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ASSESSING THE EFFICIENCY OF THE BLACK SOLDIER FLY (*Hermetia illucens* L.) LARVAE AS BIOCONVERSION AGENT FOR GROUND BANANA PEELS

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ABSTRACT

Black Soldier Fly larvae (BSFL) are insect larvae that can be utilized as a bioconversion agent. In this research, BSFL larvae were used as a bioconversion agent on ground banana peels (GBP) and chicken feed (CF). This research determined the effect of GBP as diet on larval weight increment (LWI), larval development time (LD), and the ability of BSFL to convert the GBP based on Approximate Digestibility (AD), Weight Reduction Index (WRI), and Efficiency of Conversion of Digested food (ECD). The study used 10-day-old BSFLs, which were fed with constant food amount of CF and GBP at levels of 50 g/day and different numbers of larvae (100, 200 and 300) were utilized. The experiment was arranged as a randomized complete block design, with four replicates for each diet. Results showed that BSFL fed with CF has a better LWI (ranging between 1.33±0.38 g/d to 1.38±0.39 g/d). The LD results show that CF fed larvae resulted in faster development time (12±0.000001 days) compared to GBP fed larvae (30±0.14 days). The study also found that a greater number of larvae resulted in a more efficient bioconversion activity, where 300 larvae resulted in higher values for key parameters such AD (%), WRI (%) and ECD (%), compared to 200 and 100 larvae. The correlation analysis revealed no significant and weak negative relationship between the number of larvae and LD that were fed with CF (R^2=-0.237, P>0.05). Similarly, when fed with GBP, there was no significant and weak positive relationship (R^2=0.118, P>0.05) between the number of larvae and LD. Conversely, there was a highly significant strong positive relationship between the number of larvae with ECD when fed with CF (R^2=0.946, P<0.001) and GBP (R^2=0.946, P<0.001). In conclusion, the findings indicate that BSFLs fed with GBP have low WRI (%) and ECD (%).

Keywords: Organic waste, food waste, larval development, sustainable waste management, diet

ABSTRAK

Larva Lalat Askar Hitam (BSFL) adalah larva serangga yang boleh digunakan sebagai agen biopenukaran. Dalam kajian ini, larva BSFL digunakan sebagai agen biopenukaran untuk kulit

pisang kisar (GBP) dan makanan ayam (CF). Kajian ini menentukan kesan GBP sebagai diet pada kenaikan berat larva (LWI), masa perkembangan larva (LD), dan keupayaan BSFL untuk menukar GBP berdasarkan anggaran kebolehcernaan (AD), Indeks Pengurangan Berat (WRI), dan kecekapan Penukaran makanan dicerna (ECD). Kajian ini menggunakan BSFL berusia 10 hari, yang diberi makan dengan jumlah makanan tetap CF dan GBP pada tahap 50 g/hari dan bilangan larva yang berbeza (100, 200 dan 300) telah digunakan. Eksperimen ini dilaksanakan menggunakan reka bentuk blok lengkap secara rawak, dengan empat replikasi untuk setiap diet. Keputusan menunjukkan bahawa BSFL yang diberi makan dengan CF mempunyai LWI yang lebih baik (julat antara 1.33±0.38 g/h sehingga 1.38±0.39 g/h). Keputusan LD menunjukkan bahawa larva yang diberi makan CF menghasilkan masa pertumbuhan yang lebih cepat (12±0.000001 hari) berbanding larva yang diberi makan GBP (30±0.14 hari). Kajian ini juga mendapati bahawa bilangan larva yang lebih banyak menghasilkan aktiviti biopenukaran yang lebih cekap, di mana 300 larva menghasilkan nilai yang lebih tinggi untuk parameter utama seperti AD (%), WRI (%) dan ECD (%), berbanding 200 dan 100 larva. Analisis korelasi menunjukkan hubungan negatif yang lemah dan tidak signifikan di antara bilangan larva dan LD yang diberi makan dengan CF (R^2=-0.237, P>0.05). Demikian juga, apabila diberi makan dengan GBP, terdapat hubungan positif yang lemah tetapi tidak signifikan (R^2=0.118, P>0.05) diantara bilangan larva dan LD. Sebaliknya, terdapat hubungan positif yang sangat signifikan antara bilangan larva dengan ECD apabila diberi makan dengan CF (R^2=0.946, P<0.001) dan GBP (R^2=0.946, P<0.001). Kesimpulannya, hasil kajian ini menunjukkan bahawa BSFL yang diberi makan GBP mempunyai WRI (%) dan ECD (%) yang rendah.

