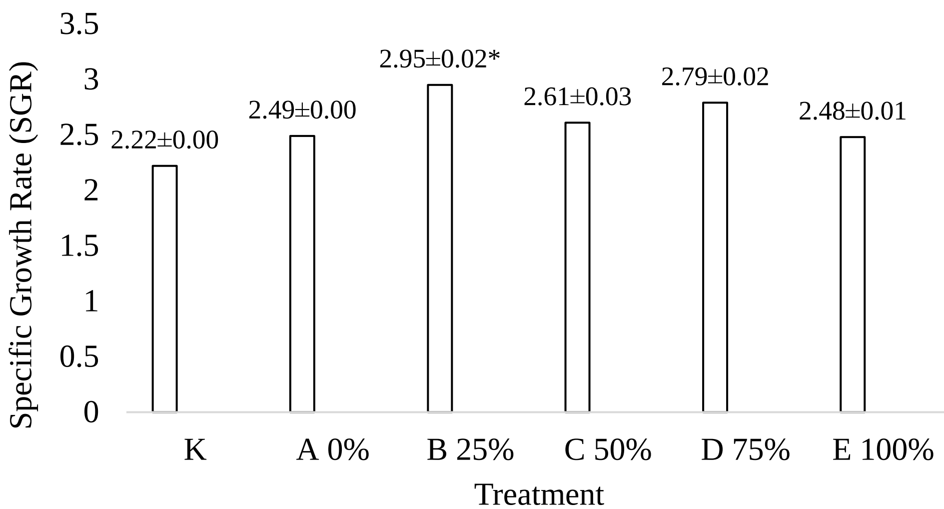

Fig. 5. Specific growth rate (SGR) of Siamese catfish
Note: Asterisk (*) indicates a significant effect on the control treatment.

The highest survival rate (SR) of *Pangasius hypophthalmus* was observed in Treatment B, which involved a 25% substitution of mealworm flour, resulting in an SR of 91.11 ± 3.85%. Lower survival rates were recorded in Treatments A, C, and E (0, 50, and 100% mealworm flour, respectively), each yielding an SR of 84.45 ± 3.85%. The complete survival rate data across all treatments are presented in Fig. (6).

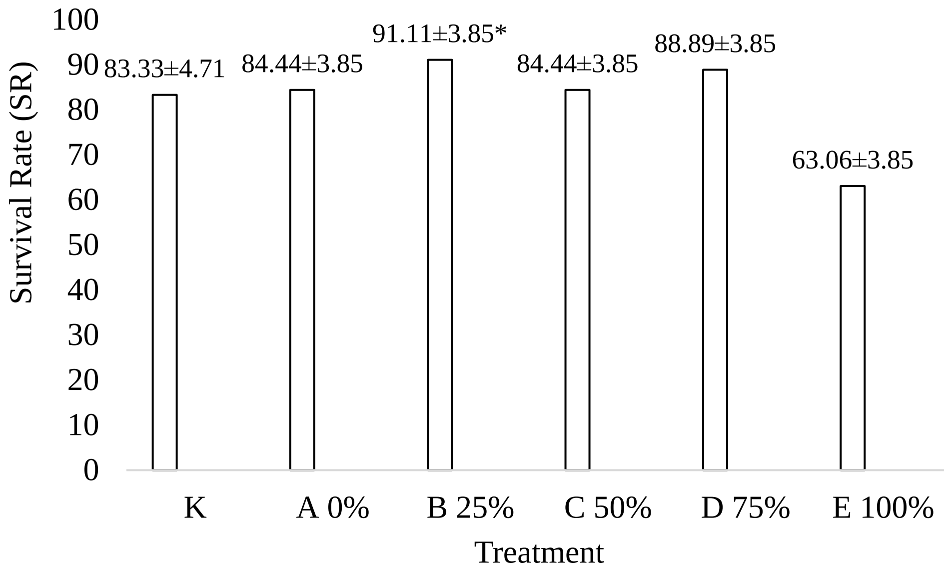

Fig. 6. Survival rate (SR) of Siamese catfish

Note: Asterisk (*) indicates a significant effect on the control treatment.

Water Quality

Water quality measurements were conducted twice daily, in the morning and afternoon, prior to feeding. The water quality parameters measured included DO, temperature, and pH. The results of the water quality parameters measured during the study is presented in Table (1).

