Research Article

Optimization of Fermented Feed with *Rhodotorula taiwanensis* UNJCC Y-171 for Black Soldier Fly (BSF) Larvae Growth and Nutritional Quality

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ABSTRACT

Black soldier fly (BSF) larvae, or maggots, are a promising alternative protein-rich feed for aquaculture. This study aims to evaluate the effect of fermented feed made from coconut pulp and rice bran using the yeast *Rhodotorula taiwanensis* UNJCC Y-171 on maggot growth and proximate composition. The study was conducted from June to August 2024 at Jakarta State University and Ornamental Fish Aquaculture Research Center. The treatments included a control group (K) and fermentation using yeast at 30% (A) and 40% (B) concentrations. Measurements were taken on days 10, 13, 16, and 19. The results showed that fermented feed significantly increased maggot wet weight and body length, particularly in Treatment B. On day 16, the wet weight of maggots in Treatment B reached 182.00±45.14 g, higher than the control (77,00±52.03 g). The body length of maggots in Treatment B was also greater (1.59±0.12 cm) than in the control (1.19±0.09 cm). Proximate analysis indicated that maggots in Treatment B had a higher fat content (15.57%) compared to the control (12.11%), while crude fiber content was lower (1.27% compared to 1.63%), indicating improved feed efficiency. Although the protein content in Treatment B (12.29%) was slightly lower than in the control (13.27%), fermentation with *R. taiwanensis* UNJCC Y-171 enhanced nutrient bioavailability. This study confirms that feed fermentation with *R. taiwanensis* UNJCC Y-171 at a 40% concentration optimally improves both maggot growth and nutritional quality. Therefore, this method has the potential to serve as a more cost-effective alternative feed for aquaculture.

Keywords: *Rhodotorula taiwanensis*, feed fermentation, maggot, proximate analysis, feed efficiency

Introduction

Animal protein intake is a major diet quality indicator and a very important measurement in nutrition and food security research. A shortage of animal protein in Indonesia is a chronic problem, leading to malnourishment and inhibiting long-term human capital formation. Economic limitations often worsen the diet gap because animal protein foodstuffs such as meat and dairy products are usually unaffordable for poor families (Umaroh & Vinantia, 2018). Research has confirmed that the intake of animal protein is strongly correlated with income, food availability, and local food systems, indicating the need for long-term strategies to enhance protein intake in all socio-economic classes (Torlesse et al., 2003).

In an attempt to face such a challenge, protein from fish provides a feasible and readily available option. Fish aquaculture, in the aquaculture industry, has a high potential to supply national protein demands while, at the same time, promoting economic development as well as food sovereignty. Indonesia's aquaculture industry is among the world's largest, and the industry is still growing, playing a very important role in enhancing access to cheap animal protein (Patmawati et al., 2022). The industry, though, is constrained by the high production costs, mainly due to the use of commercial fish feeds.

The affordability barrier of traditional feeds restricts profitability for fish farmers in addition to increasing the price of fish in the market, making fish less accessible for consumers. Hence, the formulation of low-cost, nutritionally adequate, and alternative sources of feeds to fish is essential to increase the sustainability and productivity of aquaculture production. Exploring local and natural ingredients of feeds offers a potential route to cutting down the costs of inputs while sustaining fish growth as well as health, thus promoting economic stability and nutritional welfare.

Maggots, or black soldier fly (BSF) larvae, are a promising alternative feed source due to their high protein content of approximately 44.26%, which is 20–25% higher than that of commercial feed (Indarmawan, 2014). Studies have shown that fermenting maggot feed with specific microbes can further enhance maggot weight and casgot quality (Ariskaa et al., 2024; Puspitasari et al., 2024). One of the most studied fermentation agents is the yeast *Rhodotorula taiwanensis*, which not only improves nutritional quality and digestibility but also provides antimicrobial properties that support the health of farmed fish. Yeasts and fungi, commonly found in cellulose decomposition, play a crucial role in breaking down organic matter (Sukmawati et al., 2020). *R. taiwanensis* contributes to hydrolyzing cellulose into simpler compounds such as glucose, making nutrients more bioavailable. However, cellulase activity varies among microorganisms, depending on the specific enzymes they produce, which influence the breakdown of cellulose, hemicellulose, and lignin (Sukmawati et al., 2021).

One of the groups of yeasts with high potential in the production of feeds is oleaginous yeasts, capable of storing lipids in large amounts—more than 15% of their dry weight and, in some situations, as high as 70%. The yeasts produce the following types of lipids in the form of fatty acids, including palmitate, oleate, and linoleate (Anjani & Ilmi, 2018). Miao et al. (2020) established that *R. taiwanensis*, one of the oleaginous species of yeasts, can ferment diverse substrate types, including low-cost and readily available materials such as molasses. Fermentation of xylose, in turn, is a unique capability that the yeast possesses, yet most yeasts are unable to ferment. Xylose occurs in raw rice bran in the hemicellulose structure of the form of arabinoxylan, a predominant portion of maggot feeds (Deng et al., 2023).

