

Effect of fermented pineapple silage on growth and stress tolerance of *Penaeus monodon* post-larvae

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Abstract. Honcada CA, Lemosnero JB, Namuag BP, Candole KP, Pedroso FL. 2025. Effect of fermented pineapple silage on growth and stress tolerance of *Penaeus monodon* post-larvae. *Asian J Agric* 9: 533-541. The incorporation of pineapple waste into animal feeds has been previously reported; however, its potential application in aquaculture remains underexplored. In particular, the use of liquid-fermented pineapple silage derived from industrial processing has not been documented. This study investigated the effects of liquid-fermented pineapple silage (LFPS) and yeast-enriched LFPS (LFPS+Yeast), applied by spraying onto commercial feed, as alternative feed additives for post-larval tiger shrimp (*Penaeus monodon*). Results demonstrated that the inclusion of LFPS+Yeast significantly improved weight gain ($p < 0.05$) in *P. monodon* post-larvae, with the highest mean weight gain observed in the LFPS+Yeast group (62.57 ± 3.43 mg), followed by LFPS (53.37 ± 5.63 mg), and the control (39.30 ± 3.40 mg). A similar trend was observed in growth rate (GR) ($p < 0.05$). Although the specific growth rate (SGR) did not differ significantly among treatments ($p > 0.05$), the LFPS+Yeast group exhibited the highest SGR ($11.30 \pm 0.52\%$), followed by LFPS ($10.97 \pm 0.52\%$) and the control ($9.84 \pm 0.35\%$). No significant differences were found in survival or stress tolerance; however, both LFPS+Yeast and LFPS treatments showed improved survival rates ($80.00 \pm 1.40\%$ and $73.11 \pm 2.50\%$, respectively) compared to the control ($67.56 \pm 7.45\%$), as well as enhanced stress response. These findings suggest that LFPS and LFPS+Yeast have strong potential as sustainable feed additives in shrimp aquaculture, offering a means of waste valorization while promoting improved growth and resilience in *P. monodon*.

Keywords: Industrial waste, liquid fermentation, molasses, sugpo, valorization

INTRODUCTION

The pineapple (*Ananas comosus*), a species within Bromeliaceae family, is extensively cultivated throughout tropical and subtropical regions worldwide, including the Philippines, Thailand, Indonesia, Malaysia, Kenya, India, and China (Ortega-Hernández et al. 2023). Originally domesticated in South America, the fruit is recognized for its distinctive sweet-sour flavor, juicy flesh, and characteristic aroma (Li et al. 2019). Global production of pineapple is estimated at approximately 28 million metric tons annually, with major producers including the Philippines, Costa Rica, Brazil, Indonesia, and China (FAO). In the Philippines, the Northern Mindanao region is the leading pineapple producer, contributing 391,160 metric tons, which accounts for 51.3% of the country's pineapple production during the second quarter of 2023 (PSA 2023).

Driven by rising global demand, large-scale pineapple cultivation and processing have resulted in substantial agricultural waste generation. Waste disposal has become a major concern due to its environmental implications. According to Hamzah et al. (2021), pineapple waste significantly contributes to landfill volume and greenhouse gas emissions. These residues are highly biodegradable and prone to microbial decomposition, which, if unmanaged, poses serious environmental risks (Ortega-Hernández et al.

2023). Processing waste consists mainly of peel (29-42%), core (9.4-20%), and crown (2.7-5.9%) (Rico et al. 2020). Studies show that between 60-80% of a fresh pineapple—comprising the peel, pulp, crown, and leaves—is typically discarded during harvesting and processing. This amounts to an estimated 22.5 million tonnes of pineapple by-products generated globally each year (da Silva 2013; Roda and Lambri 2019; Sukri et al. 2022; Ortega-Hernández et al. 2023). On the other hand, the utilization of pineapple industrial waste in Northern Mindanao in feed application has mainly been limited to cattle feed—its application in aquaculture has not yet been explored.

