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*Research*

# Effect of Food Waste on The Growth Performance, Waste Reduction Efficiency and Nutritional Composition of Black Soldier Fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) Larvae

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**ABSTRACT**

The rate of solid waste generation, especially in Malaysia, has become one of the major concerns for environmental and public health issues. Food waste accounts for the highest percentage of solid waste that ends up in landfills. Due to the living nature of humans and their involvement in agricultural, industrial, and municipal activities, the disposal of food waste happens on a regular basis. Due to the absence of an incineration plant, these wastes are commonly sent into landfills which are considered to be the most cost-effective method for disposal. Nevertheless, consideration for an alternative disposal method such as composting shall not be ruled out entirely. One of the established methods for composting food waste is the utilization of the larvae of the Black Soldier Fly. A study was conducted to assess the growth and nutritional composition, waste reduction capacity and nutritional composition of Black Soldier Fly Larvae (BSFL) reared on food waste. We found that the larvae reared with the food waste and effective microorganism (EM), LFWEM (BSFL reared with a mixture of food waste and effective microorganisms), have a slightly better relative growth rate (2.66 ± 0.35 $day^{-1}$) compared to larvae reared with only food waste (2.44 ± 0.17 $day^{-1}$). The waste reduction index was higher in the LFWEM group (5.36 ± 0.18 g/day) compared to the control group, LFC (BSFL reared with chicken feed) (4.85 ± 0.03 g/day) and the LFW (BSFL reared with food waste) group (5.13 ± 0.17 g/day). The nutritional composition of the BSFL reared using food waste shows some potential as it surpasses some of the amount of essential amino acids including Arginine, Histidine, Threonine and Valine, found in the commercially available animal feeds. This finding serves as a baseline to propose potential replacements for animal protein by using BSFL reared with food waste.

**Key words:** Animal feeds, Black Soldier Fly, essential amino acid, growth, waste reduction

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## INTRODUCTION

Human involvement towards agricultural, industrial, and municipal activities lead to the disposal of food waste happens regularly in Malaysia. Due to the absence of an incineration plant, these wastes are commonly sent into landfills which are considered to be the most cost-effective method for disposal. The handling and treatment of food waste also undoubtedly present a significant issue for the authorities in Malaysia due to the poor separation at source from municipal solid waste. Like most countries, food waste in Malaysia dominates the composition of municipal solid waste by 40%–64%, with 8000 tonnes being produced every day based on the data from 2014, which also reflects a drastic increase as compared to the previous year (Lim *et al*., 2016). According to Lim *et al*. (2016), the reason for the rapid increment of food waste generation is due to shifts in eating habits, rapid population growth, and urbanization. Malaysia also lacks a specified disposal channel for food wastes, therefore, the separation at source is deemed to be impractical, thus, causing it more complicated for the implementation of composting method on a larger scale. Nevertheless, consideration for an alternative disposal method such as composting shall not be ruled out entirely, supposedly, the authority and policymakers should

come up with solutions to fix the current problems before approaching an alternative method that may possibly ease the burden and overcome the challenges currently faced.

One of the established methods for composting food waste is the utilization of the larvae of the Black Soldier Fly (*Hermetia illucens*).. The utilization of Black Soldier Fly (*Hermetia illucens*) larvae in the decomposition of food waste are one of the sustainable methods in the treatment of organic waste (Kim *et al*., 2021)as this species feeds on most organic materials without posing any public health or environmental impacts

Decomposition of organic waste utilizing detritivores such as *H. illucens* have been proven to be quicker than other types of waste treatments, plus, the residue produced can be converted into edible proteins for animal feeds (Schowalter, 2019). The proteins processed from this species are one of the authorized species that have been approved by the European Commission Regulation No. 2017/893 to serve as an alternative protein source for aquafeed. This method produces the most promising output compared to the other species authorized, making it one of the most sought-after methods to decompose organic wastes for researchers to increase their knowledge of this process (Meneguz *et al*., 2018).

## MATERIALS AND METHODS

### Materials

The study was conducted at the Insectarium Laboratory of UiTM Kampus Puncak Alam. Prior to the data collection, the environment, materials, and equipment for the study are planned and prepared according to the methodology adapted from Meneguz *et al*. (2018) with slight alterations due to availability concerns. The alterations made includes the type of rearing substrates, data collection period intervals, method for determining nutritional composition and proximate analysis methods.