Several species of *Rhodotorula* are also known to produce enzymes such as protease, amylase, and lipase, which assist in breaking down proteins, carbohydrates, and fats into simpler forms. A study by Hu et al. (2022) demonstrated that these enzymes enhance nutrient availability and feed efficiency in maggots. Additionally, *Rhodotorula* exhibits high tolerance to extreme environmental conditions, including low pH, high temperatures, osmotic pressure, and inhibitory compounds. This yeast is also recognized for its carotenoid production, which acts as a natural antioxidant and possesses probiotic properties that support gut health in maggots, improve nutrient absorption, and reduce harmful pathogens.

R. taiwanensis is capable of producing polyol esters of fatty acids (PEFA) in a hypoacetylated form with enhanced surface activity. According to Lyman et al. (2018), these PEFA consist of C16 and C18 fatty acid esters of mannitol and arabitol, which serve as essential energy sources and structural components for maggot growth. The hypoacetylation increases hydrophilicity, improving nutrient absorption and digestion. Additionally, its natural biosurfactant properties contribute antimicrobial effects, promoting feed hygiene. Given these advantages—including enzyme production, improved nutrient bioavailability, environmental resilience, and antimicrobial action—*R. taiwanensis* shows strong potential to enhance maggot feed quality. Its use in fermented feed formulations could improve feed efficiency and maggot health, supporting the sustainability of maggot farming as an alternative protein source for aquaculture.

This study aims to optimize the formulation of fermented feed incorporating *R. taiwanensis* UNJCC Y-171 to enhance the growth performance and nutritional quality of BSF larvae. Specifically, it seeks to evaluate the influence of yeast-based fermentation on larval biomass yield, protein and lipid content, and fatty acid composition. The study also aims to assess the economic and practical feasibility of implementing *R. taiwanensis*-fermented feed in large-scale maggot farming, contributing to the development of sustainable and efficient alternative protein sources for aquaculture.

Materials and Methods

This study was conducted from June to August 2024 at the Microbiology Laboratory, Faculty of Mathematics and Natural Sciences, Jakarta State University and the Ornamental Fish Aquaculture Research Center, Ministry of Marine Affairs and Fisheries (KKP), Depok. The equipment used in this study included a laminar air flow (LAF) cabinet, inoculating loop, stirring rod, spatula, Erlenmeyer flask, test tubes, test tube rack, alcohol burner, vortex mixer, shaker, refrigerator, beaker glass, graduated cylinder, analytical balance, fermentation jerry can, basin, tray, gas stove, net, and mobile phone camera. Meanwhile, the materials used in this study included yeast isolate *R. taiwanensis* UNJCC Y-171, BSF eggs, coconut pulp, rice bran, and coconut water, with media consisting of malt extract, yeast extract, peptone, glucose, agar, distilled water, potato dextrose agar, and molasses.

The method used in this study was an experimental method with a Completely Randomized Design (CRD). This study consisted of three main stages: (1) fermentation of organic waste, specifically coconut pulp and rice bran, using a single yeast isolate, *R. taiwanensis* UNJCC Y-171; (2) rearing of maggots using the fermented feed medium; (3) data collection, which included measuring the total length and weight of the maggots, as well as proximate analysis to determine protein, fat, and fiber content.

The first and second stages were conducted using a Completely Randomized Design (CRD). There were three treatment groups with varying concentrations of yeast suspension in the fermented organic feed, namely: control (Treatment K), which involved fermentation with indigenous yeast; Treatment A, which involved fermentation with *R. taiwanensis* UNJCC Y-171 at a concentration of 30%; Treatment B, which involved fermentation with *R. taiwanensis* UNJCC Y-171 at a concentration of 40%. The fermented feed was then provided to 10-day-old maggots, followed by observations of their growth (length and total weight) and proximate analysis of protein, fat, and fiber content. Each treatment was repeated six times, determined using Federer's formula $(t-1)(n-1) \geq 15$, resulting in a total of 18 experimental units (Table 1).

Yeast Rejuvenation

Yeast rejuvenation was carried out using the streak plate method. This process was conducted in a LAF cabinet sterilized with 70% alcohol and UV exposure for 20 min. The culture was collected using an inoculating loop and inoculated onto yeast malt agar (YMA) medium with 15 streaks. The culture was then incubated at room temperature for 24–48 h. After incubation, the culture was stored in a refrigerator at 4°C (Katz, 2008).

Table 1. Treatment groups of the fermented waste feed designed for black soldier fly (BSF) maggot.

