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Feeding Rates of Black Soldier Fly (*Hermetia illucens*) Fed on Palm Kernel Meal and Bovine Blood

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Abstract. *Slaughterhouses are economic activities that generate significant waste, including blood. Blood is a biological hazardous material due to its potency as a source of disease. Standard waste management methods for this material, involving physical and chemical treatment technologies, are considered expensive and impractical for small-scale entrepreneurs, leading to a neglect of waste management. Another possible waste management approach for blood is to use biological agents that utilize its nutrients. One candidate is the black soldier fly, known for its ability to consume various organic materials to produce high-value biomass. However, this process is highly dependent on the feed material's characteristics and the feeding rate. In this study, bovine blood was mixed with fermented palm kernel meal as the feeding material for black soldier fly (Hermetia illucens) larvae. The objective of this study was to assess the effect of feeding rates of 50, 100, 200, 300, and 400 mg/larvae/day on the growth performance and survival of the larvae. The results showed that the time required for larvae to become pupae is 20-24 days. A 200 mg/larvae/day produced the best harvested weight and lowest Feed Conversion Ratio (FCR). The highest growth rate was achieved at a dosage of 300 mg/larvae/day. At the same time, a 400 mg/larvae/day dose produced the highest length and Waste Reduction Index (WRI). On the other hand, the survival rate ranged from 77% to 91%, with 100 mg/larvae/day being the most effective. Mixing bovine blood with palm kernel meal at a feeding rate of more than 100 mg/larvae/day will allow the effective black soldier fly (H. illucens) larval composting process.*

Keywords: *consumption, development, growth, insect, survival*

Citation

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INTRODUCTION

Rapid Population growth has led to increased food consumption, causing various problems, including increased waste (Kim et al., 2021). Densely populated areas generate more than 2.1 billion tons of waste globally every year, of which only 16% is recycled, and more than 46% is disposed of and causes problems (Nichols & Smith, 2020). The increase in food consumption does not match the efficiency of the collection, separation, and treatment processes, leading to a continued rise in waste (Kinasih et al., 2020; Siddiqui et al., 2022). In some industries, including animal husbandry and agro-industry, waste management is an important issue that needs more attention. In the field of animal husbandry, especially in slaughterhouses, which are the most important link in the meat supply chain, produce large amounts of waste but are not balanced with management efficiency (Dada et al., 2020; Ragasri & Sabumon, 2023). In the agro-industry, especially in oil palm, which produces solid waste such as empty bunches, shells, trunks, and fronds, the increasing volume of waste is feared to hurt both humans and animals in the vicinity (Azizi et al., 2021). Some waste reduction options have many drawbacks, such as requiring large areas of land or being expensive (Monita et al., 2017). Waste reduction requires efficient technology that prevents additional waste from being generated during the treatment process (Rasdi et al., 2023). Black soldier fly larvae (*Hermetia illucens*) can be a solution to reducing waste. Black soldier fly (*H. illucens*) is an insect of the order Diptera, and its distribution is found in temperate and tropical regions (Surendra et al., 2020; Gligorescu et al., 2020). Black soldier fly (*H. illucens*) larvae can reduce the quantity of waste in a short time and do not cause disease because black soldier fly (*H. illucens*) larvae are not disease vectors. From an economic perspective, black soldier fly (*H. illucens*) larvae can produce economical products with high protein content, which, in the process, require less water and land than other alternative protein sources (Siddiqui et al., 2022).

Although black soldier fly (*H. illucens*) larvae exhibit high tolerance to various abiotic factors, optimal conditions are still required to support maximal growth (Singh et al., 2022). The quality and quantity of substrate used by black soldier fly (*H. illucens*) larvae greatly affect their growth, survival, and consumption. This is caused by nutrients in the substrate that can affect growth performance and waste reduction efficiency (Plantiangtam et al., 2021). A study by Yuan et al. (2022) that used four substrates and varied feeding rates demonstrated that larvae growing on different substrates at the same feeding rate showed differences in growth, consumption, and survival. Optimizing substrate quality can be achieved through pre-treatment (Lamin et al., 2022) and by using heterogeneous substrates to increase digestibility and improve the nutrient balance of black soldier fly larvae (Isibika et al., 2019; Lalander et al., 2019). Several studies have reported that palm oil by-products improve larval palatability to the substrate (Raksasat et al., 2021; Bajra et al., 2024). Using palm kernel meal as an approach to reducing bovine blood waste, which is classified as a biohazard from animal slaughter, is necessary. This study aims to determine the effect of palm kernel meal and bovine blood waste on growth performance (growth, development, and consumption) and survival of black soldier fly (*H. illucens*) larvae.

