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Food Waste Management Utilizing Black Soldier Fly Larvae

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Abstract

Food waste is a growing concern in developing countries. This study aims to implement food waste bioconversion by utilizing black solider fly larvae for two eateries' food waste. The bioconversion process used 0.5 g of black solider fly eggs for 14 days in the six bio ponds. After 14 days, the waste, larvae, and compost are separated using sieves to measure the larvae and compost production. The bioconversion process is evaluated based on bioconversion characteristics and black soldier fly larvae and compost produced. Waste Reduction Index, Fresh Matter Consumption Rate, Dry Matter Consumption Rate, Dry Matter Rate, and Efficiency of Conversion of Digested Feed evaluated the bioconversion characteristics for reduction. According to the experimental results, utilizing BSFL is adequate for food waste management, effectively reducing up to 62.6%. Simultaneously, the fresh larvae and compost are produced within a 14-day bioconversion process. The compost meets standards for the nitrogen, C/N ratio, phosphorus, potassium, zinc, and iron content (SNI 19-7030-2004).

Keywords: bioconversion, bioconversion characteristics, black soldier fly, compost, food waste

1. Introduction

The challenge of food waste is anticipated to escalate with the ongoing growth of the global population. There exists a distinct contrast in the proportion of food waste generated between developing and developed nations, with developing countries showing a higher share [1]. In developing nations such as Indonesia, food waste is the primary source of solid waste generation, with restaurants or eateries significantly contributing to this issue. According to the Environment and Forestry Ministry of Indonesia, food waste generation in 2021 accounted for approximately approximately 39.6% of the total of solid waste generated within the country and escalating to 40.5% in 2022 of the total solid waste generation. In other developing countries, such as in sub-Saharan Africa, food waste has a percentage of 40% that originates from households and retailers [2]. India, particularly in the Solan District, has the rate of food waste generation ranges from 49.41% to 52.12% [3]. Food waste composition in developed countries, such as Trentino, Italy, witness 20% of their municipal solid waste attributed to food waste municipal solid waste [4]. These percentage values of food waste generation portray and compare the extent of food waste in developing countries is generated more than in developed countries.

The generation of food waste, particularly in the restaurant or eateries sector, is influenced by various factors such as consumer habits, food preferences that do not align with individual tastes, food allergy issues, inadequate packaging, social factors, and economic circumstances [5]. Unfortunately, a prevalent practice in many restaurants involves disposing of food waste alongside household waste, market refuse, and other public facilities without proper segregation. Most food waste in Indonesia is co-mingled with inorganic waste and transported to final disposal sites which is often through open dumping practices, exacerbating environmental concerns [6-8].

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Improper waste management practices, such as characterized by the absence of waste segregation and reliance on open dumping, have adverse environmental repercussions. Unregulated food waste significantly impacts on the environment, leading to issues such as water and soil pollution, deforestation, erosion, and emissions during the waste management production process [9]. The environmental repercussions of open dumping systems primarily stem due to the potential contamination of the soil and groundwater. This system poses a substantial risk to soil integrity, as the waste directly exposed to the soil, resulting in the accumulation of contaminants, including heavy metals, which in turn contaminate the soil and groundwater [10]. The open dumping system also creates an odor that contributes to various health issues, such as respiratory problems, irritation of the nose and eyes, and other related illnesses due to the unpleasant odor [11,12]. In addition, an open dumping system is increasingly often recognized as an environmental concern, creating an unhealthy environment that promotes the proliferation of pests, including flies, and rodents, which serve as vectors for transmitting diseases to humans [13].

The organic fraction of waste generated by restaurants or eateries, specifically food waste, holds the potential for financial benefits when managed appropriately. However, inadequate processing of such wastes can pose environmental risks. Therefore, it is imperative to ensure the proper management of food waste through the adoption of sustainable waste management technologies. The utilization of black soldier fly larvae (BSFL) for bioconversion has emerged as a financially viable method for food waste management due to its potential to reduce waste by up to 54.5% and generate compost with high nutritional value [14-15]. Leveraging black soldier fly larvae as a bioconversion agent to reduce food waste is an represents an efficient, straightforward, and highly effective approach. The development of bioconversion utilizing black soldier fly larvae (BSFL) can be achieved with relative ease by employing cost-effective facilities and minimizing financial expenditures [16].

