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Utilization of Various Palm Oil Wastes as Feed Ingredients for the Growth and Survival of Vannamei Shrimp (*Litopenaeus vannamei*)

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ABSTRACT

This study aimed to evaluate the effects of various components of palm oil waste—specifically palm kernel cake, leaves, fronds, and fermented fibers—on the growth performance and survival of *Litopenaeus vannamei*. An experimental design was employed using multiple palm oil waste-based feed formulations, with growth outcomes assessed through specific growth rate (SGR), feed conversion ratio (FCR), and survival rate over the cultivation period. The results demonstrated that the use of palm oil waste had a significant effect on absolute growth, SGR, and FCR ($P< 0.05$). Among the treatments, the feed based on palm kernel cake produced the highest performance, with an absolute weight gain of 1.919g, a relative growth rate of 5,466%, and an FCR of 0.961, outperforming both other treatments and the control. These findings suggest that palm kernel cake is a promising alternative feed ingredient for enhancing the productivity and feed efficiency in *L. vannamei* aquaculture, while also contributing to the sustainable utilization of palm oil industry waste.

INTRODUCTION

Shrimp farming of *Litopenaeus vannamei* has become a leading commodity in the global aquaculture industry due to its rapid growth, tolerance to high stocking densities, and increasing global market demand **(Department, 2018)**. However, the high cost of feed—accounting for more than 60% of total production costs—poses a major challenge to the sustainability of intensive farming **(Liu *et al*., 2018; Tacon *et al*., 2022; Araujo *et al*., 2025)**. According to **Kumar *et al*. (2017)**, feed production costs can range from 60 to 70% of total farming expenses. The limited availability of fishmeal, the primary protein source in feed, is a key factor driving these high prices **(Lin & Chen, 2022)**.

Therefore, innovation in the use of alternative feed ingredients that are economical, readily available, and capable of supporting shrimp growth and health is essential. The use of plant-based proteins as a substitute for fishmeal in shrimp feed formulations has become a strategic choice, particularly as global demand for fishmeal continues to drive up prices **(Olsen & Hasan, 2012; Shamsuddin *et al*., 2021)**. Optimizing the use of local feed ingredients is a practical approach to improve sustainability and cost efficiency in aquaculture **(Zebua *et al*., 2025)**. Efforts to minimize production costs as efficiently as possible require plant-based raw materials that can be formulated into feed **(Datta, 2012)**—one of which is derived from oil palm (*Elaeis guineensis*).

Oil palm, a major agricultural commodity in Indonesia, generates various types of waste that are often underutilized and, if improperly managed, pose significant environmental risks such as biodiversity loss and the death of aquatic organisms **(Okwute & Isu, 2007)**. These wastes include palm oil mill effluent (POME), empty fruit bunches (EFB), mesocarp fiber (MF), palm kernel shell (PKS), palm kernel meal (PKM), oil palm trunks (POT), and oil palm fronds (POF) **(Gozan *et al*., 2024)**. The production of crude palm oil (CPO) and palm biodiesel generates solid waste amounting to 35–40% of the total processed fresh fruit bunches (FFB), including empty fruit bunches, fiber, shells, and ash.

Yuliyanto *et al*. (2021) reported that processing 1 ton of FFB in Indonesia produces approximately 230kg of empty fruit bunches, 65kg of shells, 40kg of palm sludge, 130kg of fiber, and liquid waste equivalent to 50% of the processed FFB weight. To address these challenges, a circular economy approach encourages the conversion of palm waste into value-added products, such as raw materials for aquaculture feed. This is supported by **Yuliyanto *et al*. (2021)**, who suggest that palm kernel meal can be used as a feed ingredient due to its nutritional content, including 15.14% crude protein, 6.08% crude fat, 17.18% crude fiber, 0.47% calcium, 0.72% phosphorus, and 57.80% nitrogen-free extract (NFE).

Palm oil mill effluent (POME) is rich in organic materials such as proteins, carbohydrates, lipids, and nitrogen compounds, which can be used for microbial culture **(Habib *et al*., 1997; Wu *et al*., 2007)** and animal feed. Supplementing feed with palm-based materials has been shown to increase hemocyte counts and stimulate immune enzyme activity, such as prophenoloxidase (ProPO) **(Babin *et al*., 2010)**. Physiologically, this enhanced immune response positively impacts shrimp growth, feed conversion ratio (FCR), and survival rates during cultivation.

Furthermore, **Vijayaram *et al*. (2022)** reported that immune enhancement, growth, survival, and resistance to pathogenic microbes in aquatic organisms could be improved through the use of natural bioactive immunostimulant-based feed additives—an emerging strategy in aquaculture productivity.