Although often discarded as waste, pineapple by-products are actually rich in nutrients such as crude fiber, protein, sugars, moisture, and vitamin C (Sukri et al. 2022). They also contain high levels of polyphenols and other bioactive compounds, including bromelain—a proteolytic enzyme known for its anti-inflammatory, antimicrobial, and digestive benefits (Ortega-Hernández et al. 2023). Polyphenols and bromelain, both known for their antioxidants properties—play an important role in reducing oxidative stress, strengthening the immune system, and preventing lipid peroxidation (Abraham et al. 2023). Because of these valuable properties, pineapple waste holds great potential as an ingredient in functional foods and animal feeds, particularly in sustainable aquaculture. Multiple studies have confirmed the effectiveness of

pineapple by-products when used in aquafeeds. In tilapia, its inclusion has shown positive effects on immune response, gene expression, growth performance, and protein digestibility (Yuangoi et al. 2018; Van Doan et al. 2021). According to Rahman et al. (2023), incorporating pineapple by-products into animal feed can maintain physical properties comparable to those of commercial feeds. Moreover, fermentation presents a cost-effective and sustainable approach to improving the nutritional quality and safety of these by-products. This process enhances their digestibility, palatability, and functional properties, making agricultural wastes more suitable and beneficial to use in animal feed (Zhu et al. 2023).

One promising use of agro-industrial waste—particularly pineapple by-products—is in shrimp aquaculture, particularly *Penaeus monodon* Fabricius, 1798, also commonly known as giant tiger shrimp. *Penaeus monodon* is the largest and one of the most commercially valuable penaeid species, is widely favored by farmers, especially in extensive farming systems, due to its fast growth at low stocking densities, resilience to environmental stress, and high market value (Hoang et al. 2024). In the Philippines, where it is locally known as *sugpo*, this species was the leading aquaculture commodity in the 1980s. However, production sharply declined in the 1990s due to challenges associated with intensified farming practices—such as poor feed quality, suboptimal water conditions, and disease outbreaks (Arriegado 2024). Despite this downturn, *P. monodon* remains a key species in the fisheries sector. In 2020, with a combined production with *Penaeus vannamei* Boone, 1931 reached 64,578 metric tons (BFAR 2021), and the Philippines ranked fourth in Southeast Asia and eighth globally in shrimp production in 2019. Recent studies have shown that shrimp fed with fermented diets exhibit significantly improved growth performance, enhanced immune responses, greater disease resistance, better molting efficiency, and increased activity of antioxidant and digestive enzymes (Zhang et al. 2021; Ilham et al. 2024; Lee et al. 2024).

Given the challenges in feed quality, water conditions, and diseases in shrimp farming and the need for sustainable feed solutions, this study investigates the use of liquid-fermented pineapple silage as a feed additive by spraying it onto commercial shrimp diets. The objective is to evaluate its potential to improve the growth performance, survival rate, and low salinity stress tolerance of *P. monodon*, contributing to more sustainable and productive shrimp aquaculture practices and waste valorization.

MATERIALS AND METHODS

Sample collection and preparation

In this study, pineapple waste (pulp, peel, and core) were collected from a fruit processing industry in Bukidnon, Northern Mindanao, Philippines. The collected samples were weighed, packed, and stored at -4°C until the fermentation process began to avoid oxidation and contamination, which is crucial in the fermentation process.

Protocol for fermentation

The methods used by Taberna et al. (2021) was utilized with modification—the addition of pineapple waste. The molasses were diluted with distilled water at an approximate volume ratio of 1:8 (molasses to water) to achieve a concentration of 25-29% Brix. The mixture was then heated to 80°C, cooled to 40°C, and set aside. Three liters of the diluted molasses were added to one kilogram of pineapple waste in a sterilized bottle and allowed to ferment in a cool, dark, and undisturbed location for 15 days. For the treatment involving yeast, the same procedure was followed, with the addition of 5 g of Baker's Choice yeast prior to fermentation (Table 1). After 15 days, the liquid silage was harvested and stored in a cool, dark place away from direct sunlight. After the 15 days of fermentation, the harvested fermented liquid silage treatments have a lactic acid bacteria (LAB) count of 1.88×10^7 CFU/mL and a pH range of 3.8 to 4.2.

Experimental feeds

Feed preparation followed the method used by Doroteo et al. (2018) with modification—a one kilogram (kg) of Tateh Aquafeed PO1 commercially formulated shrimp feed was sprayed gradually to ensure homogenous distribution with 4 mL of liquid fermented pineapple silage (LFPS), and liquid fermented pineapple silage with yeast (LFPS + yeast) was further diluted into 100 mL of distilled water to ensure that the commercial feeds were evenly coated with the fermented mixture (Table 2). The ratio has been successfully applied by previous studies with significant results. For the control, commercially formulated shrimp feed was sprayed with distilled water only. To avoid the possibility of leaching of fermented pineapple silage, 20 mL of coconut oil was sprayed gradually to coat all the feed treatments. Feeds were air-dried prior to feeding. A portion of the feeds was sent to the Department of Agriculture Region 13, Regional Feed Chemical Analysis Laboratory in Butuan City, Philippines, for proximate analysis.