No.	Group	Treatment	Replications
1	K	Feed medium consisting of coconut pulp and rice bran (1:1)	6
2	A	Feed medium consisting of coconut pulp and rice bran (1:1) fermented using *Rhodotorula taiwanensis* UNJCC Y-171 at a 30% concentration	6
3	B	Feed medium consisting of coconut pulp and rice bran (1:1) fermented using *R. taiwanensis* UNJCC Y-171 at a 40% concentration	6

Yeast Starter Preparation

For yeast growth, molasses broth was used as a culture medium, consisting of 80% coconut water (v/v), 10% molasses (v/v), and 10% yeast suspension (10^7 FU/ml).

This medium was first sterilized using an autoclave at 121°C for 15 min. The yeast suspension was prepared by adding 10 ml of sterile distilled water to a test tube containing the yeast isolate. The tube was then shaken using a vortex mixer for 1 min, enabling the yeast to be evenly dispersed. The homogenized yeast suspension, adjusted to 10^7 CFU/ml, was then inoculated into sterile molasses broth and incubated on a shaker at 35 rpm at room temperature for 48 h (Pratiwi et al., 2019).

Fermentation of BSF Maggot Feed

The fermentation of organic waste was conducted in two stages, following the method described by Alliza (2022): (1) preparation of the inoculum starter and (2) addition of the yeast fermentation starter to organic waste, consisting of coconut pulp and rice bran, with yeast concentrations of 30% or 40% (v/v). After the starter was evenly mixed with the organic waste, the container was tightly sealed to create an anaerobic environment and left for 3 days.

Hatching of BSF Maggot Eggs

BSF egg hatching follows the method developed by Slamet et al. (2023), using a rice bran medium mixed with water at a 1:1 ratio. The hatching medium was prepared by mixing 200 g of rice bran with 200 ml of water, then stirred until evenly distributed. A mesh screen was placed on top of the container as a platform for spreading 0.5 g of BSF eggs. The ideal condition for hatching BSF maggot eggs should maintain a balanced moisture level—neither too wet nor too dry. The BSF eggs were incubated for 2 days, allowing them to hatch into BSF maggot larvae, which were then transferred to the growth medium at 10 days old.

Provision of Fermented Feed

Feed administration was carried out after an anaerobic fermentation process lasted for 3 days. Fermented feed, weighing approximately 1 kg, was given to the maggots on day 10, followed by subsequent feedings on day 13, day 16, and finally on day 19 (Putri & Mirwan, 2023; Sirait et al., 2020).

Data Collection on BSF Maggot Growth

Data collection was conducted before and after the administration of fermented feed. The collected data included:

1. Total weight of BSF maggots
   Samples were collected on days 10, 13, 16, and 19 (Figure 1). The measurement procedure involved separating the maggots from the feed medium, sieving to eliminate residual material, and subsequently weighing the maggots using an analytical balance (Wantika et al., 2020). This process was repeated until all treatments and replications (a total of 18 units) were recorded. The collected data were analyzed using IBM SPSS Statistics version 26 to assess normality and homogeneity.

Fig. 1. Black soldier fly (BSF) maggot weight data collection.

2. Individual weight of BSF maggots
   Samples were taken on days 10, 13, 16, and 19. In each replication, approximately 1 g of maggots was sampled, resulting in a total of 18 units. The individual weight of the maggots was determined by dividing the total 1-g sample by the number of individual maggots present. The collected data were analyzed using IBM SPSS Statistics version 26 to assess normality and homogeneity.
3. Body length of BSF maggots
   Samples were taken on days 10, 12, 16, and 19, with 1 g of maggots collected per experimental unit. For measurement, the maggots were arranged on a clean white sheet alongside a ruler as a scale reference. Each sample was photographed using a mobile phone camera, and the images were analyzed using ImageJ software to determine the average maggot length per unit. The resulting data were then processed using IBM SPSS Statistics version 26 to assess data normality and homogeneity (IBM Corp., 2019; Wantika et al., 2020).

Harvesting of Maggots

The BSF maggot harvesting process was conducted on day 19, following the methodology of Masir et al. (2020), as maggots had not yet entered the prepupal stage on that day. Harvesting was performed after measuring growth parameters, including wet weight, individual weight, and body length of BSF maggots.

Data Collection and Analysis Techniques

Two types of data analysis were employed in this study. Quantitative data on maggot growth—including total weight gain and length—as well as proximate composition (fat and fiber content), were analyzed using IBM SPSS Statistics version 26. The Kruskal-Wallis test was applied to assess differences among treatment groups, followed by the Mann-Whitney U test for pairwise comparisons at a 5% significance level (IBM Corp., 2019).

Results and Discussion

Yeast Isolate Rejuvenation

Yeast rejuvenation was carried out using the streak plate method based on Katz (2008). The process was conducted in a room sterilized with 70% alcohol and UV exposure for approximately 20 min. After sterilization, *R. taiwanensis* UNJCC Y-171 yeast was inoculated in a LAF cabinet and cultured on YMA medium with 15 streaks. The culture was incubated at room temperature for 24–48 h and then stored in a refrigerator at 4°C.