Palm-derived materials contain plant-based proteins, essential amino acids, and bioactive compounds such as phenols, flavonoids, and tannins, which can serve as natural immunostimulants **(Chong *et al*., 2008; Sasidharan *et al*., 2010)**. Additionally, **Harmileni *et al*. (2025)** found that palm kernel meal, leaves, fronds, and fiber contain bioactive compounds—flavonoids, saponins, polyphenols, tannins, alkaloids, steroids, and triterpenoids—that exhibit strong antibacterial potential against pathogens like *Vibrio harveyii* and *Vibrio parahaemolyticus* in vannamei shrimp **(Nasmia *et al*., 2024)**. This is supported by **Nordin *et al*. (2023)**, who found that water extracts from palm oil possess significant antibacterial properties.

Incorporating these materials into feed formulations not only supports growth and feed efficiency but also enhances shrimp immunity against environmental stress and pathogenic infections. **Ridzuan *et al*. (2025)** reported that a 10% palm oil adjuvant effectively stimulated systemic immune response and yielded the highest survival rate in red hybrid tilapia. Several studies have shown that, when properly formulated, palm pulp can result in better fish growth compared to feed without palm-based ingredients.

This study aimed to analyze the effects of adding various types of fermented palm waste—kernel meal, leaves, fronds, and fiber—into feed formulations on the growth, survival rate, and FCR of *L. vannamei*, and to identify the most effective material for use in shrimp farming systems. The findings are expected to contribute significantly to the development of functional, palm waste–based feed, promoting sustainable and cost-efficient aquaculture practices.

MATERIALS AND METHODS

1. Animal test

The test organisms used in this study were 400 post-larval (PL20) *Litopenaeus vannamei* obtained from a hatchery in Tomoli Village, Toribulu District, Parigi Moutong Regency, Central Sulawesi.

2. Feed preparation

The method for feed preparation involved grinding the palm waste and sieving it to obtain a fine texture, followed by fermentation. The finely ground palm waste flour was then mixed with EM4 (80 mL/L water per 1 kg of palm flour) and stirred evenly. The mixture was placed in a tightly sealed container for 21 days at tempreture 27°C to prevent air exposure. After fermentation, the nutrient content was analyzed. The proximate analysis results of the palm waste flour before and after fermentation are presented in Table (1).

Table 1. Proximate analysis of palm waste before and after fermentation

No.	Nutriens (%)	Fermented				Non-fermented			
		Palm kernel meal	Palm leaves	Palm fronds	Palm fiber	Palm kernel meal	Palm leaves	Palm fronds	Palm fiber
1.	Moisture	12.25	11.60	11.00	11.56	6.49	9.08	9.12	9.78
2.	Crude Fat	5.08	1.53	3.24	1.87	8.56	3.25	1.37	6.06

3.	Crude Protein	18.80	17.70	15.79	16.64	13.11	11.95	4.25	10.10
4.	Ash Content	1.88	7.73	3.57	3.80	3.93	8.23	3.96	6.14

3. Formulation of palm waste-based feed

The experimental feed was designed to contain 35% crude protein. The formulation process began with accurately weighing each ingredient based on the specified composition. Key components included fermented palm waste flour, fishmeal, shrimp head meal, soybean meal, cornmeal, rice bran, tapioca flour, vegetable oil, fish oil, and a vitamin-mineral premix. Dry ingredients were first mixed separately from the liquid components. This mixture is then gradually mixed with warm water so that the feed does not easily disintegrate to form a dough-like consistency. This dough was subsequently processed through a basic pelletizing machine, shaped into appropriate pellet sizes (2 mm), and dried under sunlight. Detailed feed formulations are provided in Table (2).

Next, the ingredients that have been prepared were mixed in a container evenly and warm water was added little by little so that the feed does not easily disintegrate and was stirred until it forms a solid.

Table 2. Experimental feed formulation

Feed Ingredient	Treatment / Feed Composition (%)				
	A	B	C	D	E
Fishmeal	45	45	45	45	45
Shrimp head meal	15	15	15	15	15
Soybean meal	10	10	10	10	10
Rice bran	5	5	5	5	5
Cornmeal	18.5	10.5	10	9	9.5
Fermented palm kernel meal	0	8.0	0	0	0
Fermented palm leaves	0	0	8.5	0	0
Fermented palm fronds	0	0	0	9.5	0
Fermented palm fiber	0	0	0	0	9
Vegetable oil	1.5	1.5	1.5	1.5	1.5
Fish oil	1.5	1.5	1.5	1.5	1.5
Tapioca flour	2	2	2	2	2
Vitamin & mineral mix	1.5	1.5	1.5	1.5	1.5
Total	100	100	100	100	100

Treatment: A (Control); B (Fermented palm pulp); C (Fermented palm leaf); D (Fermented palm fronds); E (Fermented palm fibers).