Table 1. Fermented pineapple waste treatments

	Fermented treatment composition	Ratio
LFPS	Pineapple waste + molasses + distilled water	1kg : 1L : 8L
LFPS+Yeast	Pineapple waste + molasses + distilled water + yeast	1kg : 1L : 8L : 5g

Table 2. Diet treatments

Treatments	Description	Replicates
LFPS	Feed with LFPS	3
LFPS+Yeast	Feed with LFPS + yeast	3
Control	Feed without LFPS	3

Lactic acid bacteria in experimental feed

The presence of lactic acid bacteria in the experimental feeds was evaluated following the method used by Kumru et al. (2024) with modification—a one grams (g) of feed sample was weighed and diluted in sterile tubes with 9 mL of sterile distilled water to form a ratio of 1:10. A 100 μ L homogenized solution was then spread plated in an MRS (de Man, Rogosa and Sharpe) agar (HIMEDIA Lactobacillus MRS agar) and incubated at room temperature for 48 hours for subsequent CFU/mL counting.

Feeding trial

The *in vivo* nutritional trial was conducted at the Center for Aquaculture Research, Enterprise, and Services (CARES), Institute of Fisheries Research and Development (IFRD), Mindanao State University at Naawan, Misamis Oriental, Philippines. Post larvae stage 1 (PL1) of *Penaeus monodon* were obtained from *P. monodon* hatchery at CARES and acclimated to experimental conditions until PL18. Acclimation was done in a 100 L aquarium with moderate aeration and a 50% water change every two days. Salinity was gradually reduced until it reached the experimental level of 20 ppt.

Three experimental diets (see Table 2) were used as treatments in the feeding trial. The experiment was conducted in nine aquaria; each filled with 50 L of water. A total of 1,350 PL was randomly selected and evenly distributed across the tanks, with 150 PL stocked per tank, given a stocking density of 3 PL/L. Each treatment was assigned to three replicate tanks using a Randomized Complete Block (RCB) design.

The PL were fed ad libitum (apparent satiation) at a frequency of four times daily (6:00 AM, 10:00 AM, 2:00 PM, and 6:00 PM). Water salinity was maintained at 20 ppt throughout the experiment with moderated aeration. Water was changed every two days throughout the 21-day culture period.

Data collection

The initial and final average weight and length in the 21-day feeding experiment were determined by weighing and measuring 10 randomly selected *P. monodon* PL from

each replicate. The sample PL from each aquarium was carefully blot-dried to get the excess moisture out using tissue paper to avoid bias before being placed in clean, pre-weighed aluminum foil cups and weighed using an ASUKI digital analytical balance. A digital caliper was used to measure each PL to determine the length of the shrimp. At the end of the experiments, all surviving PL was counted for survival rate, and the shrimp were ethically stunned in an ice bath for a few seconds then carefully blot-dried to get the excess moisture out using tissue paper to avoid bias before being placed in clean, pre-weighed aluminum foil cups and weighed—then measured afterwards. All procedures involving animals were conducted in accordance with institutional ethical guidelines for aquaculture experimentation. The relevant parameters of the productive performance of *P. monodon* PL were analyzed based on the following key performance indicators in Table 3.

Osmotic stress response test

An osmotic stress response test (low salinity challenge) was conducted at the end of the feeding trial, following the method used by Panah et al. (2020) with modification—the challenge was performed in 1-L tanks under gentle aeration with 10 PL. The salinity of the aquaria was gradually reduced from 20 ppt to 0 ppt by replacing saltwater with freshwater. The challenge was performed in 1-L tanks under gentle aeration. Ten *P. monodon* post-larvae (PLs) from each experimental tank were randomly selected and transferred into the challenge tanks. Mortality was recorded every 30 minutes over a 2-hour period (120 minutes).