### Rearing substrate

The study is conducted using three different groups of BSFL fed with different types of rearing substrates, known as LCF (BSFL reared with chicken feed) as the control group, LFW (BSFL reared with food waste) and LFWEM (BSFL reared with a mixture of food waste and effective microorganisms), with four replicates for each of the group. The food waste used in the LFW and LFWEM groups consists of the same food waste composition, which is obtained from one of the cafeterias in UiTM Kampus Puncak Alam. The initial waste collected weighed approximately 3 kilograms with approximately weighed over 421 grams of protein (14.03%). The food wastes consist of leftover rice, vegetables, chicken meat, fish meat, and bones, which are discarded by customers on the premise themselves. The food waste is then homogenized using a kitchen food blender to ensure a fair distribution of nutrients. For the LFWEM group, 1.5 kilograms of homogenized food waste are mixed with 75 mL of Effective Microorganisms (EM) which is approximately 5% of the weight of the food waste. For each of the replicates, 200 grams of rearing substrate are transferred into the plastic containers and labelled accordingly. The rearing substrates are then sprayed with water every day to ensure the moisture and hydration of the substrate are maintained throughout the study. Each of the replicates is also monitored daily to ensure the quantity of available feed is controlled. The rearing substrate will be added, if necessary, with the same amount for every replicate at the same time.

### BSF larvae

The BSF larvae used for this study were obtained from a private company (Entomal Biotech Sdn. Bhd.) Approximately 100 5-day-old BSF larvae (5-DOL) are assigned into 12 plastic containers for each of the replicates and rearing substrate groups. These replicates were then placed under controlled environmental conditions and protected from other variables such as the presence of houseflies (*Musca domestica),* which could affect the result of the study.

### Larvae growth and development

For the larvae development study, 20 larvae from each replicate are randomly selected and evaluated on their weight and length every 3 days until 30% of the larvae population reaches the prepupal stage. Prior to the measurement procedure, the larvae are individually cleaned and dried using a paper towel to remove any substrate from the larval body. The weights of larvae are measured using a digital micro scale which provides accurate weight readings up to 0.01 increments. The length of larvae is measured in millimetres (mm) using orthogonal photography and analysed using the ImageJ software package (v. 1.53k). Measurements using the ImageJ software are taken from the mouthpart to the last abdominal segment of the larvae. After both measurements are taken, the larvae will then be introduced back into their assigned substrates, as the measurement procedures will not alter the larvae's physical structure

and the processes are not destructive. The relative growth rates are also calculated to identify how quickly the larvae develop on different substrates. The calculation will be based on the equations below:

Relative Growth Rate (days$^{-1}$)

$$RGR = \frac{WI_f - WI_0}{t \times WI_0}$$

$WI_f$ = Final weight of larvae (g)
$WI_0$ = Initial weight of larvae (g)
t = Bioconversion time (day)

**Waste reduction efficiency**

The parameter for waste reduction efficiency for this study includes the calculation of Bioconversion Rate (BR), Substrate Reduction (SR), and Waste Reduction Index (WRI) based on the article by Meneguz *et al*. (2018) and (Rasdi *et al*., 2022). Bioconversion rate shows how effective the transformation from food waste to biomass is by the larvae, while substrate reduction shows how much of the substrate has been reduced by the larvae. The waste reduction index demonstrates the ability of the larvae to reduce the feeding substrates. All calculations are done at the end of the data collection period. The equation for the calculation of the parameters is as follows:

Bioconversion Rate (%)

$$BR = \frac{WI_f - WI_0}{W} \times 100$$

$WI_f$ = Final weight of larvae (g)
$WI_0$ = Initial weight of larvae (g)
W = total amount of rearing substrate distributed during the trial (g)

Substrate Reduction (%)

$$SR = \frac{W-R}{W} \times 100$$

W = total amount of rearing substrate distributed during the trial (g)
R = residue substrate (g)

Waste Reduction Index (g day$^{-1}$)

$$WRI = \frac{W-R}{W} \div \text{days of trial (d)} \times 100$$

W = total amount of rearing substrate distributed during the trial (g)
R = residue substrate (g)

**Larvae nutritional composition**

The larvae's nutritional composition is measured using laboratory analysis for amino acid profiling and proximate analysis procedures. The larvae from each replicate of LFW and LFWEM are prepared for analysis prior to being sent to the MyCO2 Laboratory located in Shah Alam. The larvae from both study groups are combined, dried, and cleaned to remove the substrate from their bodies before they are transferred into a separate plastic container. The sample is then sent to the laboratory to determine the amino acid content, crude fibre, crude fat, crude protein, moisture, ash content, and total carbohydrate.