The purpose of the inoculation process was to rejuvenate the isolate, allowing it to become active again and multiply. The result of the method described above was an isolate matching the characteristics of *R. taiwanensis*: an orange isolate with a smooth surface. Successful rejuvenation was indicated by the growth of the isolate on the medium, where *R. taiwanensis* UNJCC Y-171 exhibited a bright orange color with slight mucus (Maya & Alami, 2019).

Purposes of Yeast Inoculum Starter Preparation

The addition of the starter aimed to accelerate the fermentation process, allowing it to proceed more efficiently and achieve the desired fermentation conditions. The results of the starter treatment using the shaker showed optimal yeast growth, as indicated by the presence of yeast sediment at the bottom of the Erlenmeyer flask and a lighter color of the molasses solution (Rahmasari et al., 2022). The fermentation starter for maggot feed showed good yeast growth, as evidenced by the orange sediment at the bottom of the Erlenmeyer flask and the lighter color of the solution, indicating yeast activity.

Fermentation of BSF Maggot Feed

The results showed that fermentation with *R. taiwanensis* UNJCC Y-171 positively influenced the quality of maggot feed and the growth performance of BSF larvae. Treatment B (40% yeast concentration) resulted in the highest average maggot weight and length across all sampling days, followed by Treatment A (30% concentration), while the control group (Treatment K) exhibited the lowest growth metrics. This indicates a dose-dependent effect of *R. taiwanensis* on nutrient availability and digestibility. The anaerobic fermentation process appeared effective in suppressing undesirable microbial activity while enhancing the functional impact of the yeast (Sirait et al., 2020). Anaerobic fermentation produces NAD+ and pyruvate. Pyruvate undergoes decarboxylation into acetaldehyde (CH_3COH) and CO_2, where acetaldehyde acts as an electron acceptor. The formation of NAD+ serves as a redox balance regulator and a driver in the glycolysis process (Onesiforus et al., 2021).

After 72 h, the fermented feed became more moist, watery, and emitted a distinctive odor. Among the three treatments, Treatment B had the highest moisture content after fermentation. Fermented feed is a type of livestock feed based on rice bran and coconut pulp waste that undergoes structural changes with the help of microorganisms. In this case, *R. taiwanensis* UNJCC Y-171 plays a role in enhancing the nutrient content, making fermented feed more nutritionally rich than conventional commercial feed (Kusmiah et al., 2021).

Hatching of BSF Maggot Eggs

The hatching medium serves as the incubation site for BSF maggot eggs to hatch into larvae. This medium must be nutrient-rich to serve as the primary food source for newly hatched larvae. A common issue during this process is fungal contamination, which occurs when the feed-to-water ratio is imbalanced. Excessive moisture allows fungi to grow faster than larvae, thereby absorbing nutrients that should be available for the larvae. Consequently, newly hatched larvae experience reduced survival rates, and only a few manage to thrive (Kaharap et al., 2023).

Fig. 2. Hatching process of black soldier fly (BSF) maggot eggs.

The ideal maggot hatching medium consists of rice bran and water at a 1:1 ratio (500 g rice bran and 500 ml water). Maggot eggs were obtained from Loca Feed, BRBIH, Depok, and were weighed at 0.5 g per experimental unit. The eggs were scattered onto a mesh placed above the hatching medium to prevent them from clumping, which could extend the hatching period due to excessive moisture. Newly hatched maggots are very small and can pass through the mesh gaps. This process lasts 10 days, during which the maggots fully hatch and begin consuming the feed medium before being provided with fermented feed (Figure 2).

Provision of Fermented Feed

The administration of fermented feed, initiated on day 10 post-hatching, yielded noticeable differences in maggot growth across the three treatment groups. By day 13 and in subsequent observations, Treatments A and B consistently showed improved growth metrics compared to the control. Treatment B demonstrated the most significant increase in both maggot length and total weight, suggesting that a higher concentration of *R. taiwanensis* enhanced nutrient bioavailability. Treatment A also showed moderate improvements over the control, while the control group exhibited the slowest growth. These trends were observed consistently across all six replicates per treatment, indicating a positive correlation between yeast concentration in fermented feed and BSF larvae performance.

The organic waste initially used as maggot feed, consisting of coconut pulp and rice bran, exhibited a coarse texture that limited its suitability for maggot consumption. However, following fermentation with *R. taiwanensis* UNJCC Y-171, the texture of the feed became noticeably softer and more uniform. This transformation enhanced its palatability and digestibility for BSF larvae. The use of low-value organic by-products, particularly coconut pulp, in the production of maggot feed presents an effective strategy for organic waste reduction. Fermentation not only improves the physical properties of the feed but also contributes to waste valorization by converting agricultural residues into high-quality insect biomass for sustainable protein production.