Statistical analysis

The data were presented as mean \pm standard error. The data were analyzed to verify the homoscedasticity of variances using Levene's test. Differences between the results were determined via analysis of variance (ANOVA) with the significance level established at $\alpha=0.05$ and Tukey's HSD test for post hoc analysis. A value of $p < 0.05$ was taken as a significant difference. All statistical analyses were performed using JASP statistical software.

Table 3. Formula use for calculating the survival and growth parameters of *P. monodon* PL after 21 days of feeding experiments

Parameter	Formula	Description
Average Body Weight (ABW)	$ABW = Wt/N$	Wt: total body weight, N: number of individuals
Absolute Growth Rate (GR)	$SG(gd^{-1}) = (W1-W0)/T$	W0 is the ABW of <i>P. monodon</i> PL at the start of the experiment (0 day), W1 is the ABW of the PL at the end of the experiment (21 days), and T is the duration of the experiment in days.
Specific Growth Rate (SGR)	$SGR(\%gd^{-1}) = (\ln W1 - \ln W0) \times 100/T$	Ln: natural logarithm; W0 is the ABW of <i>P. monodon</i> PL at the start of the experiment (0 day), W1 is the ABW of the PL at the end of the experiment (21 days), and T is the duration of the experiment in days.
Survival Rate (SR)	$SR(\%) = Ni/N0 \times 100$	Ni: Number of PL at the end of the experiment (21 days), N0: Number of PL initially stocked at the start of the experiment (0 day).

RESULTS AND DISCUSSION

Feed proximate composition analysis

The proximate composition of the experimental diets used in the experiment (Table 4) showed that the inclusion of liquid fermented pineapple silage had no significant effect on the proximate composition of the test diets. Though there was a slight increase in the carbohydrate content, LFPS + Yeast recorded the highest at $29.56 \pm 0.18\%$, followed by LFPS, $28.13 \pm 0.47\%$ and lastly the control with $27.66 \pm 0.26\%$. However, there were no significant difference ($p > 0.05$) between the proximate compositions of the experimental diets.

Lactic acid bacteria in experimental feed

The evaluation of viable cell counts of lactic acid bacteria (LAB) in the experimental diets is presented in Table 5, with the LFPS and LFPS + Yeast diets showing the presence of LAB with 200 ± 0.58 CFU/mL and 100 ± 0.33 CFU/mL, respectively, with no significant difference ($p > 0.05$). However, the control diet showed no presence of LAB. The result could indicate that the inclusion of the liquid fermented pineapple silage could increase the presence of LAB, as it remained viable in the experimental diets.

Growth performance of *P. monodon* fed with an experimental diet

A significant increase ($p < 0.05$) in both length and weight was observed in shrimp fed with the experimental diets over the 21-days feeding experiment. Among the treatments, the LFPS + Yeast (24.19 ± 0.36 mm) exhibited the significantly highest final length followed by LFPS (23.26 ± 0.59 mm) and lastly the control (21.12 ± 0.50 mm) (Figure 1.A). The increased length gain was shown in Figure 1.B, wherein the LFPS + Yeast (12.32 ± 0.13 mm) have the significantly highest length gain followed by LFPS (11.86 ± 0.48 mm) and lastly the control (9.42 ± 0.86 mm). The same trend was followed by the increase in final weight. LFPS + Yeast (69.17 ± 4.39 mg) exhibited the significantly highest final weight, followed by LFPS (59.23 ± 5.56 mg) and lastly the control (45.10 ± 4.23 mg) (Figure 1.C). These trends are very evident in Figure 1.D, as it followed the same trend with weight gain of LFPS+Yeast (62.57 ± 3.428 mg), followed by the LFPS group (53.37 ± 5.626 mg), while the control group ($p > 0.05$) showed the significantly lowest value (39.30 ± 3.402 mg).

A similar trend was also observed in the growth rate (GR); see Figure 1.E. The LFPS + Yeast group showed the

highest GR (2.98 ± 0.164), which was followed by the LFPS group (2.54 ± 0.270) and lastly the control group (1.87 ± 0.161). There was no significant difference ($p > 0.05$) in specific growth rate (SGR) (Figure 1.D); however, the LFPS + Yeast group showed the highest SGR ($11.30 \pm 0.520\%$), followed by the LFPS group ($10.97 \pm 0.522\%$) and the control group ($9.84 \pm 0.350\%$). These results suggest that the inclusion of LFPS in the diet significantly enhanced the growth performance of shrimp, while the addition of yeast may further enhance its growth-promoting benefits.