Kata kunci: Sisa organik, sisa makanan, perkembangan larva, pengurusan sisa mampan, diet

INTRODUCTION

Food waste is a significant global issue as approximately 16,688 tons of food waste are being disposed of daily in Malaysia from agricultural, industrial, and domestic sectors throughout the year 2021 (Ramli et al. 2022). According to Thi et al. (2015), food waste can be categorized into three different categories which are food losses, unavoidable food waste and avoidable food waste. Food is currently getting thrown into the landfills every year and the escalating quantity of food waste has contributed to many environmental concerns in Malaysia (Lim et al. 2016). Banana peels for example, are a significant source of waste produced from banana consumption and by banana fritters vendors which contribute to this issue when it is being discarded into the waste bins that end up in landfills (Nur et al. 2023). Other than that, banana peels contain large amounts of nitrogen and phosphorus, and their high-water content makes it an environmental problem (Romano et al. 2022) In addition, banana peel waste can take up to years to decompose, producing odors and excessive emissions of greenhouse gases (GHG), which contribute to environmental pollution (Alzate Acevedo et al. 2021).

The Black Soldier Fly (BSF) is gaining recognition as an innovative and eco-friendly tool for managing organic waste. Various research has shown that black soldier fly larvae (BSFL) can efficiently convert various organic wastes, such as livestock manure, municipal solid waste, and biodegradable waste, into valuable products like larval biomass rich in protein and fat, biodiesel, chitin, and biofertilizer (Salam et al. 2022; Amrul et al. 2022). This technology offers a sustainable and cost-effective solution for waste management, particularly in developing countries, and has the potential to address the increasing environmental issues associated with organic waste (Siddiqui et al. 2022). The black soldier fly technology is

considered effective for the biological breakdown of diverse biodegradable wastes and is being explored for its potential in sustainable waste management, including the production of high-quality nutrients for various purposes such as pet foods and aquaculture (Rehman et al. 2022). Overall, the use of black soldier fly larvae in waste management is a rapidly evolving field with significant potential for addressing organic waste challenges and generating valuable resources.

Black Soldier Fly adult is not considered as a pest like other dipterans. Unlike houseflies, adult black soldier flies have greatly reduced sponging mouthparts, so it can only consume liquids such as flower nectar or not eat at all. According to Isa and Hassan (2021), the adult BSF accumulates all of supplementary nutrients during the preceding larval phase. BSF does not spread diseases since it does not regurgitate food along with digestive enzymes like houseflies do (Shelomi 2020). Thus, BSFL is used as a bioconversion agent to reduce various types of organic waste (Abd El-Hack et al. 2022; Fadhillah & Bagastyo 2020). BSFLs are known for their vigorous feeding behavior, which enables them to eat a wide variety of organic waste and transform it into biomass (Wang & Shelomi 2017). The advantages of utilizing BSFL as a bioconversion agent include its ability to treat organic waste expeditiously and lower bacterial growth and odor (Bohm et al. 2022). In addition, BSFL is an alternative source of protein for aquaculture, animal feed, and pet food (Abd El-Hack et al. 2022; Fairuz et al. 2023). This preliminary study conducted in Sabah aimed to investigate the BSFL performance as a bioconversion agent of ground banana peels and to study the influence of the number of larvae in the bioconversion efficiency of ground banana peels together with the chicken feed which serves as a control diet. The study aimed to contribute to a more sustainable future and explore the potential uses of BSFL as a bioconversion agent of ground banana peels.

MATERIALS AND METHODS

Study Location

The experiments were carried out at the Entomology Laboratory of the Faculty of Tropical Forestry, Universiti Malaysia Sabah, Malaysia. The established lab colony was reared in the entomology laboratory insectarium throughout the study.