For the amino acid profiling, methods from the Association of Official Agricultural Chemists (AOAC), namely AOAC 994.12 (Performic acid oxidation with acid hydrolysis-sodium metabisulfite method), and JAOAC, Vol 71, No 6, 1988 is conducted. The performic acid oxidation is conducted by adding performic acid in order to convert cystine and methionine to cysteic acid and methionine sulfone, respectively. Then, the performic acid is broken down by the addition of sodium metabisulfite. By using 6M of hydrochloric acid, the amino acids are released from the protein through the process of hydrolysis. The pH of the hydrolysates is brought down to 2.20 by using a sodium citrate buffer, or neutralization, and different

individual amino acid components are separated using ion-exchange chromatography. However, along the process of oxidation and hydrolysis, tyrosine is obliterated, and tryptophan is eliminated, therefore those amino acids are unable to be identified by using this method. For the proximate analysis, the method used is as presented in Table 1:

**Table 1.** Methods Used in the Proximate Analysis

| Proximate Analysis | | | |
|---|---|---|---|
| Analyte | Unit | Method Used | Test Description |
| Crude Fibre | %w/w | AOAC 978.10, 20th Ed (2016) | Determination of crude fibre in animal feed and pet food using the Weende method (Sequential acid and alkali extractions). |
| Crude Fat | %w/w | AOAC 920.39, 20th Ed (2016) | Determination of fat (crude) or ether extract in animal feed using gravimetric equipment. |
| Crude Protein | %w/w | AOAC 988.05, 20th Ed (2016) | Determination of crude protein in animal feed and pet food using the Kjeldahl / mixed catalyst technique. |
| Moisture | %w/w | AOAC 930.15, 20th Ed (2016) | Loss on drying (moisture) for feeds (at 135 °C for 2 hours) using gravimetric equipment. |
| Ash Content | %w/w | AOAC 942.05, 20th Ed (2016) | Determination of ash content of animal feed by placing it in a temperature-controlled furnace (at 600 °C for 2 hours) and weight immediately. |
| Total Carbohydrate | %w/w | MY/STP/378 based on US FDA 21 CFR101.9 Part 101 (2017) | Determination of total carbohydrate by calculation (subtraction from the sum of the crude protein, total fat, moisture, and ash from the total weight of the food). |

## Statistical analysis

The statistical analysis in this study was performed using IBM SPSS Statistics Version 28.0.0.0 (190). Due to the small sample size of larvae, determining the distribution of substrate variables is very important for deciding to choose the correct appropriate statistical method. Therefore, a Shapiro-Wilk test was performed to first test the normality of the data distribution. The results from the normality test for this study turn out to be not normally distributed, therefore, a one-way ANOVA will be conducted to compare the means between the groups (LFC, LFW, and LFWEM). Tukey post hoc test was only conducted if there is a significant difference found during the ANOVA test. A T-test for the bioconversion rate, reduction rate and waste reduction index of the LFW and LFWEM was also conducted to statistically compare the results with the control group (LFC).

## RESULTS AND DISCUSSION

### Larvae growth and development

The Figure 1 illustrates the development of BSFL weight that was measured every 3 days throughout the study for 15 days. As observed from the graph in Figure 1 all of the BSFL groups reared on different substrates have different growth curves, which can be differentiated by the number of days taken to reach each of their own maximum weights indicated in the graph as the dotted line.