4. Experimental design

The study was structured using a completely randomized design (CRD), consisting of five treatment groups with four replications each, resulting in a total of 20 experimental units. The treatments were as follows: Treatment A served as the control without the addition of palm oil waste; Treatment B included fermented palm kernel cake; Treatment C involved the addition of fermented palm leaves; Treatment D incorporated fermented palm fronds; and Treatment E utilized fermented palm fiber. The maintenance period of the test organisms (*Litopenaeus vannamei*) was 40 days.

5. Preparation of maintenance tanks

Aquariums measuring 50 × 25 × 40cm were thoroughly cleaned using detergent, rinsed with clean water, and left to dry. Each tank was then filled with 20 liters of high-quality seawater. Aeration equipment, including air stones and tubing, was installed to maintain adequate oxygen levels, and all tanks were labeled based on the randomized treatment allocation.

6. Stocking and maintenance of test organisms

Each 20-liter aquarium was stocked with 20 vannamei shrimp as test organisms. The shrimp were fed three times a day—at 07:00, 12:00, and 17:00 WITA—at a rate of 10% of their total biomass. To maintain water quality, daily siphoning was carried out to remove uneaten feed and fecal matter, followed by replenishment with clean seawater.

7. Water quality parameters

Water quality parameters—including temperature, pH, dissolved oxygen (DO), and salinity—were measured every 10 days throughout the study period. Additionally, ammonia concentration was assessed at the midpoint of the experiment to monitor potential accumulation and its impact on shrimp health.

8. Research variable

Growth performance was calculated using data according to the following equations:

8.1 Absolute weight growth (Felix & Sudharsan, 2004)

$$W = Wt - W0$$

W : Absolute weight growth
Wt : Final weihgt (g)
W0 : Initial weight (g)

8.2 Relative growth rate (Far *et al*., 2009)

$$\text{LPSH (\%/hari)} = \frac{\text{Ln}\overline{W_t} - \text{Ln}\overline{W_o}}{\Delta t} \times 100$$

LPSH : Relative growth rate
$\text{Ln}\overline{W_t}$: ln final wt
$\text{Ln}\overline{W_o}$: ln initial wt
Δt : Duration (days)

8.3 Survival rate (Felix & Sudharsan, 2004)

$$SR\ \% = \frac{Nt}{No} \times 100$$

SR : Survival rate (%)
Nt : Number of prawns survived at the end of the experiment
No. : Number of prawns stocked at the start of the experiment

8.4 *Feed conversion ratio (FCR)* (Ariadi & Wafi, 2020)

$$FCR = \frac{F}{Wt - Wo}$$

FCR : Feed conversion ratio
F : Total feed given (g)

9. Data analysis

The effect of palm oil waste-based feeding treatment on absolute growth, relative growth rate, and FCR was analyzed using ANOVA analysis of variance. The data obtained were tabulated and analyzed using Microsoft Excel 2010 and Minitab 2016 programs. If the results of the analysis of variance showed an effect of the treatment, further testing was continued to determine the differences between treatments. Survival parameters and water quality were analyzed descriptively and are presented in tabular form.

RESULTS

1. *Litopenaeus vannamei* growth

Table (3) summarizes the results of the absolute weight growth and relative growth rate of *L. vannamei* during the study.

Table 3. Average absolute weight growth and relative growth rate of *L. vannamei*

Parameter	Treatment				
	A (non-palm/ Control)	B (Fermented palm pulp)	C (Fermented palm leaf)	D (Fermented palm fronds)	D (Fermented palm fronds)
Absolute Weight Growth (g)	1.210±0.19[ab]	1.919±0.23[e]	1.243±0.15[abc]	1.144±0.07[b]	1.488±0.12[bcd]
Relative Growth Rate (%)	4.181±0.28[a]	5.466±0.39[d]	4.668±0.15[bc]	4.468±0.05[b]	4.969±0.25[c]

The results indicate the highest absolute weight growth and relative growth rate in treatment B (fermented palm pulp), which significantly outperformed the other treatments.

2. Absolute weight growth

The results of absolute weight growth (Fig. 1) show that the highest growth occurred in Treatment B (palm meal), with a value of 1.919 ± 0.234g, followed by Treatment E (palm fiber) at 1.488 ± 0.121g, Treatment C (palm leaves) at 1.243 ± 0.155g, Treatment A (control, without palm waste) at 1.210 ± 0.199g, and the lowest growth in Treatment D (palm fronds) at 1.144 ± 0.073g.