Diet Source and Preparation

The banana peels were collected from several banana fritter stalls situated around Kota Kinabalu, Sabah. Prior to the experiments, the banana peel waste was placed in an oven at a temperature of 80℃ for 20 minutes. Ground banana peel (GBP) diet substrates were ground with a grinder before introducing it to the larvae. Chicken feed (CF) was prepared with 60% moisture (tap water) added.

Experimental Procedure and Design

The egg were hatched in chicken feed media until day nine. A day before the experiments, BSFL were starved for 24-hours. The larvae used in the experiments were 10 days old. A constant food weight of 150 g was provided to the larvae every three days in each treatment until they reached 50% prepupal stage to obtain the larval development time (LD). A randomized complete block design (RCBD) was employed in this study, with four replications (n=4) for each treatment. The treatments employed different numbers of larvae which were 100, 200, and 300 larvae, as the independent variables. Two types of diets were used, CF and GBP, where CF was used as the control diet.

Data Collection and Calculation

Larval weight increment (LWI) (g/d) was assessed in every replicate. For this purpose, 10 larvae were chosen randomly from each unit and weights were recorded at an interval of every three days. Besides the LWI, other parameters measured were larval development time (LD) (d), survivability rate (SR) (%), approximate digestibility (AD) (%), weight reduction rate (WRI) (%) and efficiency of conversion of digested food (ECD) (%). The parameters were calculated according to the following formulae: The AD and ECD were determined using equations (1) and (3) from earlier research by Waldbauer (1968). While WRI was calculated using equation (2) from the study by Diener et al. (2009).

$$\text{AD (\%)} = \left(\frac{Total\ feed - Residue}{Residue}\right) X\ 100\% \quad [1]$$

$$\text{WRI (\%)} = [(Total\ Diet\ (g) - Residual\ substrate\ (g))/(Total\ \ substrate\ (g))\ )\ X\ 100)/(Days\ of\ trial\ (day)] \quad [2]$$

$$\text{ECD(\%)} = \left(\frac{Final\ larval\ weight - Initial\ larval\ weight}{Ingested\ Feed\ or\ Residue}\right) X100 \quad [3]$$

Statistical Analysis

All data were analyzed by using IBM SPSS statistical software for Microsoft Windows (V. 27.0.0). The Shapiro-Wilk test was performed to test the normality of the data set and the result stated that the variable is not normally distributed. To compare the means between the parameters, the Kruskal Wallis test (H test) was performed. The correlation between the number of larvae and other parameters were determined using Spearman's correlation coefficient analysis.

RESULTS AND DISCUSSION

Larvae Growth and Development

The growth and development of Dipteran larvae can be influenced by their diet type. It is shown that BSFL fed with CF has a shorter development time than BSFL fed with GBP. CF recorded a consistent 12.00±0.000001 days LD, and the number of larvae did significantly affect the LD (P<0.05). In contrast, the LD for larvae fed with GBP took a longer time as the number of larvae increased, and the longest LD took 36.75±1.44 days for L3 (Table 1). This indicates that the number of larvae did not significantly affect the development time for GBP-fed larvae (P>0.05). It has been proven that an increasing number of larvae leads to a slower development time due to competition for food resources (Cammack & Tomberline 2017). Furthermore, it has been observed that the duration of larval development to the prepupal stage is extended when larvae are reared on diets lacking specific nutrients, particularly protein, which prolongs the overall cultivation period (Fairuz et al. 2023; Pliantiangtam et al. 2021). In terms of daily growth, larvae fed with CF resulted in LWI value that ranged from 1.33±0.38 g/d to 1.38±0.39 g/d which is higher than larvae fed with GBP whose value ranged between 0.68±0.09 g/d to 0.86±0.09 g/d. Thus, LWI is influenced by the diet composition provided to the larvae. When larvae are fed with low-protein and low-fat diet, such as GBP, the LWI tends to be lower. This

indicates that the larvae may experience reduced growth or development when their diet lacks sufficient protein and fat (Barragan-Fonseca et al. 2018). Conversely, BSFLs that are nourished with a high-protein and high-fat diet, such as CF, tend to exhibit an increased LWI. This implies that a sufficient fat and protein diet for the larvae will enhance their growth and development (M. Kieβling et al. 2023).