Survival rate of *P. monodon* PL at the end of the feeding experiment

Although not statistically significant ($p > 0.05$), a notable increase in survival rates in Figure 2 was observed among the treatments with the highest LFPS + Yeast group ($80.00 \pm 1.389\%$), followed by the LFPS group ($73.11 \pm 2.502\%$), and the control had the lowest survival rate ($67.56 \pm 7.446\%$) among the treatments. These findings suggest that the addition of LFPS in the diet didn't negatively affect shrimp survival but enhanced the survival of *P. monodon* PL, and the presence of yeast may have further supported overall health and resilience.

Osmotic challenge test

The cumulative mortality rate of *P. monodon* PL at different time periods when exposed to 0 ppt salinity was presented in Figure 3. Which illustrates the tolerance of *P. monodon* PL to low salinity conditions. When PL were exposed to freshwater for stress conditions for two hours, the shrimp in the control treatment exhibited higher mortalities at an earlier time period compared to those treatments fed with formulated diet sprayed with LFPS. After two hours of low salinity exposure, the control treatments have reached 100% mortality compared to the LFPS treatments. However, there were no significant differences (ANOVA, $p > 0.05$) in shrimp survival and mortality among all treatments after two hours of exposure to 0 ppt salinity.

Table 5. Viable cell count of lactic acid bacteria presence in experimental diets

Experimental Feeds	LAB presence (CFU/mL)
Feeds with LFPS	200 ± 0.58
Feeds with LFPS + Yeast	100 ± 0.33
Control	-----

Note: CFU/mL- colony-forming unit/mL

Table 4. Proximate composition of experimental diets

Proximate composition (%)	Feeds with LFPS	Feeds with LFPS + Yeast	Control
Moisture	6.20 ± 0.04	5.22 ± 0.01	7.73 ± 0.03
Crude Protein	43.70 ± 0.19	43.55 ± 0.11	43.36 ± 0.14
Crude Fat	7.30 ± 0.23	7.11 ± 0.18	7.03 ± 0.23
Ash	11.89 ± 0.26	11.94 ± 0.03	11.84 ± 0.01
Crude Fiber	2.78 ± 0.28	2.68 ± 0.18	2.37 ± 0.20
Carbohydrate	28.13 ± 0.47	29.56 ± 0.18	27.66 ± 0.26

Note: LFPS: Liquid Fermented Pineapple Silage; LFPS + Yeast: Liquid Fermented Pineapple Silage + Yeast; Control feed. Values were computed as dry matter percentage