MATERIALS AND METHODS

Location and Time of Research

Research was conducted in the insect toxicology laboratory of the Bandung Institute of Technology from October to November 2024, under average environmental conditions of 26°C temperature, 77% relative humidity, and 25 candela light intensity.

Research Method and Data Collection process

250 g Palm kernel meal obtained from PT Okta Palm Oil North Sumatra was added to a fermentation solution of EM4, molasses, and distilled water in the ratio of 1:1:1. The mixture was fermented for 2 days (anaerobic) (Damanik et al., 2023). Before being given to the larvae, 10% of fresh bovine blood (10% of the substrate weight) obtained from Ciroyom Slaughterhouse was added. Black soldier fly (H. illucens) larvae eggs were purchased from BSF Priangan Indonesia, located at Cipadung Village Road No. 146A, Cipadung, Bandung City, West Java. Eggs were hatched and reared until 6 days old on Hi-Pro-Vite A594k chicken feed with 60% moisture content.

The 6-day-old larvae were transferred to a rearing plastic container with a diameter of 7 cm and a height of 15 cm, and then covered with a material that allows aeration. The number of larvae placed in the rearing container was 100. Larvae were divided into five different feeding rates with five replicates each:50 mg/larvae/day,

A. 100 mg/larvae/day,
B. 200 mg/larvae/day,
C. 300 mg/larvae/day, and
D. 400 mg/larvae/day.

Feed was given once every 3 days, with the amount depending on the number of larvae left in the container. Then, the initial and final weights of the feed were weighed, both dry weight and wet weight (residue). Every three days, five larvae from each cup-rearing container were weighed and measured for length. Variables measured included the initial and final weights of the substrate, larval length and weight, the larval period between developmental stages, and larval survival. Length measurements were taken with a caliper to an accuracy of 0.01 mm. At the same time, larval weight was measured using an analytical balance to an accuracy of 0.001 mg. Dry weight of the substrate and larvae was measured in a 600°C oven for 48 hours. Length and weight measurements were taken every 3 days during feed changes, along with dead larva counts. Substrate feeding was continued until 60% of the larvae had turned into prepupae (Diener et al., 2009).

Observed Variables

Growth Rate

Growth rate was calculated using the following formula:

$$\text{Growth rate} = \frac{\text{final weight of larvae} - \text{initial weight of larvae}}{t}$$

with t = time to reach prepupae.

Waste Reduction Index (WRI)

WRI is calculated using the following formula:

$$WRI = \frac{D}{t} \times 100 \qquad D = \frac{W - R}{W}$$

(Diener et al., 2009)

With W is total amount of waste reduced (g), t is total time larvae feed on waste (BSF larval cycle)/(days), R is total waste remaining after a certain time/residue (g), D is reduction in total waste (g).

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Feed Conversion Ratio (FCR)

FCR is calculated using the following formula (Broeckx et al., 2021):

$$FCR = \frac{\text{Total feed given}}{\text{Final larval weight} - \text{Initial larval weight}}$$

Survival Rate

Survival rate was calculated using the following formula:

$$\text{Survival Rate} = \frac{\text{Number of live larvae}}{\text{Initial number of larvae}} \times 100\%$$

Statistical analysis

All data were tested for normality and homogeneity using the Levene and Shapiro-Wilk tests. Based on its results, a nonparametric test, specifically the Kruskal-Wallis test, was used, and the pairwise Wilcoxon test was used as a post hoc test (Significance level: $p<0.05$) (Dzepe et al., 2020). Statistical analysis was conducted using R Studio version 4.2.0.

RESULTS AND DISCUSSION

Growth and Development

The application of a feeding rate of 200 mg/larvae/day (group C) produced the highest harvested larval weight, while the longest harvested larval length was achieved at group E (400 mg/larvae/day) (Figure 1). In general, applying a feeding rate of less than 200 mg/larvae/day resulted in significantly lower weight and length (Kruskal-Wallis, $p<0.05$). The highest weight was recorded on group C (156.8 mg), while the longest larvae were recorded on group E (14.98 mm).