Additionally, BSF larvae can be used as an alternative source of animal protein for livestock feed, with improved nutritional value due to fermentation (Figure 3). Maggots can be processed into dried maggot meal, which is known to be more cost-effective, environmentally friendly, and plays an essential role in the ecosystem. Maggots also have a high feed conversion rate, allowing them to be mass-produced to meet livestock feed demands (Izzah et al., 2023).

Fig. 3. Process of providing fermented feed to black soldier fly (BSF) maggot.

Growth of BSF Maggots

The growth of BSF larvae was assessed through wet weight measurements and individual body weight across four sampling days: 10, 13, 16, and 19. On day 10, the average wet weight of maggots in Treatment K was 105.00±57.65 g, in Treatment A was 91.00±14.19 g, and in Treatment B was 115.00±28.89 g. Statistical analysis using IBM SPSS Statistics version 26 with the Kruskal-Wallis test, followed by the Mann-Whitney U test, indicated no significant differences among the treatments on day 10 (notation a), as the effects of fermentation had not yet manifested. The results of the maggot wet weight analysis are presented in Figure 3.

However, by days 13 and 16, maggots in Treatments A and B exhibited significantly higher wet weights compared to the control (notation b). This improvement in growth performance is attributed to the inclusion of *R. taiwanensis* UNJCC Y-171 in the fermentation process. Unlike the control, which utilized only a basic molasses and coconut water medium, Treatments A and B benefited from enzymatic activity provided by *R. taiwanensis*. This yeast is capable of breaking down complex carbohydrates such as cellulose and hemicellulose in the feed ingredients (rice bran and coconut pulp), converting them into more digestible compounds like glucose and fatty acids (Miao et al., 2020). The degradation of crude fiber also enhances crude protein availability, facilitating better nutrient absorption and growth in BSF larvae (Fitriani & Asyari, 2017). These findings suggest that fermentation enriched with *R. taiwanensis* plays a critical role in improving feed efficiency and maggot biomass production.

Table 2. Black soldier fly (BSF) maggot wet weight analysis.

Treat-ment	BSF Maggot Wet Weight ± SE (g)			
	Day 10	Day 13	Day 16	Day 19
K	105 ± 57.65[a]	66 ± 49.84[a]	77 ± 52.03[a]	96 ± 55.32[a]
A	91 ± 14.19[a]	121 ± 17.52[b]	159 ± 23.81[b]	204 ± 23.72[a]
B	115 ± 28.89[a]	159 ± 35.44[b]	182 ± 45.14[b]	216 ± 51.81[a]

P value = 0.05.

Total maggot weight is associated with maggot population in kilograms, affecting harvest yield. Based on Table 2, optimal harvest results were observed on days 13 and 16, with good quality. However, on day 19, the differences between treatments became insignificant, as shown by notation a, indicating that the effect of yeast had begun to decline. This was due to the maximum limit of maggot growth, where further weight gain had plateaued.

Table 3. Black soldier fly (BSF) maggot body weight analysis.

Treat-ment	BSF maggot body weight ± SE (g)			
	Day 10	Day 13	Day 16	Day 19
K	0.108± 0.004[a]	0.075± 0.006[a]	0.076± 0.004[a]	0.091± 0.006[a]
A	0.103± 0.003[a]	0.068± 0.006[a]	0.091± 0.004[b]	0.102± 0.004[a]
B	0.096± 0.007[a]	0.102± 0.009[a]	0.104± 0.008[b]	0.117± 0.010[a]

P value = 0.05.

On days 10 and 13, maggot body weight showed a similar growth pattern, with no significant differences (notation a). The optimal body weight was observed on day 16, as indicated by the significant difference in Treatments A and B (notation b) compared to the control (Treatment K), which was not influenced by yeast. This suggests that on day 16, feed efficiency and maggot digestibility were at their peak. However, by day 19, individual maggot growth had reached its maximum limit, as they were approaching the prepupal stage, causing differences between treatments to no longer be significant. The length of maggots was measured by sampling all experimental units on days 10, 13, 16, and 19. Data were obtained using a mobile phone camera, with a ruler as the measurement scale, and analyzed using ImageJ software to determine maggot length from the images. This data is essential for assessing the optimal maggot growth rate among Treatments K, A, and B.

Table 4. Black soldier fly (BSF) maggot body length test.

Treat-ment	BSF maggot body length ± SE (cm)			
	Day 10	Day 13	Day 16	Day 19
K	1.49± 0.07[a]	1.29± 0.17[a]	1.19± 0.09[a]	1.30± 0.17[a]
A	1.45± 0.10[a]	1.36± 0.11[a]	1.56± 0.09[b]	1.36± 0.11[a]
B	1.39± 0.14[a]	1.44± 0.12[a]	1.59± 0.12[b]	1.45± 0.12[a]

P value = 0.05.