Table 1. Water quality of Siamese catfish aquaculture (*P. hypophthalmus*)

No	Variable	Unit	Value	Reference
1	Temperature	°C	25.6 – 27.2	25-30[a]
2	pH	–	7.8 – 8.1	6.5 – 8.5[b]
3	Dissolved Oxygen (DO)	mg/L	4.8 – 6.4	> 4[b]

Note:

a. SNI 01-6483.2-2000

b. SNI 6488.4:2016

DISCUSSION

Growth

The satiation feeding method allows fish to consume feed until they are full or no longer exhibit a feeding response **(Zhang *et al.*, 2024)**. This approach differs from scheduled feeding, which provides a fixed feed amount based on a percentage of body weight, and has been shown to enhance feed utilization efficiency compared to conventional methods **(Chen *et al.*, 2022)**. A key metric for evaluating this strategy is the relative feeding rate (RFR), which measures the ratio of actual to potential maximum feed intake under specific conditions. Studies indicate that satiation feeding enables fish to self-regulate according to physiological needs, resulting in a higher RFR **(Liu *et al.*, 2023)**. This method also improves feed conversion efficiency and reduces competition among fish **(Rodriguez *et al.*, 2024)**.

Quantitative comparisons of restricted RFR methods with satiation feeding show significant differences. Under the RFR method (3% of body weight), feed provision averaged 1.5 grams per feeding at the start of rearing. In contrast, satiation feeding typically led to feed consumption of about 3 grams per session and, over time, exceeded 4% of body weight **(Garcia *et al.*, 2022; Wang *et al.*, 2023; Anderson *et al.*, 2024)**. This increase reflects the growth potential constrained by restricted feeding methods. Feed conversion ratio (FCR) optimization has also been linked to satiation feeding, with lower FCR values indicating improved efficiency **(Thompson *et al.*, 2023)**.

The success of the satiation method is influenced by feed palatability and composition. In aquaculture, feed quality is critical for growth, serving as the main source of energy and essential nutrients. Mealworm flour has been shown to act as a natural attractant due to its sweet, shrimp-like aroma **(Seo *et al.*, 2020)**. However, excessive inclusion can compromise feed stability and pellet binding. High levels of substitution reduce dough elasticity and viscosity **(Xie *et al.*, 2022)**, and insect meals often have lower water absorption during processing **(Bottle *et al.*, 2024)**.

Feed palatability directly impacts feed intake and efficiency, especially in satiation feeding. This was evident in Treatment B (25% mealworm flour), which produced the best growth metrics:

- TFC: 187.88 ± 0.68 g
- FUE: 84.08 ± 0.75%
- FCR: 1.17 ± 0.04
- SGR: 3.26 ± 0.06%/day
- Absolute weight gain: 155.08 ± 3.72 g

These findings highlight that integrating a palatable, nutritionally balanced feed with an effective feeding strategy substantially enhances aquaculture outcomes.

Digestibility, amino acid balance, and protein utilization

Feed intake in fish depends on physiological factors such as stomach capacity, digestibility, and gastric emptying rate **(Karimah *et al.*, 2018)**. This study showed that substituting fish meal with mealworm flour significantly impacted feed utilization efficiency ($P < 0.05$). The highest TFC (215.70 ± 0.74 g) was in Treatment B, while the lowest (190.42 ± 2.63 g) was in Treatment A (0% substitution).

Environmental factors also influenced consumption. The cool temperatures during early study weeks, due to heavy rainfall, likely reduced feed intake **(Pratama *et al.*, 2018; Wulandari *et al.*, 2019)**. Feeding frequency also plays a role, as fish species differ in digestive efficiency and gastric emptying **(Simanjuntak *et al.*, 2022)**.

The palatability-enhancing effect of mealworm flour, particularly its savory-sweet aroma, likely drove increased feed intake at the 25% substitution level. This, in turn, correlated with improved protein utilization efficiency (PUE), a critical measure of feed quality **(Wulandari *et al.*, 2019; Putra *et al.*, 2020)**.

Treatment B had the highest PUE (79.51 ± 0.88%), while Treatment E (100% mealworm) had the lowest (63.06 ± 0.74%). The superior PUE in Treatment B is attributed to lysine content (29.13g/ 100g protein), which falls within the optimal range for Siamese catfish growth **(Nguyen *et al.*, 2019)**. Complementary amino acid profiles from combining fish meal and mealworm flour improve protein balance **(Young & Pellett, 1994)**. At high substitution levels, lysine content falls below optimal, leading to metabolic inefficiencies.