Differences in energy allocation could explain the differences in weight across feeding rates. When larval feeding rates are low, larvae experience nutrient deficiency due to food scarcity (Mojikon & Lardizabal, 2023; Camperio et al., 2025).

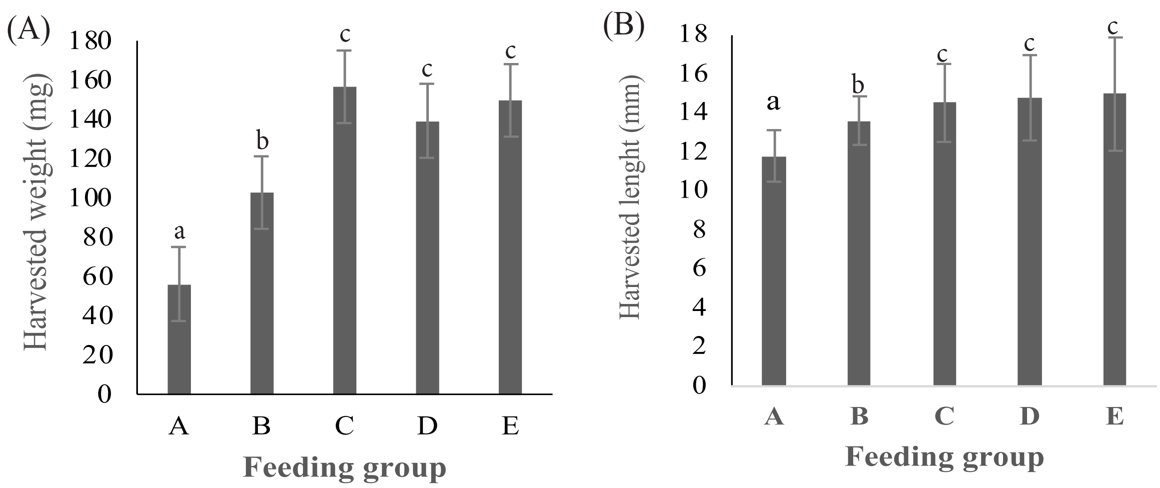

Figure 1. Average (A) harvested weight and (B) length of black soldier fly (*Hermetia illucens*) larvae fed on different feeding rates. (A)50 mg/larvae/day, (B) 100 mg/larvae/day, (C) 200 mg/larvae/day, (D) 300 mg/larvae/day, (E) 400 mg/larvae/day. Different letters indicate statistically significant data at $p < 0.05$

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Larvae on low-feeding substrates compensate for nutrient deficiencies by allocating energy to maintenance rather than growth. This leads to poor performance (Rintu et al., 2021). In this study group A (50 mg/larvae/day) has lowest weight (50 mg), shortest lenght (11 mm), and lowest growth rate (0,56 mg/larvae/day), On the other hand, treatments with feeding rates of 300 and 400 mg/larva/day did not produce high weight as also reported by Cattaneo et al. (2025).Larval length of each treatment is directly proportional to the increase in feeding rate. This is also found in research by Haryanto & Setioyono (2021). This phenomenon can be due to the high quantity of media balanced by the high quality of the substrate, as in this study, where the growth media was fermented and included a co-substrate, allowing larvae to meet the energy requirements for the next developmental stage.

The growth pattern showed that larvae in group A (fed at the lowest feeding rate) grew the slowest throughout the observation period. This group of larvae also has a longer development time, the period needed to reach pupae, compared to the other group (Figure 2). On the other hand, groups C, D, and E showed a similar growth pattern, suggesting that feeding rate affects the growth of black soldier fly (*H. illucens*) larvae.