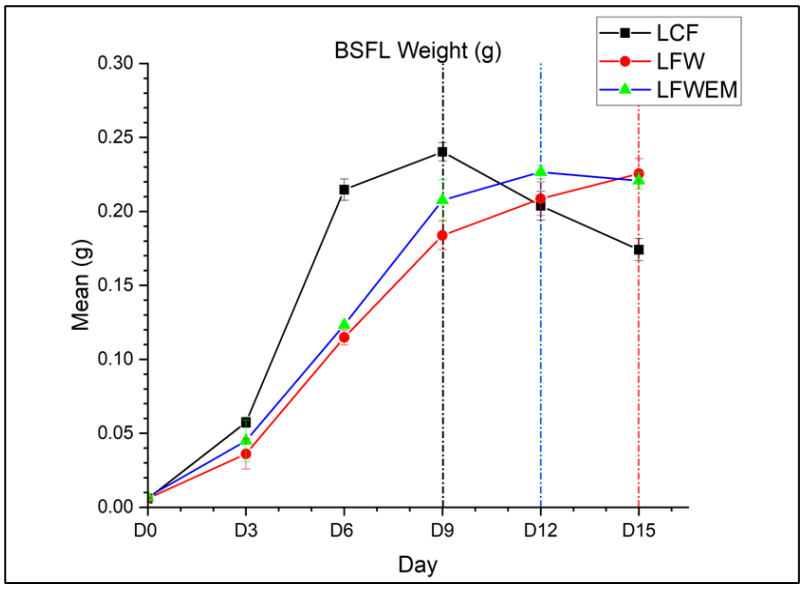


**Fig. 1.** The effect of different rearing substrates on the weight (g) development of BSFL (Error bar = standard deviation)

In the LCF groups, the larvae reared with chicken feed were observed to be the first to reach their

maximum weight, which is on D9 (0.24 ± 0.006g), followed by the LFWEM group on D12 (0.227 ± 0.005g) and the LFW group on D15 (0.225 ± 0.01g). For the weight development of BSFL, the data did not show evidence of non-normality for the LFC (W = 0.863, *p*-value =0.198), LFW (W = 0.897, *p*-value = 0.354) and LFWEM (W = 0.860, *p*-value = 0.190) when α = 0.05. Therefore, a parametric statistical analysis, the one-way ANOVA was conducted in order to compare the effect of rearing substrates on the weight of BSFL. The one-way ANOVA revealed that there was no statistically significant difference in weight between at least two groups (F (2,15) = [0.069], *p* = 0.934).

Similar to the BSFL weight, the length of larvae illustrated in Figure 2, also suggests that the LCF groups are among the first to reach their maximum length, which is on D9 (1.938 ± 0.424 cm), followed by the LFWEM on D12 (1.948 ± 0.142 cm) and the LFW group (1.96 ± 0.166 cm) on the same day. In both parameters, the development time of larvae length and weight difference in the time to reach their maximum length indicates different growth rates which can be further calculated using the relative growth rate, RGR equation as mentioned in Equation 1, in the methodology.

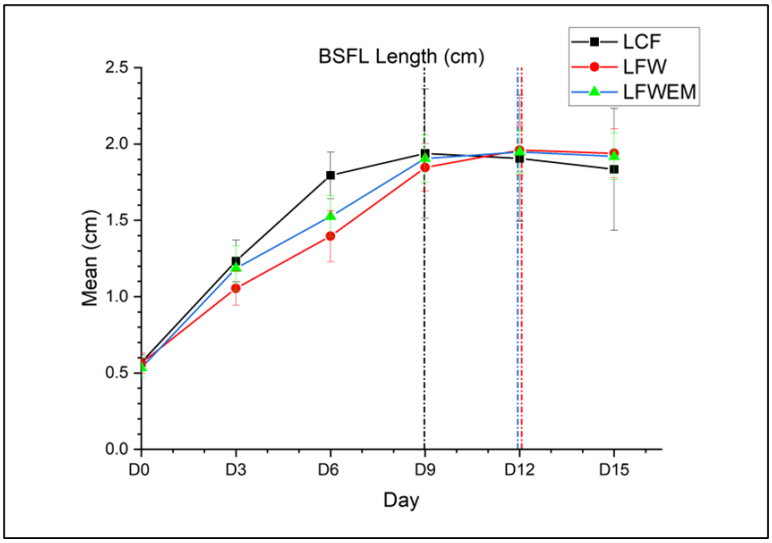


**Fig. 2.** The effect of different rearing substrates on the length (cm) development of BSFL (Error bar = standard deviation)

According to the specifications from the manufacturer of the chicken feed used for the LCF group in this study, the main ingredient for the chicken feed consists of corn, soybean meal, other grains and grain by-products, animal protein, vegetable oil, salt, and calcium carbonate. The specifications of crude protein, crude fibre and crude fat of the Gold Coin 201C (Broiler Starter) are 21.0%, 5.0%, and 4.5%, respectively. High amounts of crude protein may be the contributing factor that differentiates the growth rate of the LFC from other groups. Following the results for the larvae weight, there was also no statistically significant difference between group means as determined by one-way ANOVA for length (F (2,15) = [0.036], *p=0.965)*.