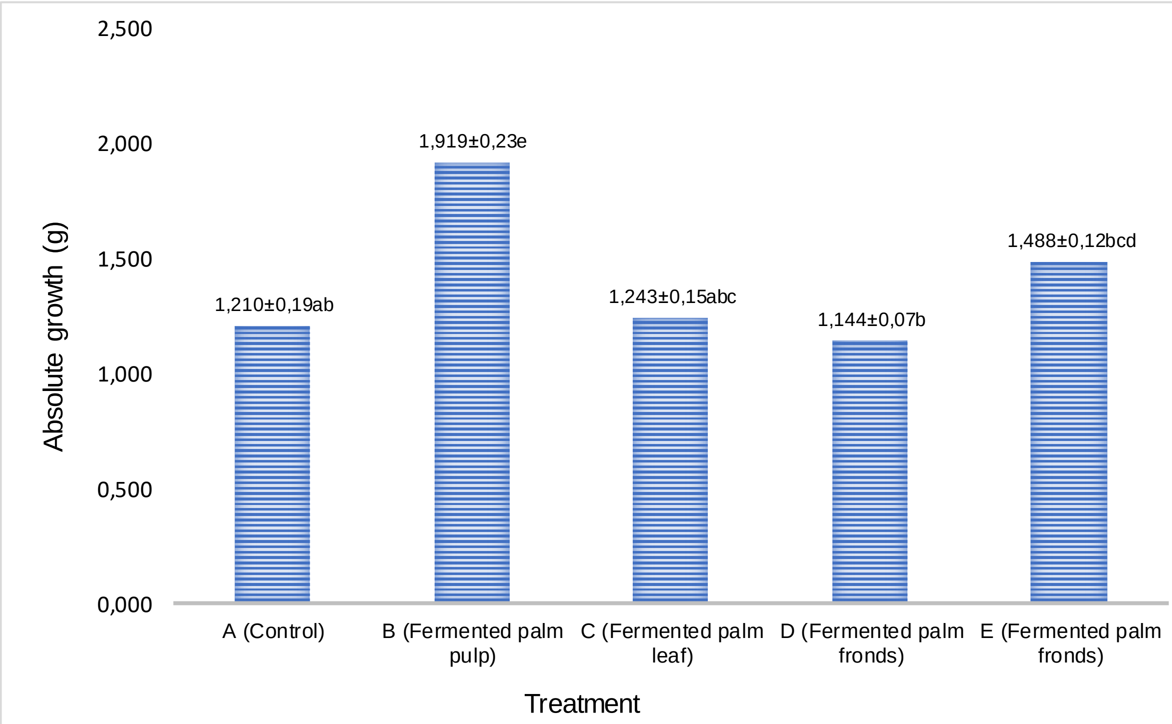

Fig. 1. Absolute weight growth of *L. vannamei* fed on diets containing palm oil waste fermentation

Based on the results of the ANOVA test, the addition of fermented palm waste flour (including palm meal, leaves, fronds, and fibers) in artificial feed significantly affected the absolute weight growth of *L. vannamei* ($P<0.05$). The Duncan's multiple range test showed that treatment B (palm meal) was significantly different from all other treatments, including A (control), C (palm leaves), D (palm fronds), and E (palm fiber). Treatment C was significantly different from treatment B, but it did not differ significantly from treatments A, D, and E.

3. Specific growth rate

The results of the specific growth rate of *L. vannamei* during the 40-day study are shown in Fig. (2). The highest daily specific growth rate was observed in treatment B (palm meal) with a value of 5.466±0.397g, followed by treatment E (palm fiber) at

4.969±0.250g, treatment C (palm leaves) at 4.668±0.145g, treatment D (palm fronds) at 4.468±0.054g, and the lowest growth rate was in treatment A (control) at 4.181±0.281g.