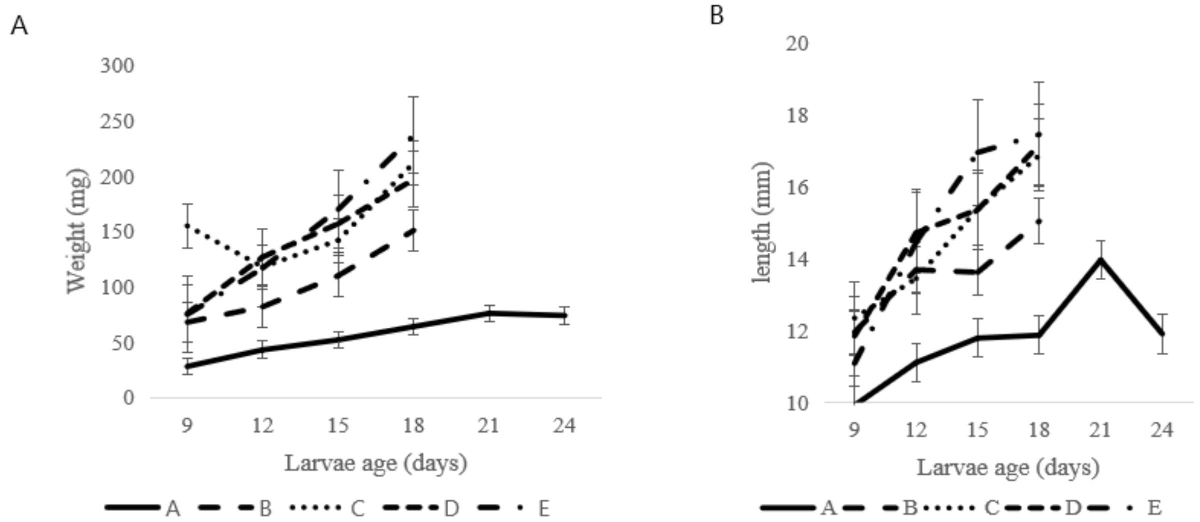

Figure 2. Growth pattern of weight (left) and length (right) of black soldier fly (*Hermetia illucens*) larvae fed on different feeding rates, (A)50 mg/larvae/day, (B) 100 mg/larvae/day, (C) 200 mg/larvae/day, (D) 300 mg/larvae/day, (E) 400 mg/larvae/day

The growth of black soldier fly (*Hermetia illucens*) larvae fluctuates. Larvae underwent rapid growth during early rearing. During this time, carbohydrate metabolism, specifically glycogen, increases because insects need a lot of nutrients and energy for growth (Lu et al., 2021). After rapid growth at 18 days, groups B, C, D, and E reached maximum weight. Group A, on the other hand, reached its maximum weight at 24 days of larval age. After larvae reach their critical or maximum weight, prothoracicotropic hormone (PTTH) is released, gradually terminating feeding (Edgar, 2006). Larvae in the stop-feeding stage, or post-feeding larvae, have morphological differences from those still in the feeding stage. When feeding stops, the larval head develops and forms a chitinous puparium sheath. The mandibular rudiment separates from the maxilla, and its eyes develop into compound insect eyes. Labium then elongates, reaching almost the length of the maxilla (Bruno et al., 2020). The prepupae usually move from the rearing substrate to harden, then, after a few days, develop into adult flies (Dzepe et al., 2020). Larvae fed with the feeding rate of 200 and 300 mg/larvae/day had significantly higher growth rates than other groups (Table 1) (Kruskal-Wallis, $p < 0.05$).

Table 1. Growth rate of Black Soldier Fly Larvae (*Hermetia illucens*), (A) 50 mg/larva/day, (B) 100 mg/larva/day, (C) 200 mg/larva/day, (D) 300 mg/larva/day, (E) 400 mg/larva/day. Different letters indicate statistically significant data at $p<0.05$

Treatment	Growth rate (mg/larvae/day)
A	0.56 ± 0.54^a
B	1.24 ± 0.76^b
C	4.76 ± 2.31^c
D	5.24 ± 2.55^c
E	2.98 ± 1.86^d

The lowest growth rate was observed in groups A and B, indicating that bovine blood as the feeding material resulted in the lowest growth rate. The highest growth rate was in group C (200 mg/larvae.day). This is because at the highest feeding level, the larvae could not grow optimally. After all, based on Brambel's five stages of insect freedom, which is often used to maximize larval performance to grow optimally under rearing conditions, black soldier fly (*H. illucens*) larvae did not fulfill the five stages of insect freedom. The five stages of freedom are freedom from thirst and hunger (starvation and malnutrition), freedom from discomfort, freedom from pathogens, freedom to express normal behavior, and freedom from stress (Barret et al., 2022). In a study by Cattaneo et al. (2025), larvae at high feeding levels did not achieve optimal growth performance due to the non-fulfillment of the second and fourth larval freedoms (larval freedom from discomfort and larval freedom to express normal behavior).