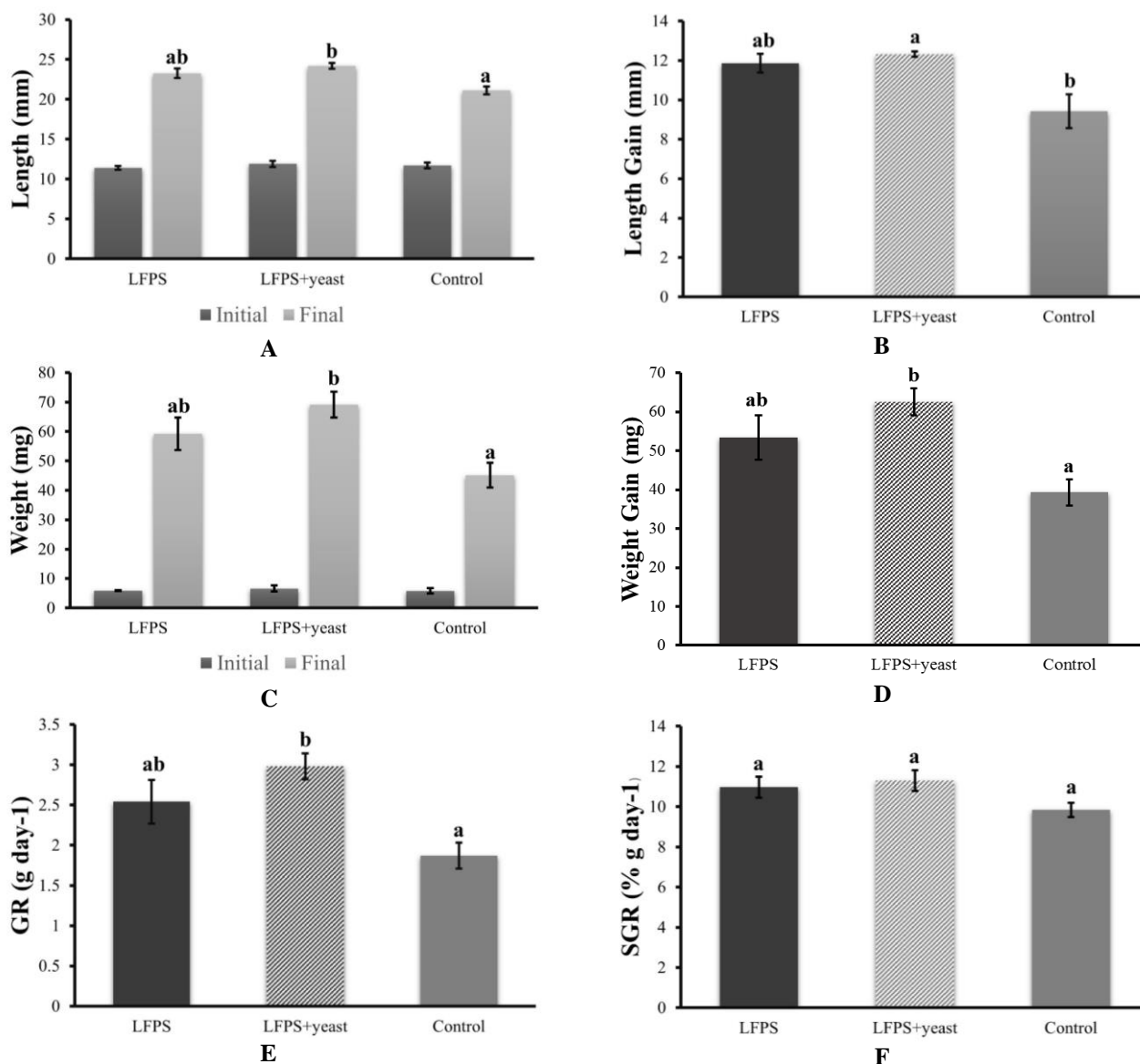


Figure 1. Growth performance of tiger shrimp (*P. monodon*) PL fed with experimental diets after 21 days of feeding experiment. Values are expressed as mean + standard error of the mean (n = 3). Treatment means with the same superscript in the same bar graph are not significantly different (ANOVA, p < 0.05) from each other according to Tukey’s HSD test. A. Length (mm); B. Length gain (mm); C. Weight (mg); D. Weight gain (mg); E. Growth Rate (g day⁻¹); F. Specific Growth Rate (% g day⁻¹)

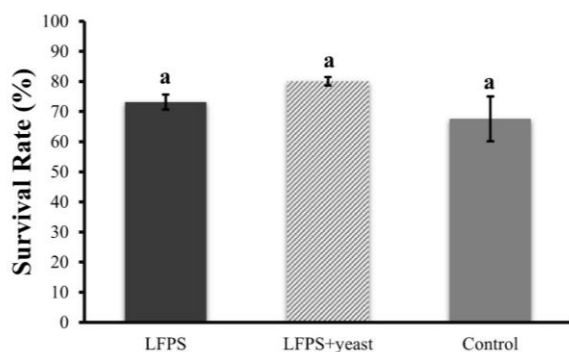


Figure 2. Survival Rate (%) of tiger shrimp (*P. monodon*) PL fed with experimental diets after 21 days of feeding experiment. Values are expressed as mean + standard error of the mean (n = 3). Treatment means with the same superscript in the same bar graph are not significantly different (ANOVA, p > 0.05)

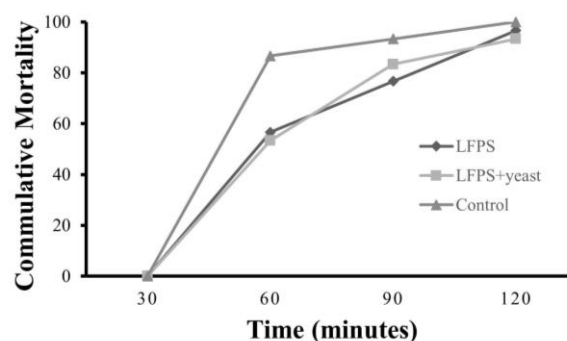


Figure 3. Low salinity test of *P. monodon* PL at different time periods when exposed to 0 ppt salinity (ANOVA, p > 0.05)