Differences in notation in Table 4 show a body length growth pattern similar to Table 3 on maggot body weight, but with different values. Data on days 10 and 13 did not show significant differences, as indicated by notation a. However, on day 16, a significant difference was observed in Treatments A and B, as indicated by notation b, demonstrating the effectiveness of yeast on that day.

Like body weight, maggot body length serves as a reliable indicator of growth rate and feed efficiency. In this study, yeast growth and its contribution to feed quality were inferred from experimental timing rather than solely from references. While previous studies report that *R. taiwanensis* typically reaches optimal growth within three days of fermentation, the actual effectiveness of the fermented feed was evaluated through observed maggot performance across multiple time points. On day 10, the fermentation process had only recently begun, and no significant improvements in maggot length or weight were recorded, supporting the notion that fermentation effects had not yet manifested. By day 16, however, both maggot weight and length in yeast-treated groups (Treatments A and B) showed significant increases compared to the control, suggesting that *R. taiwanensis* had reached an active phase. This improvement is likely due to the production of glycolipids with amphipathic properties by the yeast, which enhance feed digestibility through better emulsification and nutrient availability (Lyman et al., 2018). Thus, while optimal yeast growth was anticipated based on prior findings, the actual confirmation came from the experimental data showing improved maggot performance at later fermentation stages.

Proximate Analysis

The proximate analysis results for Treatment B showed a fat content of 15.57%, protein content of 12.29%, and crude fiber content of 1.27% (Table 5). The nutritional composition of maggots depends greatly on the feed medium used. All values obtained in this study were lower than those reported by Wantika et al. (2020), who found maggot fat content of 29–32%, protein content of 40–50%, and crude fiber content of 18.82%. Maggots fed with fermented feed containing *R. taiwanensis* UNJCC Y-171, as shown in Table 5, had higher fat content than maggots fed with molasses-based fermented feed alone. Treatment B with 40% yeast concentration showed 15.57% fat content, based on the average of two proximate analysis replications. This was 3.46% higher than the control, which had only 12.11% fat content.

These results indicate that fermentation with *R. taiwanensis* UNJCC Y-171 plays a role in increasing stored energy in the form of fat within maggots. This is also supported by its ability to break down crude fiber into simpler compounds, thereby facilitating greater fat accumulation in maggots (Miao et al., 2020). The protein content in the 40% yeast fermentation treatment (12.29%) was slightly lower than the control (13.27%). The difference was not highly significant, with a decrease of 0.98% in Treatment B. This may be due to molasses serving as a simple carbon source, which can be directly utilized in the fermentation process without affecting the available protein in the feed medium. Meanwhile*, R. taiwanensis* UNJCC Y-171 has the ability to produce protease and PEFA, which hydrolyze proteins into amino acids. This delays the fermentation process, but it also provides an additional benefit by enhancing maggot cell bioavailability, allowing better protein absorption when consumed by livestock (Lyman et al., 2018).

A significant reduction in crude fiber content was observed in Treatment B, where fermentation with *R. taiwanensis* UNJCC Y-171 at 40% concentration resulted in a final crude fiber content of 1.27%, representing a 0.63% decrease compared to the control (1.63%). Treatment B was more effective in breaking down crude fiber in rice bran and coconut pulp, compared to fermentation in the control using molasses alone.

Table 5. Black soldier fly (BSF) maggot proximate analysis*.

Component	Treatment	
	K	B
Fat	12.11	15.57
Protein	13.27	12.29
Crude fiber	1.63	1.27

*Samples tested were selected based on the best growth results.
P value = 0.05.

R. taiwanensis UNJCC Y-171 demonstrated greater ability to degrade crude fiber and convert it into simpler compounds, ultimately supporting higher fat production in maggots. Lower crude fiber content benefits maggots by increasing nutrient accessibility from the feed medium, allowing for faster metabolic processes. This also affected the appearance of maggots in Treatment B, whereby the final days of feed administration, maggots had grown with superior body weight and length, and their color changed more rapidly to a mature brown shade (Rashid et al., 2020).

Conclusion

The use of *R. taiwanensis* UNJCC Y-171 yeast in the fermentation of organic waste (coconut pulp and rice bran) as BSF larvae or maggot feed has been proven to have a positive impact on maggot body length and total weight growth, with a 40% yeast concentration yielding the most optimal growth compared to the control and the 30% treatment, particularly on day 16, when the increase in maggot length and weight was significant. Fermenting maggot feed with this yeast has the potential to serve as a more economical alternative feed for fish farming, which is expected to help reduce feed costs and meet the protein needs of farmed fish at a more affordable price for the community.

Conflict of Interest

All authors have no conflicts of interest to disclose.