In general, larvae with a high feeding rate showed a relatively strong positive correlation between length and weight, resulting in perfect tube-shaped larvae. On the other hand, larvae fed at a lower feeding rate had a relatively similar length-to-weight ratio, producing round-shaped larvae that did not fit the market (Figure 3). The result of this study showed that the feeding rate influenced the length and weight characteristics of larvae. Larval weight, in addition to substrate feeding rate, can also be influenced by substrate type. In the study by Dani et al. (2023), the substrate that produced small and thin larvae was characterized by higher levels of cellulose (32%), lignin (38%), and hemicellulose (0.25%), which affected larval consumption rate and, in turn, larval characteristics. Compared with other studies using slaughterhouse waste, the development time of black soldier flies in this study is quite similar to those in studies that mixed blood with different materials (Table 2). This indicated that although blood is rich in protein and fat, its dose should be precisely applied to increase the development of black soldier fly (*H. illucens*) larvae.

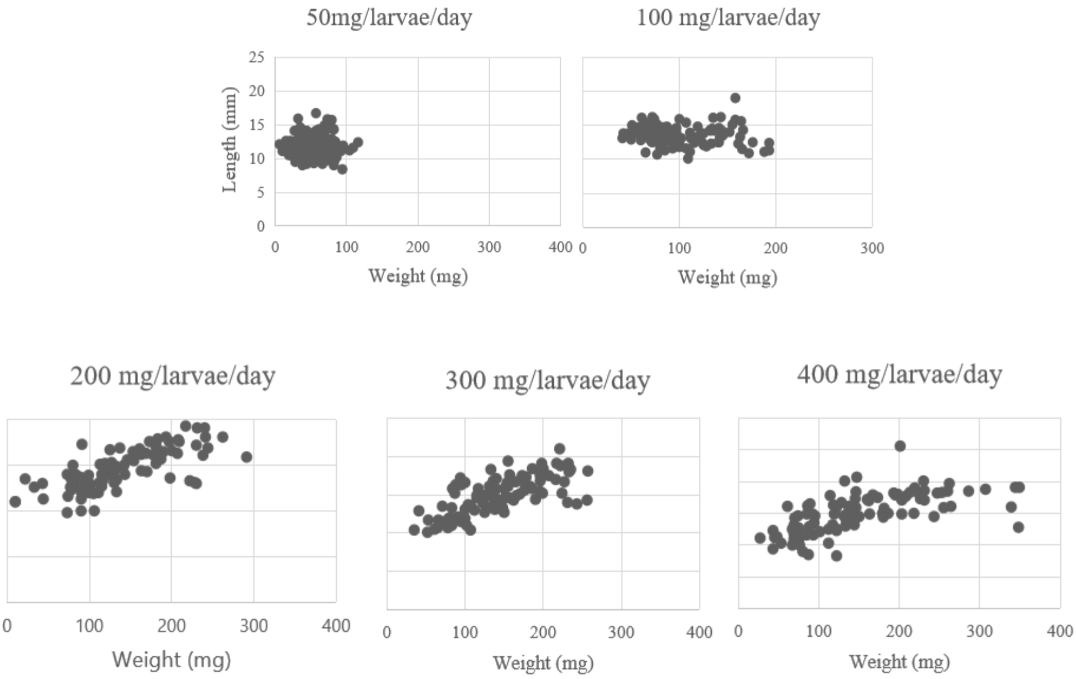

Figure 3. Length and weight characteristics of black soldier fly (*Hermetia illucens*) larvae at different feeding rates

Table 2. Comparison of the development time of black soldier fly larvae (*Hermetia illucens*) to prepupa in several studies

Substrate	Time to reach pupa	Research
Palm kernel meal + bovine blood	20 - 24 days	This study
Chicken blood waste + restaurant waste	21 days	Monita et al., 2017
Slaughterhouse waste	83-86 days	Shumo et al., 2019

Shumo et al. (2019) had the longest development time among the studies, followed by this study and Monita et al. (2017). This can be due to the surrounding substrate (Dzepe et al., 2020). In this study, prepupae were directly transferred into a plastic cup. In Shumo et al. (2019), after larvae developed into prepupae, prepupae were stored in the media with a wet sawdust substrate. In the study by Monita et al. (2017), larvae were transferred to fiberglass as they developed into prepupae. A study by Dzepe et al. (2020) comparing pupation on wood shavings, fine sand, wheat bran, and no substrate showed that the pupation substrate affects pupation time and rate. This is because post-feeding larvae tend to bury themselves in the soil to avoid predators. The denser the surrounding substrate, the less likely they are to bury themselves. Therefore, the density

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of the surrounding substrate and the ambient temperature affect dispersal, pupation time, and pupation rate.