The incorporation of black soldier fly larvae (BSFL) into food waste management is pivotal for establishing a sustainable waste system. Therefore, this study aims to execute the bioconversion of food waste by employing black soldier fly larvae (BSFL) for two specific sources of food waste (FW#1 and FW#2) within the Dramaga area of Bogor, Indonesia. Furthermore, the research seeks to assess the bioconversion process by analyzing the bioconversion characteristics and the volume of black soldier fly larvae and compost produced. The utilization of black soldier fly larvae (BSFL) for processing restaurant-generated food waste presents numerous ecological advantages for sustainable waste management. This approach obviates the need for transporting waste to final dump sites, as it eliminates the requirement for an open dumping system.

2. Materials and Methods

2.1. *Materials*

The materials used for the bioconversion process in this study are food waste sourced from two eateries near IPB University in Dramaga, Bogor, Indonesia (FW#1 and FW#2), 0.5 g of BSF eggs, and bio-ponds or bioconversion container boxes (Green Leaf, manufactured in Indonesia) with the dimension 48 cm × 31 cm × 18 cm. The tools used to determine the FW#1 and FW#2 moisture content are porcelain cups (50 mL capacity) and an oven (Memmert UNB200, manufactured in Germany) with a capacity of up to 220°C. The tools used to determine the larvae and compost produced from 14-day bioconversion are digital balance (with an accuracy of 0.1 g) and sieves (mesh size2, 4, and 20).

2.2. *Food Waste Moisture Content Test*

The moisture content of food waste is computed using Eq. (1), employing the gravimetric method. Five-gram samples from FW#1 and FW#2 undergo oven-drying at 105°C for 24 hours, representing the food waste sample. This moisture content testing is cross-referenced with a prior study to ascertain the dry mass of the food waste, especially those with elevated water content [12]. This objective of this test is to determine the optimal water content for feeding larvae. Eq. (1) is once again employed to calculate the moisture content of the food waste.

$$\text{Moisture content} = (a-b)/a \times 100\% \qquad (1)$$

Where a is the initial mass of food waste and b is the final mass of food waste after oven-drying.

2.3. Food Waste Bioconversion

For the entire experiment, six bio-ponds (three repetitions for each FW#1 and FW#2) are utilized for the bioconversion process, with 0.5 grams of BSF added to each bio-pond. The bioconversion process incorporates 3.4 kilograms of food waste per bio-pond from each restaurant for 14 days. On day 0, BSF eggs (0.5 g of BSF eggs) are laid on the waste media in bioconversion container boxes (Bio-pond).

Following 14 days of bioconversion, the waste and larvae undergo separation using mesh 2-sieve, 4-sieve, and 20-sieve. Substantial amounts of residual waste are retained in the mesh 2-sieve, while the larvae are collected in the mesh 4-sieve, and the compost passes through the mesh 4-sieve. The larvae produced are dried using sand roasting at 100-180°C for 15 minutes [16], and the dried larvae are used to test their nutritional value and protein and lipid content. The quality of the compost produced is also tested. This bioconversion process is referenced from a previous study [17]. Figure 1 provides a visual representation of the experiment conducted in this study.