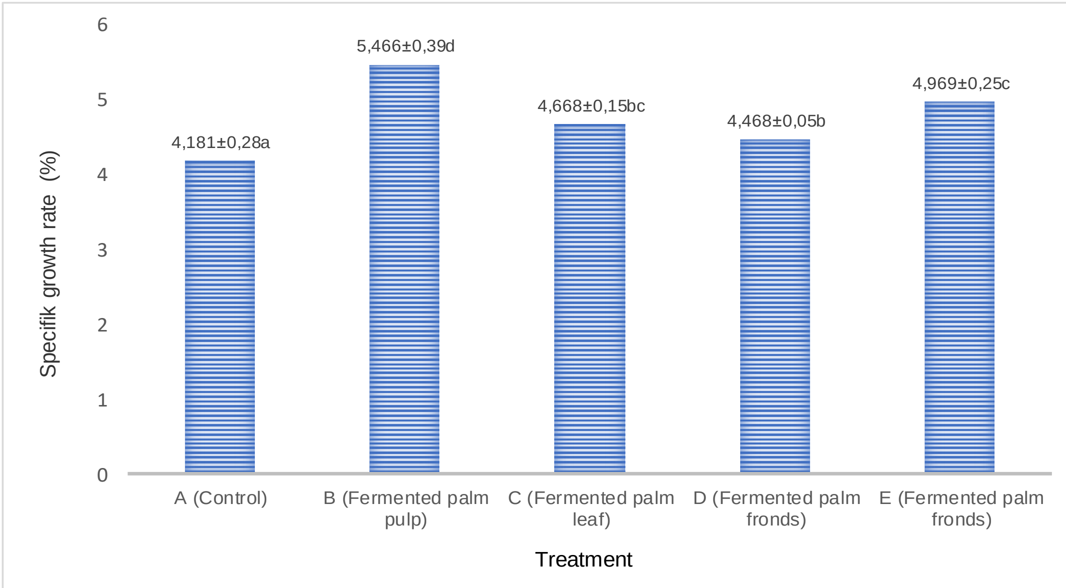

Fig. 2. Relative growth rate of *L. vannamei* fed on diets containing palm oil waste fermentation

The results of the ANOVA analysis showed that the addition of palm waste flour (meal, leaves, fronds, and fiber) in the artificial feed significantly ($P< 0.05$) affected the specific growth rate of *L. vannamei*. The Duncan's post hoc test revealed that treatment B was significantly different from all other treatments. Treatment C did not differ significantly from D and E, but was significantly different from treatments A and B. Treatment D was not significantly different from C, but was significantly different from A, B, and E. Treatment E did not differ significantly from C, but was significantly different from A, B, and E. Meanwhile, treatment A was significantly different from all other treatments (B, C, D, and E).

4. Survival of *Litopenaeus vannamei*

Survival reflects the level of success of an organism in surviving during the maintenance period, which is highly influenced by the nutritional quality of the feed, environmental conditions, and the physiological balance of the shrimp. The survival results of *Litopenaeus vannamei* with the addition of fermented palm flour (meal, leaves, fronds, and fiber) in the feed, based on observations over 40 days, are presented in Fig. (3).

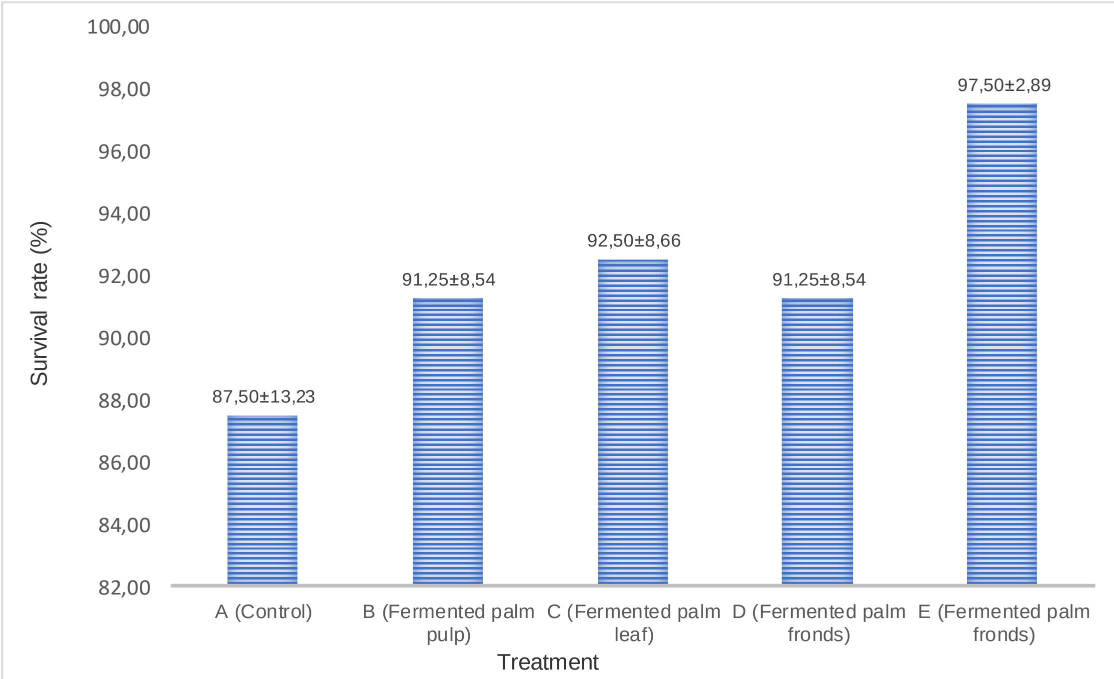

Fig. 3. Survival of *L. vannamei* fed on diets containing palm oil waste fermentation

The survival rate of *L. vannamei* during the maintenance period for all treatments ranged from 87.50 to 97.50%. The highest survival rate was observed in treatment D (palm fiber) at 97.50%, followed by treatment C (palm leaves) at 92.50%, treatments B (palm meal) and D (palm fronds) at 91.25%, and the lowest survival rate was in treatment A (control), which did not include any palm waste, at 87.50%.