Survival Rate

In general, the survival rate of black soldier fly (*H. illucens*) larvae among observation groups was relatively similar (Kruskal-Wallis, $p>0.05$). The highest survival rate was recorded on group B (91.4%) and the lowest on group D (77.2%) (Figure 4).

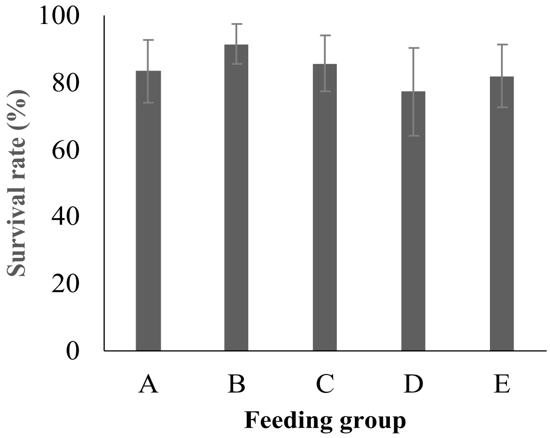

Figure 4. Survival rate of black soldier fly (*Hermetia illucens*) larvae at different feeding rate, (A) 50 mg/larva/day, (B) 100 mg/larva/day, (C) 200 mg/larva/day, (D) 300 mg/larva/day (E) 400 mg/larva/day

The physical properties of the substrate used for black soldier fly (*Hermetia illucens*) may be related to survival, which ranged from 77% to 91%. The moisture content used in this study is 60%. This causes no structural changes in the growth medium. In a study conducted by Khairuddin et al. (2022), a substrate with a moisture content of 60-80%. Showed no change in the structure of the substrate. The structure of the substrate is crucial because it can aerate and allow larval movement, enabling them to grow on optimal growth media. In addition to no structural changes in the growth media, the use of 60% moisture content is also optimal for larval movement. According to Bekker et al. (2021), they used chicken feed as substrate with a moisture content below 60% (45%-50%). It caused larval movement only at the bottom of the substrate, and in chicken feed with a moisture content of 75%, larvae were found only at the top. The application of palm kernel meal also affects larval survival rate. The type of growth media used can also affect porosity, which directly affects the larvae (Yakti et al., 2023). In a study by Dzepe et al. (2020) using 3 types of growth media, larval survival was found to differ across media types. The growth media used in this study are palm kernel meal, which maintains optimal moisture content for larval survival. Research by Yuan et al. (2022), which used four types of substrate, including food waste from the cafeteria, fish head waste, yard waste (mango tree leaves), and palm oil waste, showed that yard waste growth media had the highest mortality compared to the other three substrates. This is because yard waste has a finer, denser texture, causing moisture to be lost faster than in the other three types of substrate.

Consumption

The study showed a positive correlation between waste reduction and feeding rate, with values ranging from 4.1 to 28.27% (Figure 5). The level of waste reduction between group A and B (feeding rate of 50 and 100 mg/larvae/day) was significantly lower than other groups, with the highest recorded on larvae that received at group E (400 mg substrate/larvae/day) (Kruskal-Walis, $p<0.05$).

Figure 5 shows a significant difference between groups ($p<0.05$), because the larval consumption rate is influenced by the amount of substrate used. According to Salsabila et al. (2021), substrate consumption is influenced by the particle size of the growth medium and the media's quality and quantity. The higher the WRI value, the higher the larval ability to reduce the substrate. In this study, as shown in