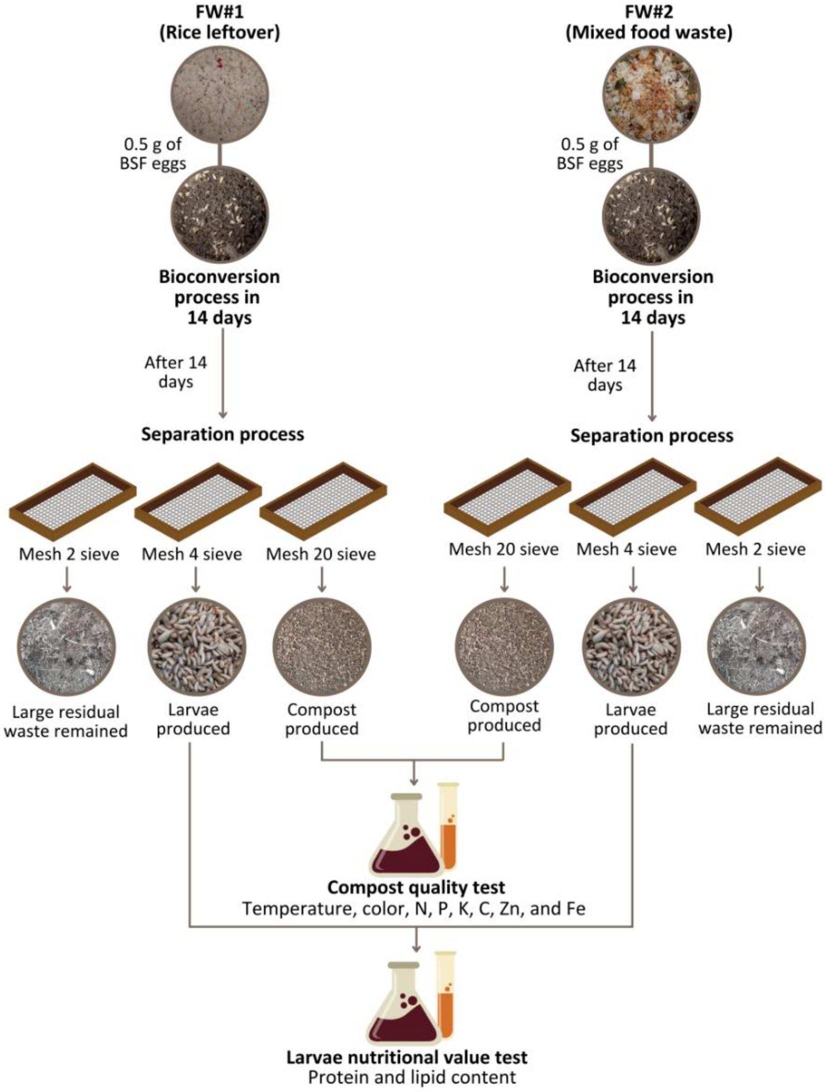

Fig. 1 Procedures for bioconversion process

The bioconversion characteristics are used to evaluate the efficiency of the bioconversion process. The efficiency of the bioconversion process is assessed through various bioconversion characteristics, namely Reduction, Waste Reduction Index (WRI), Fresh Matter Consumption Rate (FMCR), Dry Matter Consumption Rate (DMCR), Dry Matter Reduction (DMR), and Digested Feed Conversion Efficiency (ECD). These characteristics serve as key indicators in evaluating the effectiveness of the bioconversion. The remaining waste from the separation process is used for calculating the reduction rate. Subsequently, the Waste Reduction Index (WRI) is determined based on the previously calculated reduction rate. Diener [17] defined the reduction and waste reduction index by BSF larvae using Eq. s (2) and (3).

$$D=(W-R)/W\times 100\% \tag{2}$$

Where D is the waste reduction rate, W is the initial waste mass, and R is the remaining waste mass after the 14-day bioconversion process.

$$WRI=D/t \tag{3}$$

Where WRI is the waste reduction index and t is the bioconversion period.

In this study, various bioconversion characteristics were evaluated, including the fresh matter which represents organic waste in terms of wet weight, and the dry matter consumption rate (DMCR), representing the daily consumption rate of organic waste in terms of dry weight. Additionally, the dry matter reduction (DMR) and the efficiency conversion coefficient (ECD) were assessed to quantify the effectiveness of conversion by BSF larvae [18-19]. Eq. s (4) through (7) define FMCR, DMR, DMCR, and ECD.

$$FMCR=(c/d)/e \tag{4}$$

Where $FMCR$ is the fresh matter consumption rate, c is the organic waste added, d is the time range addition, and e is the number of larvae.

The fresh matter consumption rate (FMCR) is defined as the rate at which organic waste is consumed, denoted by 'c' for the amount of organic waste added, 'd' for the time range of addition, and 'e' for the number of larvae. The determination of the number of larvae in each bio-pond involves dividing the total weight of larvae produced in the bio-pond (measured in milligrams) by the average weight per larva in that bio-pond (measured in milligrams per larva). The average weight per larva (mg/larva) is determined by collecting 100 samples of larvae from each bio-pond. These samples are weighed individually using a digital balance. Subsequently, the weights of the individual larvae are averaged to derive the average weight per larva.

$$DMR=(j-k)/j\times 100\% \tag{5}$$

$$DMCR=(FMCR\times DMR)/100 \tag{6}$$

Where DMR is the dry matter reduction, j is the initial organic dry mass, and K is the final organic waste dry mass. The FMCR and DMR are used for calculating DMCR.

$$ECD=B/(I-F)\times 100\% \tag{7}$$

Where ECD is the efficiency consumption of digested feed, B is the organic waste added, I is the time range addition, and F is

The bioconversion process yields larvae biomass and a 14-day-old compost. On the fourteenth day, the waste, larvae, and compost, filtered through mesh sizes 2, 4, and 20, undergo separation. Subsequently, the remaining waste, Black Soldier Fly (BSF) larvae, and the resultant compost are weighed on a scale to ascertain the byproducts of the 14-day bioconversion process.