Table 2 shows the relative growth rate (RGR) of the black soldier fly larvae reared on 3 different substrates, including chicken feed (LCF), food waste (LFW), and food waste with effective microorganisms (LFWEM). All of the above larvae groups were reared for almost 15 days with the initial amount of 200g of substrates and 50g of additional substrate, which was added on day 7 of the experiment.

**Table 2.** Relative Growth Rate of BSFL reared on different substrates

| Group | Relative Growth Rate, RGR ($day^{-1}$) |
|---|---|
| LCF | 4.47 ± 0.39 |
| LFW | 2.44 ± 0.17 |
| LFWEM | 2.66 ± 0.35 |

As the table suggests, the highest relative growth rate observed was in the control group (LCF), which shows an estimated development rate of 4.47 ± 0.39 grams per day. This indicates that the larvae groups reared with chicken feed provide best conditions for the efficiency of larval growth compared to the study groups (LFW and LFWEM). The LFWEM group shows the second-highest RGR with 2.66 grams per day, while the LFW group shows the slowest growth rate of only 2.44 grams per day. This proves that the addition of EM into food waste as a rearing substrate affects the growth rate of BSFL positively.

Relative growth rate, RGR, is defined as the rate of the development of weight of larvae per day,

which shows how fast or slow the larvae grow in different substrates. Higher RGR also indicates a better rearing environment for larval development. The growth and development of BSFL are highly dependent on the environmental conditions in which it is reared. According to Salam *et al*. (2022), temperature, humidity, sunlight, moisture contents, and pH of substrates are some of several parameters that are vital in determining the growth and development rate of BSFL. For this study, parameters including temperature, humidity, and sunlight intensity were considered to be part of the constant variables because all of the replicates were reared in the same room and the same environmental settings. However, differences in moisture content and pH may be present, which might have been affecting the growth and development of the BSFL. Different substrates were used in this study for each of the rearing groups, which were chicken feed, food waste, and food waste with EM.

The moisture content of a rearing substrate can be loosely defined as the amount of water in the substrates (Neil, 2009). As recommended by Liu *et al*. (2021) in their study for the optimal moisture content for BSFL growth, it is suggested that the moisture content for rearing substrates is kept in the 65% to 90% range. Too high of moisture inside the rearing substrate may compromise the survival of BSFL and also the growth, due to the consideration of nutrient quantity in an equally weighted substrate. Substrates with higher moisture content consist of more water as compared to the actual nutrients needed by the BSFL, therefore, the growth and development of BSFL will be affected (Scala *et al*., 2020). Additionally, when the moisture content of the substrate is too low, microbial degradation seems to take precedence over larval growth in the context in which the competitive interplay might harm the well-being of the larvae, thus, affecting its growth rate (Bekker *et al*., 2021). On the other hand, as mentioned before, the pH of substrates also plays a vital role in determining the growth rate of BSFL. According to a previous study by Ma *et al*. (2018), the optimal pH of the rearing substrate for BSFL used in organic waste biotransformation must be in the range of 6.0 to 8.0, to ensure the survivability of larvae. The findings from this study can be applied to determine which of the three easily available resources is the best rearing substrate for BSFL in order to ensure a faster growth rate and reduce the time taken to prepare the BSFL for usage in waste decomposition process.

**Waste reduction efficiency**

Apart from the relative growth rate, other calculations were also made, including the bioconversion rate (BR), substrate reduction (SR), and waste reduction index (WRI). Calculations were made based on the equation mentioned previously, in order to measure the ability of larvae to reduce organic matter.

**Table 3.** Waste reduction efficiency of BSFL reared on different substrates

| Group | Bioconversion Rate, BR (%) | Substrate Reduction, SR (%) | Waste Reduction Index, WRI (g/day) |
|---|---|---|---|
| LCF | 1.35 ± 0.06 | 72.7 ± 0.01 | 4.85 ± 0.03 |
| LFW | 1.76 ± 0.08 | 77 ± 0.03 | 5.13 ± 0.17 |
| LFWEM | 1.71 ± 0.04 | 80.4 ± 0.03 | 5.36 ± 0.18 |

Based on the results obtained, the LFW and LFWEM groups show significantly higher bioconversion rates of 1.76% and 1.71%, respectively compared to the control group, LCF, which is only capable of converting 1.35% of the substrate into larval biomass. The BR when a comparison is made between the LCF (1.35 ± 0.06%) and LFW (1.76 ± 0.08%), shows a statistically significant difference where LFW shows a higher bioconversion rate compared to the control group, $t(6) = -8.582$, $p<0.001$. When a comparison is made between the LCF and LFWEM (1.71 ± 0.04%), the results are the same; where LFWEM shows a higher BR, $t(6) = -10.336$, $p<0.001$. Bioconversion rate, also known as biotransformation rate, is the measurement of how much of the organic materials in the substrates are converted by living organisms into usable products in this study, the substrates were translated into the amount of larval biomass produced (Peguero *et al*., 2022).