Discussion

Pineapple waste has been widely used in terrestrial animal feed, utilized into various forms such as powder, extract, or mixed with other materials like hay to create silage (Sukri et al. 2022). Fermentation has been proven effective in improving nutritional quality by reducing crude fiber content while increasing levels of fat, ash, and soluble protein (Adrızal et al. 2017; Aruna 2019). In addition to its nutritional benefits, fermentation enhances the digestibility, palatability, and functional properties of plant-based materials, making them more suitable for animal feed (Zhu et al. 2023). These improvements were supported by studies showing that the inclusion of fermented pineapple waste in broiler diets can significantly enhance digestibility and nutrient absorption (Mandey et al. 2018). However, despite its proven benefits in terrestrial applications, the use of pineapple waste—particularly in the form of liquid fermented pineapple silage (LFPS)—had not been previously reported in aquaculture prior to this study.

Pineapple waste is a promising source of bioactive compounds, and fermentation—either solid-state or submerged (liquid)—can enhance its valorization by releasing functional metabolites beneficial for aquaculture and other industries. Fermentation is one of the oldest methods used to transform raw materials into value-added products through microbial activity (Sadh et al. 2018). During fermentation, the composition and profiles of bioactive molecules are modified: phenolic compounds may be altered into a form with enhanced biological activity, while undesirable components such as excess sugars and anti-nutritional factors are reduced. Additionally, fermentation leads to the production of beneficial compounds such as bioactive peptides, short-chain fatty acids, and polysaccharides (Septembre-Malaterre et al. 2018). Based on previous reports, pineapple waste is a rich source of bromelain—bromelain, a mixture of cysteine proteases with antibiotic, anti-inflammatory, anti-cancer, anti-thrombotic, anticoagulant, and anti-edematous properties. Bromelain, a proteolytic enzyme, is found throughout the pineapple plant—including the peel, core, crown, and flesh—with the highest concentrations typically found in the peel and flesh (Misran et al. 2019; Abbas 2021). In aquaculture, dietary supplementation with bromelain has shown promising benefits. Studies on *Penaeus vannamei* have demonstrated that bromelain can promote growth and help reduce the effects of *Vibrio parahaemolyticus* (Fujino et al., 1951) Sakazaki et al., 1963, the pathogen responsible for Acute Hepatopancreatic Necrosis Disease (AHPND) (Ng and Mong 2024). Additionally, bromelain has been found to improve protein digestion and may contribute to enhanced gut microbial diversity and immune modulation.

Research on the use of pineapple waste in aquaculture has shown promising results. Deka et al. (2003) reported that incorporating 25% powdered pineapple waste into the diet of *Labeo rohita* (Hamilton, 1822) improved growth rates, feed conversion efficiency, and protein utilization. Similarly, Sukri et al. (2022) reported an enhanced weight gain in Nile tilapia fingerlings, while Van Duan et al.

(2021) reported an improved growth and feed efficiency in Nile tilapia fed with diets containing pineapple waste, with or without *Lactobacillus plantarum*. In another study, Yuangsoi (2018) reported optimal protein digestibility and feed utilization when using pineapple waste extract.

However, the nutritional composition of pineapple waste can vary significantly depending on factors such as plant variety and the specific part of the plant that was utilized (Spalvins et al. 2018). For instance, Sulaiman et al. (2022) reported reduced weight gain in hybrid tilapia fed pineapple crown, likely due to its high fiber content and low digestibility. In contrast, Attalla et al. (2022) found that low inclusion levels (2%) of pineapple crown improved growth performance in Nile tilapia fry. These contrasting findings could be due to the difference in processing methods employed, which played a critical role in the nutritional profile of the raw material used in the development of the formulated feeds. According to Repamonte et al. (2025) sun-dried pineapple waste retained higher carbohydrate content, while dehydrated waste showed greater levels of fiber, ash, protein, and fat. However, despite these differences, a consistent growth-promoting effect of pineapple waste has been reported across multiple studies.