Lysine, the first-limiting amino acid in catfish, is essential for protein synthesis **(Cowey & Tacon, 1983; Ahmed & Khan, 2018; Li *et al.*, 2019)**. Its deficiency reduces nitrogen retention and increases protein catabolism **(Wilson, 2002; Gatlin *et al.*, 2018; Ahmad *et al.*, 2019)**.

Interestingly, Treatment B outperformed Treatment A in FUE despite lower lysine content, suggesting a synergistic effect from protein complementation **(Barroso *et al.*, 2017; Hua *et al.*, 2019; Basto *et al.*, 2020)**. Partial fish meal replacement enhances amino acid balance and palatability. However, at higher substitution levels, lysine deficiency suppresses the mTOR pathway and related protein synthesis genes **(Seiliez *et al.*, 2018; Wang *et al.*, 2019; Liang *et al.*, 2020)**.

Chitin effects and feed conversion ratio

Chitin content from mealworm flour becomes problematic at higher substitution levels (75–100%), as catfish lack adequate chitinase to digest it efficiently **(Kroeckel *et al.*, 2018; Belghit *et al.*, 2019)**. However, moderate chitin levels (2–4%) function as prebiotics, enhancing digestive enzyme activity and gut health **(Henry *et al.*, 2015; Józefiak *et al.*, 2019; Terova *et al.*, 2019; Rawski *et al.*, 2020;)**.

The FCR, a key indicator of feed efficiency, was lowest in Treatment B (1.19 ± 0.05) and highest in Treatment E (1.49 ± 0.00) **(Abdel-Tawwab *et al.*, 2020; Hasan *et al.*, 2021)**. This inverse relationship with FUE confirms consistent results across metrics **(Rimmer & Hasan, 2021)**. The protein-rich composition of Treatment B (36.16% protein, 10.03% fat, 9.22% fiber) contributed to superior performance. In contrast, the high ash content (17.18%) in Treatment E likely hindered nutrient absorption **(Tran *et al.*, 2020; Boyd & D'Abramo, 2023)**.

The rising FCR with increased substitution is attributed to lysine deficiency, amino acid imbalance, and high chitin content **(Kaushik & Seiliez, 2019; Makkar *et al.*, 2020; NRC, 2021; van Huis *et al.*, 2021)**. Economically, Treatment B provides the most cost-effective option, reducing dependency on increasingly scarce fish meal **(Kobayashi *et al.*, 2022)**.

Growth performance and nutritional mechanisms

The highest SGR (2.95 ± 0.02%/day) occurred in Treatment B, correlating with superior PUE and FUE **(Hasan *et al.*, 2018; Barroso *et al.*, 2019)**. This was due to the combined effect of digestible protein sources and amino acid complementation. High branched-chain amino acid content in mealworm flour supports this effect **(Liu *et al.*, 2020; Rawski *et al.*, 2021)**.

The mechanism underlying enhanced SGR is increased proteolytic enzyme activity, promoted by mixed protein sources **(Sanchez *et al.*, 2015; Henry *et al.*, 2018; Józefiak *et al.*, 2019)**. Balanced energy distribution from protein, carbohydrate, and fat further supports efficient growth **(Subandiyono *et al.*, 2018; Hua *et al.*, 2019; Tran *et al.*, 2020)**.

The highest absolute weight gain (171.51 ± 1.46 g) was recorded in Treatment B, consistent with other performance metrics. This outcome is linked to improved nutrient digestibility and balanced feed texture, contributing to effective biomass accumulation **(Devic *et al.*, 2018; Gasco *et al.*, 2018; Belforti *et al.*, 2019; Van Huis *et al.*, 2020)**. The formulation in Treatment B (36.16% protein, 10.03% fat, 9.22% fiber) was optimal for catfish growth, while the high ash content in Treatment E impaired weight gain **(Renna *et al.*, 2017; Vargas *et al.*, 2018; Magalhães *et al.*, 2019; Ido *et al.*, 2021)**.