BSFL can convert different kinds of waste. An interesting response is observed when BSFLs are provided with a high-fiber diet such as GBP. When fed with GBP, a higher number of larvae resulted in a higher SR (L3 = 84.75±3.04 %). Therefore, the number of larvae did not have a significant (P>0.05) effect on the SR of larvae fed with GBP. Generally, CF-fed larvae exhibit a higher SR percentage compared to GBP. This indicates that survivorship of BSFL can be influenced by the feeding media texture and balanced nutrition (Kashif Ur Rehman et al. 2017). However, it is important to note that the recorded SR for both GPB and CF was due to some larvae that failed to survive during molting and a few that were stunted and eventually died during the experiment period.

Table 1. Larval growth and development for different numbers of larvae treatment fed with CF and GBP

Type of Diet	**Chicken Feed (CF)**			**Ground Banana Peels (GBP)**		
Number of Larvae	**L1 - 100**	**L2 - 200**	**L3 - 300**	**L1 - 100**	**L2 - 200**	**L3 - 300**
	(Mean±SE)	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**
LD (days)	12.00±0.00	12.00±0.00	12.00±0.00	21.25±0.75	32.00±2.12	36.75±1.44
LWI (g/d)	1.38±0.39	1.33±0.38	1.37±0.41	0.80±0.13	0.68±0.09	0.86±0.09
SR (%)	87.25±7.59	99.63±0.24	100.00±0.00	82.75±3.47	78.25±2.78	84.75±3.04

Efficiency of black soldier fly larvae as bioconversion agent

The BSFL can reduce waste by feeding into it. The WRI was used to assess the reduction rate when BSFL was reared on GBP and CF diets. The larvae fed with both CF and GBP in this study resulted significant WRI differences across the different numbers of larvae (CF: P<0.05 GBP: P<0.05). Based on the results, it is shown that CF is likely to be more digestible and nutrient-rich compared to GBP. CF, being a formulated feed, provides a more balanced and digestible nutrient profile, resulting in better waste reduction (Dabbou et al. 2018). In the case of GBP, it was reported that BSFL has difficulty converting fiber in GBP as it contains less digestible components, leading to slower waste reduction (Dabbou et al. 2018). However, it is proven that BSFL can convert the less digestible diet into frass (Agustiyani et al. 2021).

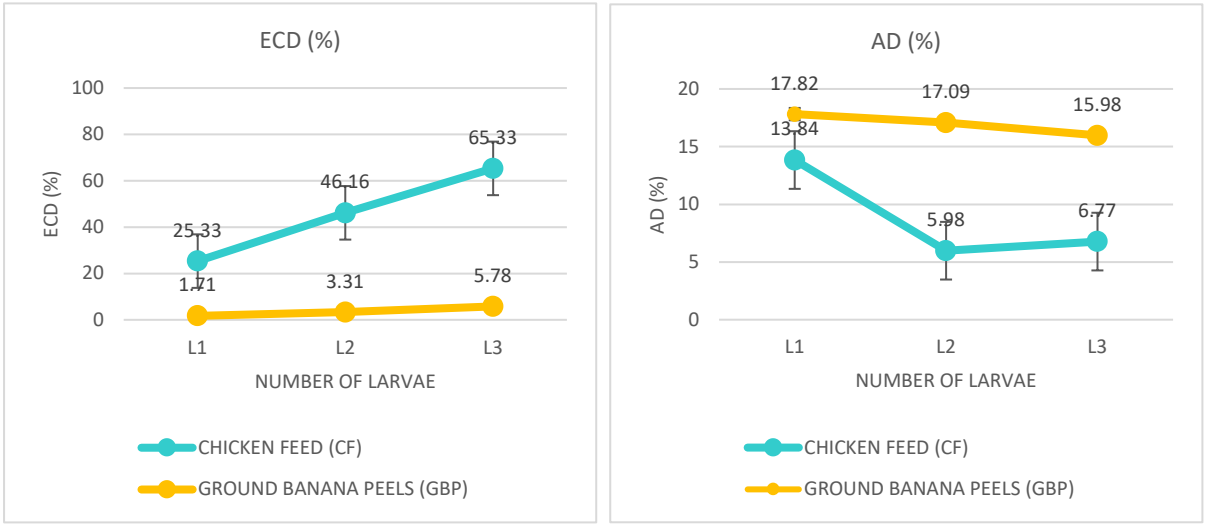
When feeding into the diet, BSFL can convert digested food into their body biomass. The ECD represents the percentage of digested food that is converted into larval biomass while AD shows the amount of feed assimilated in the larvae body. BSFLs are more efficient in converting CF, as the ECD values increase with an increasing number of larvae. The ECD values range from 25.33±2.07% to 65.33±4.98% in CF. A similar increasing trend was also observed in BSFL fed with GBP as the number of larvae increased (Table 2), although the ECD values were lower compared to CF-fed larvae. This is due to GBP being less nutritionally dense compared to CF. This means that GBP may lack certain nutrients or have lower nutrient availability, resulting in reduced conversion efficiency. That leads to a smaller proportion of the digested food from GBP being converted into larval biomass. In general, the number of