5. Food conversation ratio (FCR)

Food Conversion Ratio (FCR) is one of the main parameters in assessing feed efficiency in shrimp farming. A low FCR value indicates that feed is more efficiently converted into body weight gain, making it an important indicator in evaluating the performance of alternative feeds, and a lower FCR value indicates higher feed efficiency and reflects optimal nutrient conversion in the shrimp body. The results of the FCR value are shown in Fig. (4).

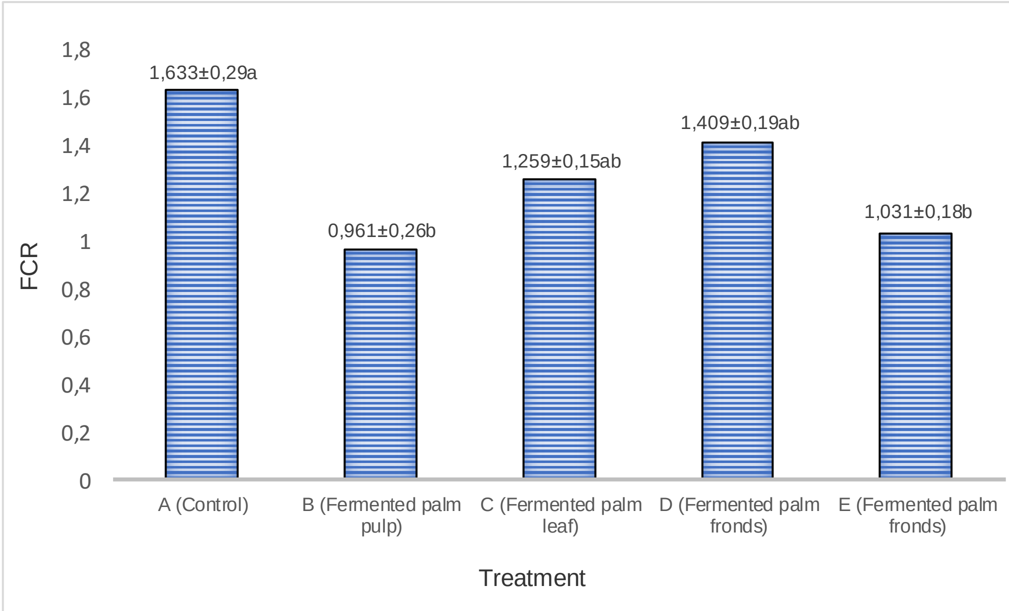

Fig. 4. FCR results of *L. vannamei* fed with feed containing palm oil waste

The results of the ANOVA test showed that the addition of different palm oil waste flour fermentation, namely dregs (B), leaves (C), fronds (D), and fibers (E) to artificial feed had a significant effect (P< 0.05) on the feed conversion value (FCR). The results of further tests showed that treatment B was not significantly different from treatments C, D, and E but was significantly different from treatment A. Treatments C and D were not significantly different from all treatments, treatments A and B, treatment A was not significantly different from treatments C and D, but was significantly different from treatments B and E.

6. Water quality

The results of water quality measurements during the study for each treatment are shown in Table (4).

Table 4. Results of water quality measurements

Treatment	Temperature (°C)	pH	Salinity (ppm)	Dissolved Oxygen (ppm)	Ammonia (mg/L)
A (control)	26–28.7	7.4–7.9	30	5.0–7.9	0.265–0.319
B (fermented palm pulp)	26–28.5	7.4–7.9	30	4.5–8.0	0.269–0.354
C (fermented palm leaf)	26–28.9	7.4–7.9	30	4.5–7.7	0.267–0.371
D (fermented palm fronds)	26–28.6	7.4–7.9	30	4.8–7.7	0.271–0.367
E (fermented palm fronds)	26–28.5	7.4–7.9	30	4.5–7.9	0.269–0.332

Proper water quality is essential for the success and sustainability of shrimp aquaculture operations. Water quality parameters such as temperature, dissolved oxygen, pH, salinity, and ammonia concentration must be consistently monitored to maintain optimal aquatic conditions. Effective water quality management plays a critical role in minimizing disease outbreaks and maximizing the growth and survival of shrimp populations **(Anjaini *et al.*, 2024)**. Based on measurements taken during the study (Table 4), all water quality parameters (temperature, pH, salinity, dissolved oxygen, and ammonia) were within acceptable ranges to support the growth and survival of *L. vannamei*.