Survival rate

The survival rate (SR) of Siamese catfish (*Pangasius hypophthalmus*) was influenced by the level of mealworm flour substitution in their diet. The highest SR was observed in Treatment B (25% mealworm flour), reaching 91.11 ± 3.85%. In contrast, the lowest SR values (84.45 ± 3.85%) were recorded in Treatments A, C, and E (0%, 50%, and 100% substitution, respectively), while Treatment D (75%) showed an intermediate SR of 88.89 ± 3.85%.

Most fish mortality occurred during the early weeks of the experiment, largely due to temperature fluctuations associated with the rainy season and stress induced by sampling procedures. The inclusion of mealworm flour at an optimal level (25%) proved beneficial, partly due to its chitin content, which functions as a natural prebiotic and immunostimulant. Chitin promotes immune cell proliferation and cytokine production, thereby enhancing disease resistance and resilience to environmental stress **(Henry *et al.*, 2022)**.

Mealworm flour also contains antimicrobial peptides such as defensin and cecropin, which help regulate pathogenic bacteria in the gut **(Fontes *et al.*, 2021)**. Additionally, it contains antioxidants like tocopherol and carotenoids, as well as lauric acid, all of which exhibit antimicrobial and immune-boosting properties **(Rawling *et al.*, 2021)**.

At higher substitution levels (50–100%), the reduced SR is likely due to excessive chitin content, which impairs digestibility and nutrient absorption. Catfish lack sufficient chitinase enzymes to effectively digest the chitin found in insect exoskeletons **(Fawole *et al.*, 2020)**. Other contributing factors to catfish survival include water quality, feed nutritional profile, stocking density, and the immune system's response to stress and pathogens. In intensive aquaculture, an optimal SR for catfish typically ranges from 80–95% **(Nguyen *et al.*, 2022)**.

Proper feed management, including balanced alternative protein sources and functional feed additives such as probiotics and immunostimulants, can improve survival rates by up to 15% under intensive rearing conditions **(Haider *et al.*, 2024)**.

Water quality

Water quality parameters measured during the study included pH, temperature, and dissolved oxygen (DO). The observed ranges were:

- **pH**: 7.8–8.1
- **Temperature**: 25.6– 27.2°C
- **Dissolved oxygen (DO)**: 4.8– 6.4mg/ L

These values fall within the optimal standards set by the Indonesian National Standards (SNI), which specify a pH range of 6.5–8.5 (SNI 6488.4:2016), a temperature range of 25– 30°C (SNI 01-6483.2-2000), and a minimum DO level of 4.0mg/ L (SNI 01-6483.2-2000).

Water quality is a critical determinant of aquaculture success, as parameters like pH, temperature, and DO directly influence fish metabolism, health, and growth **(Roy *et al.*, 2021)**. Fluctuations in pH are often caused by feeding activity and waste accumulation, which elevate ammonia and carbon dioxide levels through respiration and decomposition **(Dauda *et al.*, 2019)**.

Seasonal changes—particularly during the early weeks of this study—had a significant impact. Continuous rainfall lowered water temperature and diluted nutrients, contributing to shifts in pH and DO levels **(Boyd *et al.*, 2020)**.

To address environmental variability, integrated water quality management systems, such as biofiltration, are recommended to maintain stability **(Widiastuti *et al.*, 2022)**. The application of probiotics has also been shown to improve water quality by breaking down organic waste and preventing the buildup of toxic compounds, thus creating a more sustainable aquatic environment **(Rahman *et al.*, 2023)**.

CONCLUSION

Based on the results of the study investigating the substitution of mealworm (*T. molitor*) flour in the diet of Siamese catfish (*P. hypopthalmus*), it is evident that replacing fish meal with mealworm flour in formulated catfish feed significantly influences ($P< 0.05$) the growth parameters of catfish. These parameters include total feed consumption (TFC), feed utilization efficiency (FUE), feed conversion ratio (FCR), absolute weight gain, and specific growth rate (SGR). The substitution level of 25% mealworm flour (Treatment B) produced the most favorable growth performance. Specifically, fish in the Treatment B exhibited the highest growth performance, with a total feed consumption (TFC) of 215.70±0.74 grams, feed utilization efficiency (FUE) of 79.51±0.88%, feed conversion ratio (FCR) of 1.19±0.05, specific growth rate (SGR) of 2.95±0.02%/day, and an absolute weight gain of 171.51±1.66 grams.

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