larvae has a highly significant strong positive relationship with ECD when fed with CF (R^2=0.946, P<0.001) and GBP (R^2=0.946, P<0.001). Moreover, the efficiency of converting GBP was significantly (P<0.05) affected by the number of larvae, as the ECD values increased when the number of larvae increased.

Table 2. Efficiency process of black soldier fly larvae as bioconversion agent

Type of Diet	**Chicken Feed (CF)**			**Ground Banana Peels (GBP)**		
Number of Larvae	**L1 - 100**	**L2 - 200**	**L3 - 300**	**L1 - 100**	**L2 - 200**	**L3 - 300**
	(Mean±SE)	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**	**(Mean±SE)**
AD (%)	13.84±0.84	5.98±0.10	6.77±0.10	17.82±1.44	17.09±0.12	15.93±0.22
WRI (%)	4.61±0.28	5.98±0.10	6.77±0.10	5.78±0.48	6.94±0.06	5.12±0.07
ECD (%)	25.33±2.07	46.16±0.97	65.33±4.98	1.71±0.06	3.31±0.08	5.71±0.62

Overall, the results presented in Figure 1 demonstrate a line graph that shows a trend between the values of ECD and AD for larvae fed with both CF and GBP diets. Specifically, as ECD values increased, the AD values decreased for both diet groups. This negative relationship between ECD and AD values is supported by the statistical analysis, with CF (R^2= -0.434, P>0.05) and GBP (R^2 = -0.503, P>0.05). Furthermore, GBP demonstrates a higher AD (Range 15.93±0.22% to 17.82±1.44%) compared to CF (Range 6.77±0.10% to 13.84±0.84%). The high AD value of GBP which compared AD value of CF indicates only a small amount of feed was assimilated into the BSFL body due to its high-fiber content.



(a) (b)

Figure 1. Efficiency conversion of digested food (ECD) (a) and approximate digestibility (AD) (b) based on the number of larvae

CONCLUSIONS

Black soldier fly larvae are a good potential bioconversion agent for GBP where the number of larvae influences the bioconversion efficiency of GBP. The results of this study indicate that BSFL can adapt to a high-fiber diet like GBP. The type of diet and the number of larvae have notable effects on the larval growth and development of the studied species. The CF diet promoted consistent larval growth and higher survival rates across all numbers of larvae, while GBP-fed larvae showed prolonged development and reduced weight gain. Although BSFL showed higher efficiency in converting CF compared to GBP, BSFL is proven to still be able to decrease GBP with low efficiency.

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AUTHORS DECLARATIONS

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Declarations

No ethical issue required for this research.

Data Availability Statement

My manuscript has no associated data.

Authors' Contributions

Evahtira Gunggot (EG) and Maria Lourdes T Lardizabal (MLTL) conceived the research, EG designed the experiments. EG and MLTL participated in the interpretation of the data. EG did the research and collected waste from the banana-fritters stalls. EG, performed the lab experiments and data analysis with MLTL supervision. EG and MLTL wrote the paper and participated in the revisions of it. All authors read and approved the final manuscript.

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