The SR and WRI for the study groups, LFW and LFWEM also indicate a significant difference in the ability to reduce the mass of the rearing substrates as compared to the LCF signalled by the difference in the substrate reduction and waste reduction index of the larvae. The LFWEM group indicates a promising result to reduce almost 10% more organic matter for the SR and a 9.5% better waste reduction index (WRI) compared to the LCF group. According to the statistical analysis conducted using an independent t-test, the LFW group (77 ± 0.03%), $t(6) = -3.269$, $p=0.017$ and LFWEM group (80.4 ± 0.03%), $t(6) = -5.621$, $p=0.001$ are statistically proven to have higher substrate reduction compared to the LCF (72.7 ± 0.01%) The differences of the SR and WRI between study groups and control group shows significant promising potential for the implementation of food waste composting by using the larvae of black soldier fly as they provide better and more efficient waste reduction.

As the result also suggests, the addition of effective microorganisms (EM) also helps to boost

the efficiency of waste reduction. In another study conducted by Ahmad *et al*. (2022), the addition of EM was proven to be significantly helpful in the composting of food waste by using BSFL in terms of accelerating the composting process as observed from the WRI result. WRI result signifies the mass of substrates being reduced per day, thus, higher WRI indicates a higher waste reduction rate. Through this study, the application of EM in the composting of food waste is once again proven to be the best method in order to reduce the time taken to compost food waste, therefore, also reducing the costs and batch holding time needed for composting. This study found that the larvae reared using food wastes (LFW) had statistically significant higher WRI (5.13 ± 0.17 g/day) compared to the LFC (4.85 ± 0.03 g/day), $t(6) = -3.317$, $p=0.016$. The larvae reared using food waste and EM also showed a statistically significant higher WRI (5.36 ± 0.18 g/day) compared to the LFC, $t(6) = -5.743$, $p=0.001$. Through a comparison made between the LFW and LFWEM, it was found that there is no significant difference between the means found in BR ($t(6) = 1.036$, $p=0.340$), SR ($t(6) = -1.823$, $p=0.118$) and WRI. ($t(6) = -1.857$, $p=0.113$).

**Larvae nutritional composition**

Table 4 shows the result of amino acid profiling for BSFL reared with combinations of food waste for 15 days. The results were obtained through the analysis using AOAC 994.12 method which is the performic acid oxidation with acid hydrolysis-sodium metabisulfite method to determine the amino acid content in animal feed. However, by using this method, certain amino acids were not able to be quantified tyrosine and tryptophan as these amino acids were destroyed along the process. The results (Serial No. RS3481250338957511) which were obtained from MyCO2 Laboratory, Shah Alam, show the amount of amino acid detected from the sample of BSFL reared with food waste.

**Table 4.** Amino acids profiling of BSFL reared on food waste

| Description | BSFL | Corn** | Broiler Finisher feed** | Broiler Starter Feed** |
|---|---|---|---|---|
| Unit | | | % w/w | |
| Arginine* | 5.96 | 0.40 | 1.28 | 1.57 |
| Aspartic Acid | 1.61 | 0.54 | 1.68 | 2.29 |
| Alanine | 1.03 | 0.61 | 1.17 | 1.28 |
| Glutamic Acid | 3.89 | 0.51 | 3.25 | 4.04 |
| Glycine | 1.96 | 0.33 | 1.27 | 1.27 |
| Histidine* | 0.79 | 0.27 | 0.50 | 0.65 |
| Isoleucine* | ND <0.01 | 0.28 | 0.76 | 0.95 |
| Leucine* | ND <0.01 | 0.99 | 1.66 | 1.97 |
| Lysine* | ND <0.01 | 0.26 | 1.07 | 1.35 |
| Methionine* | ND <0.01 | 0.18 | 0.53 | 0.62 |
| Phenylalanine* | ND <0.01 | 0.38 | 0.87 | 1.12 |
| Proline | 2.91 | 0.73 | 1.39 | 1.47 |
| Serine | ND <0.01 | 0.39 | 0.94 | 1.12 |
| Threonine* | 1.16 | 0.29 | 0.73 | 1.12 |
| Valine* | 1.96 | 0.38 | 0.92 | 1.11 |