DISCUSSION

1. *Litopenaeus vannamei* growth

Shrimp and crustacean growth refers to changes in body weight and length **(Serdiati *et al.*, 2025; Tahya *et al.*, 2025; Zubaidah *et al.*, 2025)**. The growth of *L. vannamei* is influenced by the quality of the feed and how well it meets the shrimp's nutritional requirements. The results of this study (Figs. 1, 2) show that the highest values for absolute growth and specific growth rate were obtained in Treatment B, which included the addition of fermented palm kernel cake, with values of 1.919 ± 0.234 g and $5.466 \pm 0.397\%$, respectively. This indicates that shrimp growth is closely related to the nutritional value of the feed, particularly energy-yielding components such as protein, fat, and carbohydrates.

Proximate analysis (Table 1) revealed an increase in the protein content of palm waste materials after fermentation. Fermented palm kernel cake had the highest protein content at 18.80%, compared to only 13.11% before fermentation. Similarly, other palm waste materials also showed protein increases: palm leaves from 11.95% to 17.70%, fronds from 4.25% to 9.73%, and fibers from 10.10% to 16.64%. These findings align with previous research **(Kompiang *et al.*, 1994; Adebo *et al.*, 2022)**, which reported that fermentation improves the nutritional quality of feed ingredients. This occurs through chemical transformations in carbohydrates, fats, proteins, and fibers by microbial enzymes under aerobic or anaerobic conditions.

According to **Irianto (2003)**, probiotics produce digestive enzymes that help break down feed components, enhancing nutrient absorption and shrimp growth. Enzymes such as proteases and amylases hydrolyze proteins, lipids, and carbohydrates, thereby improving digestibility and feed efficiency. Fermentation also likely increases digestibility, as microbes such as *Lactobacillus casei* and *Saccharomyces cerevisiae* in EM4 produce enzymes that break down complex compounds into simpler, more absorbable nutrients, leading to improved shrimp performance compared to non-supplemented feed **(Damanik *et al.*, 2023; Telaumbanua *et al.*, 2023)**.

Fermented feed shows promise as an eco-friendly alternative to conventional shrimp diets, improving growth performance and feed efficiency while enhancing stress tolerance and immune function **(Awad *et al.*, 2025)**. In addition to economic benefits, recycling palm oil waste contributes to environmental sustainability and future food security **(Gozan *et al*., 2024)**.

Chen *et al*. (2022) suggested that microbes in EM4 secrete enzymes that simplify palm kernel cake components, making nutrients more bioavailable. Additionally, **Pamungkas (2011)** reported that fermentation reduces anti-nutritional factors such as lignin, while increasing crude protein and essential amino acid content. Anti-nutrients like phytic acid, which binds minerals and impairs absorption, can hinder growth **(Suprayudi *et al*., 2012)**. Thus, fermentation plays a vital role in improving palm kernel cake quality by reducing anti-nutrients and fiber content, which enhances digestibility **(Lin & Mui, 2017)**.

Crude fiber in palm kernel meal can reduce feed digestibility, which is why probiotics are added to help convert complex components into simpler forms. **Noviana (2014)** stated that probiotics enhance fish digestibility by producing digestive enzymes that hydrolyze protein into absorbable compounds. Probiotic-supplemented feeds can improve protein content and reduce fiber. Moreover, fermentation can generate beneficial substances like organic acids, short peptides, flavonoids, and probiotics, all of which contribute to better feed quality **(Mukherjee *et al*., 2015; Yang *et al*., 2022)**.

Several factors influence protein absorption in *L. vannamei*, including protein type, feed quality, environmental conditions, and shrimp health. Adequate protein intake and absorption are critical for optimal growth and development **(Dong *et al*., 2022; Ma *et al*., 2024)**. Poor protein absorption can result in stunted growth and physiological dysfunction. Thus, feed must be formulated with optimal nutritional levels to support shrimp performance **(Cuzon, 1989; Pratoomyot *et al*., 2010; Molina-Poveda *et al*., 2013)**. Feed quality, reflected by the balance of nutrients—such as protein, amino acids, fat, ash (minerals), moisture, and carbohydrates—directly affects growth.