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References

Alliza, A. I. (2022). Pengaruh penambahan inokulum dan fermentasi dua tahap terhadap produksi biogas dari *palm oil mill effluent* (POME). [thesis]. Yogyakarta: Universitas Gadjah Mada.

Anjani, K. D., & Ilmi, M. (2018). Penapisan isolat khamir oleaginous dari nektar bunga dan madu hutan. *Jurnal Mikologi Indonesia*, *2*(2), 100–111. https://doi.org/10.46638/jmi.v2i2.42

Ariskaa, R., Surono, & Sukmawati, D. (2024). Enhancing the quality of kasgot biofertilizer using *Pichia cecembensis* UNJCC Y-157 and amino acids to boost mustard greens (*Brassica juncea* L.) growth. *Buitenzorg: Journal of Tropical Science*, *1*(2), 10–19. https://doi.org/10.70158/buitenzorg.v1i2.10

Deng, F., Hu, X., Wang, Y., Luo, S., & Liu, C. (2023). Improving the yield of feruloyl oligosaccharides from rice bran through enzymatic extrusion and its mechanism. *Foods*, *12*(7), 1369. https://doi.org/10.3390/foods12071369

Fitriani, & Asyari, H. (2017). Kandungan protein kasar dan serat kasar pakan komplit berbasis tongkol jagung dengan penambahan *Azolla* sebagai pakan ruminansia. *Jurnal Galung Tropika*, *6*(1), 12–18. https://doi.org/10.31850/jgt.v6i1.181

Hu, P., Mao, J., Zeng, Y., Sun, Z., Deng, H., Chen, C., Sun, W., & Tang, Z. (2022). Isolation, identification, and function of *Rhodotorula mucilaginosa* TZR2014 and its effects on the growth and health of weaned piglets. *Frontiers in Microbiology*, 13. https://doi.org/10.3389/fmicb.2022.922136

IBM Corp., 2019. *IBM annual report 2019*. Retrieved from https://www.ibm.com/investor/att/pdf/IBM_Annual_Report_2019.pdf

Indarmawan (2014). Hewan avertebrata sebagai pakan ikan lele. Fakultas Biologi, Universitas Jenderal Soedirman, Purwokerto.

Izzah, A. Z. N., Mulandari, D. A., Putri, D. A., & Nagita, F. (2023). Analisis pemberian pakan berbeda terhadap kandungan *maggot* (*Hermetia illucens*). *Prosiding Seminar Nasional Pembangunan dan Pendidikan Vokasi Pertanian.* https://doi.org/10.47687/snppvp.v4i1.655

Kaharap, Y., Dotrimensi., Setiawan, F., & Nasution, R. P. S. (2023). Pelatihan pengembangan *maggot* sebagai pakan ternak di desa Karang Tunggal, kec. Parenggean sebagai model kewirausahaan sosial masyarakat. *Jurnal Pengabdian kepada Masyarakat*, *3*(2), 307–325.

Katz, D. S. (2008). *The streak plate protocol*. Retrieved from https://asm.org/asm/media/protocol-images/the-streak-plate-protocol.pdf?ext=.pdf

Kusmiah, N., Mahmud, A. T. B. A., & Darmawan, A. (2021). Pakan fermentasi sebagai solusi penyediaan pakan ternak di musim kemarau. *Jurnal Pengabdian kepada Masyarakat*, *1*(2), 31–36.

Lyman, M., Rubinfeld, B., Leif, R., Mulcahy, H., Dugan, L., & Souza, B. (2018) *Rhodotorula taiwanensis* MD1149 produces hypoacetylated PEFA compounds with increased surface activity compared to *Rhodotorula babjevae* MD1169. *PLoS ONE*, *13*(1), e0190373. https://doi.org/10.1371/journal.pone.0190373

Miao, Z., Tian, X., Liang, W., He, Y., & Wang, G. (2020). Bioconversion of corncob hydrolysate into microbial lipid by an oleaginous yeast *Rhodotorula taiwanensis* AM232 for biodiesel production. *Renewable Energy*, *161*(C), 91–97. https://doi.org/10.1016/j.renene.2020.07.007

Patmawati, Trilaksani, W., Zahirudin, W., Fatmaningrum, W., & Nadhiroh, S. R. (2022). Diversification of local products based on wet protein isolate of catfish (*Clarias* sp.) as a protein source to prevent stunting. *Media Gizi Indonesia*, *17*(1SP), 6–12. https://doi.org/10.20473/mgi.v17i1SP.6-12

Pratiwi, R., Gunam, I. B. W., & Antara, N. S. (2019). Pengaruh penambahan gula dan konsentrasi starter khamir terhadap karakteristik *wine* buah naga merah. *Jurnal Rekasaya dan Manajemen Agroindustri*, *7*(2), 268–278. https://doi.org/10.24843/JRMA.2019.v07.i02.p10