* Essential amino acids (EAA) are required in animal feeds.
**Source: Interlaboratory studies of amino acid profiling by AOAC
ND = Not detected / below detection limit

For Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Serine and Tyrosine, the amounts were not able to be detected as they were found to be below 0.01%w/w. As for the other amino acid, a comparison of the amount of amino acid found in the sample with currently available animal feeds was done to decide on the suitability and the possibility of an alternative protein source in animal feeds.

As the results were compared to the interlaboratory studies from AOAC, it was found that the amount of amino acid in the BSFL reared using food waste surmount the % of amino acids found in corn except isoleucine, leucine, lysine, methionine, phenylalanine and serine which were below detection limit of 0.01% w/w in the BSFL. For arginine, the percentage found in BSFL (5.96%) from this study exceeds the amount found in all 3 of the comparison feed including corn (0.4%), broiler finisher feed (1.28%) and starter feed (1.57%). Arginine (Arg) is one of the functional essential amino acids (EAA) that are necessary for animal feed as it is required to support protein synthesis, animal growth and its biological functions. Apart from that, it also plays an important role in supporting the urea cycle regulation, hepatic detoxification and increase of insulin-like growth factor 1 (IGF-1) (Si *et al*., 2021). IGF-1 is a type of hormone which plays a role in physiological of animals and humans in the context of growth regulation, development, metabolism and lactation in cattle (Mullen *et al*., 2011). For poultry animals, arginine is also one of the significant amino acids in the diet which helps egg-laying hens to

produce larger size eggs as they are not able to synthesize arginine on their own, due to the lack of urea cycle (Kemin Industries, 2019). Another example of EAA that is required in animal feed is histidine. For poultry animals including chicken, histidine is important in increasing the concentration of carnosine and anserine, which provides a significant anti-oxidative activity in the breast muscle of the chicken. Histidine is also significant for other animals including fish, in which the intake of dietary histidine was proven to have a positive impact on muscle growth, due to higher myogenin expression. In ruminants, histidine is not only considered to be the first amino acid limiting factor for growth in growing ruminants but also the supplementation causes an increase in milk production and milk protein synthesis in ruminants (Moro *et al*., 2020). The amount of histidine found in BSFL (0.79%) reared using food wastes is higher than the one found in corn (0.27%), broiler starter (0.65%) and finisher feed (0.5%), thus, further supporting the idea for an alternative of protein source in animal feeds.

Threonine, on the other hand, plays a critical function in modulating intestinal homeostasis, macromolecular biosynthesis and nutritional metabolism in pigs and poultry. As one of the EAAs for animals, threonine functions as a nutritional modulator that affects the intestinal immune system through intricate signalling networks, including the mitogen-activated protein kinase and target of rapamycin signal pathways. Apart from that, threonine is also acknowledged as an essential ingredient for cell development and proliferation (Tang *et al*., 2021). In this study, the amount of threonine found in BSFL (1.16%) also overcomes the percentage found in all the other animal feeds, which proves that BSFL can provide a better nutritional supplement for animals as animal feed.

The high percentage of valine found in BSFL in this study also supports the usability and efficiency of BSFL as an alternative to other animal feeds. The amount of valine found in BSFL is 1.96%, meanwhile, for corn, broiler finisher feed and starter feed, the mean percentage of valine found was only 0.38%, 0.92% and 1.11% respectively. Valine is considered to be an important component of all significant proteins and is required for protein production in animals. The infrequent use of additional protein building blocks in animals is typically hampered by the low valine percentage of plant-based basic feed sources.