The absolute weight gain and specific growth rate of shrimp are significantly influenced by the availability of nutrients, particularly protein, which is often the limiting factor. Feed with optimal nutrients supports metabolic processes and enhances growth. The increased growth observed in Treatment B likely resulted from the fermentation of palm kernel cake, which improved amino acid availability and digestibility. Amino acids such as lysine and methionine enhance nutrient absorption and support optimal shrimp growth. They also serve as precursors for the synthesis of glucose, lipids, nitric oxide, glutathione, polyamines, histamine, and hormones that regulate physiological and immune functions **(Li *et al*., 2021)**.

2. Survival of *Litopenaeus vannamei*

The survival rate of *L. vannamei* increased with the addition of fermented palm waste flour, ranging from 91.25% to 97.50%, compared to 87.50% in the control group without palm waste (Fig. 3). This is consistent with **Shamsuddin *et al*. (2021)**, who reported that substituting up to 25% of fishmeal with palm flour did not compromise specific growth rate, FCR, or survival rate—demonstrating that palm flour is a viable, cost-effective protein source in intensive systems.

Palm fiber flour yielded the highest survival rate (97.50%), outperforming other treatments, despite its lower protein content. This suggests its role as a natural prebiotic that promotes gut health, nutrient absorption, and immune enhancement. **Winanti *et al*. (2025)** noted that fermented palm kernel meal is a source of mannan oligosaccharides (MOS), applicable in the crayfish. Synbiotic combinations, such as MOS or galactooligosaccharides with *Enterococcus faecalis* or *Pediococcus acidilactici*, have shown to increase survival, immune response, and growth in the crayfish **(Safari *et al*., 2017; Safari & Paolucci, 2018)**. Synbiotics also boost mucus antibacterial activity, beneficial gut flora, and nutrient digestibility **(Safari & Paolucci, 2018; Alvanou *et al*., 2023)**.

Processing methods like fermentation and probiotic addition enhance nutrient bioavailability from palm fiber, increasing resilience against stress and pathogens. **Awasthi *et al*. (2022)** confirmed that MOS prebiotics derived from *S. cerevisiae* membranes improve health and stress tolerance in the crayfish. **Winanti *et al*. (2025)** also found that fermented palm kernel meal increased non-specific immune responses in the red claw crayfish. Conversely, the control feed—despite containing fishmeal and soy—yielded the lowest survival rate, likely due to the absence of functional fibers and bioactive compounds necessary for gut and immune health in high-density environments.

Survival rates from palm meal, leaves, and fronds treatments ranged from 91.25% to 97.50%. Moderate protein content in palm meal and bioactive compounds in leaves and fronds supported shrimp health, though not as effectively as palm fiber. These findings highlight palm fiber's potential as a functional feed ingredient for improving survival and sustainability in shrimp farming.

3. Feed conversion ratio (FCR)

The feed conversion ratio (FCR) reflects feed efficiency by comparing feed consumed to weight gained **(Inez *et al*., 2024)**. This study found that the inclusion of fermented palm waste significantly ($P< 0.05$) affected the FCR. Treatment with palm meal achieved the lowest FCR (0.961), indicating superior feed efficiency, while the control (without palm flour) recorded the highest FCR (1.633), reflecting lower efficiency.

The higher protein content in palm meal (18.80%) likely contributed to its efficient utilization. Additionally, its lower crude fiber content compared to other palm parts made it easier to digest. **Amri (2007)** reported that fermenting palm kernel meal with *Rhizopus oligosporus* at 18% in carp feed significantly improved feed consumption, weight gain, and FCR. This aligns with the idea that fermentation enhances digestibility and reduces anti-nutritional content, enabling better nutrient absorption.

Despite the use of fishmeal and soy, the control feed was less efficient, likely due to the absence of functional fibers and bioactive compounds that promote gut health and nutrient utilization. Feed quality depends on balanced nutrients, particularly protein. A low FCR indicates efficient nutrient conversion into biomass, while a high FCR suggests poor digestibility or suboptimal feed composition.

CONCLUSION

The utilization of various parts of palm oil waste—such as pulp (palm kernel cake), leaves, fronds, and fibers—as alternative raw materials in feed formulation demonstrates significant potential to enhance the productivity of *Litopenaeus vannamei* cultivation. The findings of this study indicate that the use of fermented palm oil waste-based feed had a notable impact on absolute growth, specific growth rate, feed conversion ratio (FCR), and shrimp survival. Among the treatments, feed based on palm oil pulp yielded the best results in terms of both growth and feed efficiency compared to other treatments and the control. Beyond serving as an economical and functional alternative to conventional feed ingredients, the use of palm oil waste supports the principles of sustainability by optimizing agro-industrial byproducts. With appropriate formulation and processing, palm oil waste has the potential to become a key component in the development of functional feed for more efficient and environmentally friendly shrimp farming systems.

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