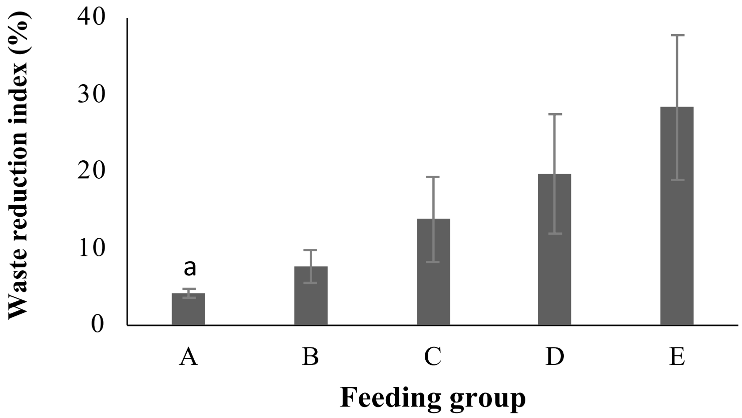

Figure 5. Waste Reduction Index of black soldier fly larvae (*Hermetia illucens*) at different feeding rates. (A) 50 mg/larva/day, (B) 100 mg/larva/day, (C) 200 mg/larva/day, (D) 300 mg/larva/day, (E) 400 mg/larva/day. Different letters indicate statistically significant data at $p < 0.05$

Figure 5, the highest WRI value was obtained in group E (400 mg/larvae/day), which amounted to 28.27% while the lowest was in group A (50 mg/larvae/day), which amounted to 4.1%. The range in this study is greater than in other studies. In the study (Hosseindoust et al., 2024) that used a substrate derived from slaughterhouse waste, the WRI was 2.08%. This study uses heterogeneous substrates: bovine blood waste and palm kernel meal. Research reported by Amri et al. (2022) found that mixed substrates tend to produce higher WRI values, while homogeneous substrates tend to trigger anaerobic processes during maintenance because there is no substrate texture balancer. Figure 5 showed a strong positive correlation between increases in WRI and feeding rate. This pattern was also obtained in the results of previous research (Amin et al., 2024), where in each type of feed given, the highest WRI value was obtained from the highest feeding rate. This is caused by mechanical pretreatment, such as cutting the feed into pieces and mashing it before giving it to the larvae to increase larval palatability. In this study, the substrate also received pre-treatment, which is fermentation using EM4. Pre-treatment aims to facilitate the larvae during the ingestion process.

Based on statistical analysis, feeding rate does not affect FCR value (Kruskal-Wallis, p>0,05). This pattern was also observed in Rintu et al. (2021), who used substrates derived from slaughterhouse waste at different feeding rates and densities, resulting in FCR that was not significantly different among groups. Also, in a study by Riberio et al. (2022), abiotic factors, such as substrate moisture content, did not affect FCR. This indicates that the assimilation process of BSF larvae must be precisely calculated before cultivation to achieve a low FCR, which could be helpful for large-scale production.

The highest feed conversion rate was recorded in group C, while the lowest was in group E (Table 3). As low FCR indicated that less feed was required to produce biomass, the application of 200 mg substrate/larvae/day was the best in terms of substrate quality. Table 3 showed that increasing the feeding rate was not directly proportional to the FCR value. This also happened in the study (Nyekeri et al., 2019), the lowest FCR was not obtained at the highest feeding level. This is caused by consuming more feed; larva requires more energy to assimilate feed into biomass (Schneider et al., 2025).

Table 3. FCR larva (*Hermetia illucens*), (A) 50 mg/larva/day, (B) 100 mg/larva/day, (C) 200 mg/larva/day, (D) 300 mg/larva/day (E) 400 mg/larva/day.

Groups	FCR
A	0.14 ± 0.002
B	0.11 ± 0.001
C	0.09 ± 0.009
D	0.20 ± 0.010
E	0.19 ± 0.003

CONCLUSION

The time required for larvae to become pupae is 20-24 days. 200 mg/larvea/day treatment produced the highest weight and the lowest FCR (Feed Conversion Ratio). The highest growth rate was at 300 mg/larvae/day. While 400 mg/larvae/day produced the highest length and WRI (Waste Reduction Index). On the other hand, the survival rate in this study ranged from 77% to 91%, with the highest at 100 mg/larvae/day. Mixing bovine blood with palm kernel meal at a feeding rate of more than 100 mg/larvae/day enabled an effective black soldier fly (*H. illucens*) larval composting process.

AUTHOR CONTRIBUTION

R.S. collected and analyzed the data and wrote the manuscript, and **R. E. P.** designed the research and supervised the entire process.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this study.

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