**Table 5.** Proximate Analysis of BSFL reared on food wastes

| Description | BSFL | BSFL | Soybean Meal [a] | Corn Gluten Feed [b] | Poultry Meal [c] |
|---|---|---|---|---|---|
| Unit | % w/w | | | % DM | |
| Crude Fibre | 3.8 | 9.8 | 4.3 | 8.3 | - |
| Crude Fat | 8.3 | 21.4 | 0.55 | 3.4 | 27.9 |
| Crude Protein | 13.5 | 34.8 | 43.8 | 21.7 | 60.2 |
| Moisture (Dry Matter) | 61.2 (38.8) | - | - | - | - |
| Ash Content | 2.2 | 5.7 | 5.6 | 6.9 | 10.6 |
| Total Carbohydrate | 14.8 | 38.1 | 31.85 | - | - |

[a] Source: Banaszkiewicz (2011)
[b] Source: Feedipedia (2015)
[c] Source: Feedipedia (2015)

Results from the proximate analysis of the BSFL larvae are used to determine the major constituents and quantity of macromolecules in animal feed. Through different method combinations, the determination of crude fibre, fat, protein, ash, and total carbohydrates is made possible with proximate analysis. As observed in Table 4.3.2, the amount of crude fibre found in BSFL (9.8% DM) as calculated in % DM, surpasses the amount found in both soybean meal (4.3% DM) and corn gluten feed (8.3% DM). The amount of feed that is inedible or which bacteria in the rumen ferment is estimated by the amount of crude fibre. It is made up of a variety of insoluble carbohydrates that are linked to plant cell walls and immune to the activity of digestive enzymes. The structural elements of plant cells, such as cellulose, hemicellulose, lignin and pectin, make up crude fibre. It is considered to be one of the important aspects of the digestive system as it is needed to maintain gut health, especially in poultry (Cherian & Berndt, 2002).

Also, for the crude fat composition of the BSFL reared with food waste (21.4% DM), the percentage was observed to be higher compared to the amount found in both soybean meal (0.55% DM) and corn gluten feed (3.4% DM). However, if a comparison were to be made with the poultry meal, the BSFL did not surmount the percentage of crude fat. Crude fat is sometimes referred to as ether extract, which may include lipids, fatty acid esters, and fat-soluble vitamins. The main function of crude fat in animal feed is to separate the feedstock component with the highest caloric value. Crude fat is added to animal feed also to lessen grain dust and bind the feed's fine particles, thus, making it more palatable (Cetingul & Yardimci, 2008).

Crude protein is also calculated as the amount of nitrogen multiplied by 6.25 which is the average grams of protein that contains 1 gram of nitrogen. Since proteins cannot be substituted by any other dietary component, determining the crude protein content in the feed is one of the most crucial studies. The amount of crude protein greatly affects the growth of animals like chickens, cattle, dairy cows, or pigs. Therefore, it is very important to provide the animals, with better quality feed with a higher amount of crude protein. In this study, the BSFL shows a slightly better crude protein percentage compared to the corn gluten feed.

According to Heinze (2022), the ash content in animal feed refers to the number of minerals which includes calcium, phosphorus, iron, copper, zinc, etc. Due to the nature of minerals which are not easily combustible, ash is produced as what's left after samples are put into a furnace where all organic materials including fat, protein, and fibre have completely burned. The normal ash content in animal feed usually falls within the range of 5-8%. The result from the proximate analysis of this study shows that the ash content of BSFL was slightly higher compared to the soybean meal but lower than the corn gluten feed and poultry meal. However, the percentage found in BSFL still falls in the range of normal ash content in animal feed, therefore, there is no worry regarding the sufficiency of this specification.

## CONCLUSION

A study on the Effect of Food Waste on the Growth Performance, Waste Reduction Efficiency, and Nutritional Composition of Black Soldier Fly (*H. illucens*) Larvae was conducted to assess the growth and nutritional composition of Black Soldier Fly Larvae (BSFL) reared on food waste with the comparison to larvae reared on chicken feed. In conclusion, the findings from this study collectively accept all the hypotheses that were made before the actual experiment with the exception of the larvae growth and development. The rate of larval growth which was determined using the weight and length development over time shows that the LCF group has a higher growth rate compared to the group reared using food waste including both LFW and LFWEM. However, the LFWEM groups were observed to have a higher RGR compared to the LFW groups. This indicates that with the supplement of EM in food waste, the rate of growth and development of larvae will be faster. For waste reduction efficiency, both LFW and LFWEM show greater performance in terms of BR, SR, and WRI compared to the LCF group. However, there was no significant difference when the two groups were compared to each other. For the nutritional composition, which considers the percentage of EAA, and macromolecules found, the BSFL reared using food waste shows a slightly better amount compared to commercially available animal feeds which indicates that the idea for an alternative animal feed can be considered.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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