Putri, A. A., & Mirwan, M. (2023). Peningkatan protein *black soldier fly* (BSF) untuk pakan ternak sebagai hasil biokonversi sampah makanan. *INSOLOGI: Jurnal Sains dan Teknologi*, *2*(3), 496–507. https://doi.org/10.55123/insologi.v2i3.1919

Masir, U., Fausiah, A., & Sagita (2020). Produksi *maggot black soldier fly* (BSF) (*Hermetia illucens*) pada media ampas tahu dan feses ayam. *AGROVITAL: Jurnal Ilmu Pertanian*, *5*(2), 87–90. https://doi.org/10.35329/agrovital.v5i2.1746

Onesiforus, B. Y., Rinihapsari, E., Yarangga, F. T. D., & Pradistya, R. (2021). Perbandingan kemampuan fermentasi khamir *Saccharomyces cerevisiae* dari berbagai media kultur. *Bioma*, *17*(2), 65–73. https://doi.org/10.21009/Bioma17(2).3

Puspitasari, A. D., Surono, S., & Sukmawati, D. (2024). Potential of *Saccharomyces cerevisiae* UNJCC y-87 and amino acid on the quality of casgot and the growth of water spinach (*Ipomoea reptans*). *Buitenzorg: Journal of Tropical*

Science, *1*(1), 33–38. https://doi.org/10.70158/buitenzorg.v1i1.6

Rahmasari, E., Wisaniyasa, N. W., & Putra, I. N. K. (2022). Pengaruh konsentrasi starter dan gula terhadap karakteristik *wine* jahe. *Itepa: Jurnal Ilmu dan Teknologi Pangan*, *11*(3), 555–567.

Rashid, W. B. A. B., Abd Malek, R., Wadaan, M. A., Elsayed, E. A., Sukmawati, D., & El-Enshasy, H. A. (2020). Medium optimization for xylanase production by recombinant *Escherichia coli* B24. *Journal of Scientific & Industrial Research*, *79*(6), 473–478.

Sirait, J., Simanihuruk, K., & Hutasoit, R. (2020). Fermentasi aerob dan an-aerob rumput gajah mini (*Pennisetum purpureum* cv. Mott) untuk pakan kambing Boerka sedang tumbuh. *Jurnal Agripet*, *20*(2), 150–159.

Slamet, P., Sopandi, T., Andriani, V., Ajiningrum, P. S., & Hariani, D. (2023). PKM budidaya *black soldier fly* (*Hermetia illucens*) pada Mahasiswa PGSD Universitas PGRI Adibuana Surabaya. *Jurnal Penamas Adi Buana*, *7*(1), 59–71.

Sukmawati, D., Sunari, A., Akbari, T. S., Ardhiani, A. Z., Afifah, Z. N., Dellanerra, D., Nurjayadi, M., & Enshasy, H. E. (2020). Isolation and selection of fungi amylolytic and cellulolytic originated from *Rhododendron* sp. flower. *AIP Conference Proceedings*, *2242*(1), 050023. https://doi.org/10.1063/5.0014409

Sukmawati, D., Sondana, G. A., Fikriyyah, N. N., Afifah, Z. N., Firhandini, A., Khumaiya, U., Komsiatun, D. A., Asmara, Y. T., Supiyani, A., Puspitaningrum, R., Ridawati, R., Prihantini, N. B., Husna, S. N. A., El Enshasy, H. A., Hanapi, S. Z., Dailin, D. J., & Surono, S. (2021). Cellulase-producing yeast isolated from fermented cocoa beans as biocontrol for pathogenic mold chocolate fruit collected from Sentul, Jawa Barat, Indonesia. *Journal of Physics: Conference Series*, *1869*(1), 012043. https://doi.org/10.1088/1742-6596/1869/1/012043

Torlesse, H., Kiess, L, & Bloem, M. (2003). Association of household rice consumption with child nutritional status indicates a role for food-based strategies to reduce stunting in Bangladesh. *Food and Nutrition Bulletin*, *24*(4), 295–309.

Umaroh, R., & Vinantia, A. (2018). Analisis konsumsi protein hewani pada rumah tangga Indonesia. *Jurnal Ekonomi dan Pembangunan Indonesia*, *18*(3), 22–32.

Wantika, N., Budiana, Suryani, E., Rubi'ah L., Dzatalini, N., Rusdiatin, Nila, Y. T., Santanumurti, M. B., Samara, S. H., Nindarwi, D. D., Lokapirnasari, W. P., Al-Arif, M. A., Alamsjah, M. A., & Lamid, M. (2020). Substitution of fermented maggot (*Hermetia illucens*) flour on commercial feed towards protein retention and energy retention in tambaqui (*Colossoma macropomum*) meat. *IOP Conference Series: Earth and Environmental Science*, *441*, 012051. https://doi.org/10.1088/1755-1315/441/1/012051