The enhanced survival rates observed in the LFPS (Liquid Fermented Pineapple Silage) + yeast treatment group in the present study may be attributed to the synergistic benefits of fermentation and yeast supplementation. Yeast provides key bioactive compounds such as β -glucans, mannan oligosaccharides, and nucleotides, all of which are known to enhance immune response, disease resistance, and overall health in aquatic species. Tahir et al. (2025), for example, reported improved health in *Hypophthalmichthys molitrix* (Valenciennes, 1844) fingerlings fed with yeast-fermented rice bran. While on the other hand, Van Duan et al. (2021) reported an increased survival and immune responses in Nile tilapia challenged with *Streptococcus agalactiae* when fed with pineapple waste in combination with *L. plantarum*. However, to date, no studies have specifically evaluated the use of liquid fermented pineapple silage in shrimp diets. The present findings suggest that LFPS, particularly when combined with yeast, holds strong potential as a sustainable and cost-effective feed additive for aquaculture.

Microbial contamination during feed preparation remains a significant concern in aquaculture, as it can increase the bacterial load in the culture environment and potentially compromise the health and survival of cultured animal. The use of antibiotics to control such pathogens has long been discouraged due to growing concerns over biosecurity and the emergence of antibiotic-resistant bacteria, which may pose risks not only to aquatic organisms but also to human health. As a result, research has increasingly focused on natural and environmentally friendly microbial inhibitors alternatives. Taka et al. (2024) demonstrated that pineapple waste possesses notable antibacterial activity against common aquatic pathogens. Dehydrated pineapple waste extracts effectively inhibited *Vibrio harveyi* and *V. parahaemolyticus*, while sun-dried and oven-dried extracts were effective against

Streptococcus agalactiae, *Edwardsiella tarda*, and *Aeromonas veronii*. Beyond its antimicrobial properties, pineapple waste has also shown potential as a prebiotic, further supporting its role as a functional ingredient in aquaculture feeds. Rahman et al. (2023) reported that powdered pineapple waste enhanced the growth of *Lactobacillus acidophilus* and *Bifidobacterium bifidum* in red tilapia feed. Further research is recommended to evaluate the long-term effects of LFPS inclusion on immune function, disease resistance, and nutrient utilization in *P. monodon* and other aquaculture species.

Fermented pineapple waste is a valuable source of beneficial microorganisms such as lactic acid bacteria (LAB), yeast, and *Bacillus* species, which produce bioactive compounds during the fermentation process with known antimicrobial and antioxidant properties. These microorganisms contribute to improved nutrient absorption, gut health, and overall growth performance in aquaculture species (Neves et al. 2024). In the present study, the addition of yeast during the fermentation process likely promoted the proliferation of beneficial gut microbes and enhanced feed efficiency. Liquid fermented pineapple silage (LFPS) may also contain probiotic strains that help *P. monodon* postlarvae better tolerate environmental stress, consistent with previous studies showing that dietary probiotics improve stress resilience in shrimp (Yeh et al. 2010).

The result of this study demonstrated the potential of LFPS, whether with or without yeast, significantly improved shrimp growth, survival, feed conversion efficiency, and resistance to environmental stress. These findings align with earlier reports indicating that beneficial microbes can enhance the performance of shrimp and other aquatic organisms under stressful conditions (Dong et al. 2013; Duan et al. 2016; Wang et al. 2016; Panah et al. 2020). Moreover, the use of fermented plant-based feed ingredients in aquaculture feed has been found to stimulate antioxidant responses and increase digestive enzyme activity. Importantly, these ingredients have also been shown to have a positive influence on intestinal structure and microbial composition in a range of aquaculture species (Shiu et al. 2013; Jiang et al. 2018; Li et al. 2020; Da Cunha et al. 2022; Ismail et al. 2021).

Conclusion

The current study demonstrated that spraying 4 mL of LFPS onto 1 kg of commercial shrimp feed positively influenced the growth performance of *P. monodon* postlarvae. Shrimp fed LFPS-treated diets exhibited significantly improved growth, as well as enhanced survival and stress tolerance. Although differences in survival and salinity stress resistance were not statistically significant, shrimp in the LFPS + Yeast group showed consistently better performance than controls. These results support the use of LFPS as a promising feed additive to improve shrimp health and productivity. However, due to limited resources, this study did not assess water quality, bacterial communities, or gene expression. Future research should investigate these factors, as well as the grow-out phase of shrimp production, and expand LFPS testing to

other aquaculture species. Additionally, in vitro evaluations of stress biomarkers such as cortisol and HSP70 may help clarify the underlying mechanisms of LFPS efficacy.

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