2.4. *Larvae Nutritional Value Test*

The nutritional values of the larvae, which are tested, include the protein and lipid content produced over 14 days. The larvae samples tested for nutritional value are dried at 300 g for Duplo sample testing. Protein content is determined using the Kjeldahl method, while lipid content is assessed using the Weibull method. Protein and lipid content measurements are obtained from Saraswanti Indo Genetech Laboratory, Bogor, Indonesia.

2.5. *Compost Quality Test*

The compost mixture of FW#1 and FW#2 produced after 14 days of bioconversion is assessed at the Indonesian Center for Biodiversity and Biotechnology Laboratory to determine its quality. The number of samples tested is 300 g. Temperature and color are among the observed physical parameters. The macroelements and microelements in the compost are evaluated to determine their quality as chemical parameters. The macroelements assessed for compost quality are carbon (C), nitrogen (N), phosphorus (P), and potassium (K), while the microelements include zinc (Zn) and iron (Fe). A thermometer is used to measure temperature. Color measurements are performed using a Munsell color chart. The carbon content is tested using the gravimetric method. Kjedal and titrimetric tested the nitrogen content, and the Spectrophotometric UV-Vis method tested the phosphorous content. Then, the potassium, zinc, and iron contents are determined by Atomic Absorption Spectroscopy

2.6. *Data Analysis*

Statistical analysis is performed using the IBM SPSS Statistics 25 software to analyze the correlation between the two parameters. Data analysis showed the relationship between the type of food waste with the bioconversion characteristics results and the larvae's nutritional value—correlation analysis using Spearman's Rank Correlation. Spearman's Rank Correlation Coefficient is a hypothesis test to determine the relationship between 2 variables. Spearman's Rank Correlation Test is a statistical test to test two variables with ordinal data, or one variable has ordinal data, and the other is nominal or ratio.

3. Result and Discussion

3.1. *Food Waste Characteristics*

Each eatery's food presents unique characteristics. The food waste characteristics from FW#1, illustrated in Fig. 2(a), are primarily consist of leftover rice. The food waste substrate could contain uncharacterized kitchen, fruit, and vegetable wastes [20–22]. The characteristics of waste from FW#2, illustrated in Fig. 2(b), are comprise mixed food waste, encompassing leftover rice, vegetables, noodles, and meat.

(a) FW#1 sample (b) FW#2 sample

Fig. 2 Food waste characteristics

The moisture content of food waste sample FW#1 is recorded as 60%, whereas for sample FW#2, it measures at 67%. The initial moisture content percentage observed in this study is conducive to the optimal growth of BSF larvae. According to a previous study, the most favorable moisture content for black soldier fly (BSF) larvae feed ranges between 60% and 80% [16]. The disparity in moisture content between the two sources can be attributed to the type of waste generated. The food moisture content of FW#2 is surpasses than that of FW#1 due to a higher amount of liquid waste, specifically vegetable waste. The moisture content is also tested on the fourteenth day to determine the last moisture content to value the maturity level of the compost produced on that particular day. On the fourteenth day, the moisture content of compost from FW#1 is 34%, while the moisture content of compost from FW#2 is 47%, respectively. In accordance with Reference [23], which sets the standard for compost quality, the compost moisture content is below 50%.

3.2. Food Waste Bioconversion Characteristics

The food waste bioconversion performance utilizing black soldier fly is evaluated based on the bioconversion characteristics that are identified by several parameters. Table 1 illustrates these bioconversion characteristics, which are percent reduction, waste reduction index (WRI), fresh matter consumption rate (FMCR), dry matter consumption rate (DMCR), dry matter reduction (DMR), and efficiency of conversion of digested feed (ECD). This identification is carried out on each food waste (FW#1 and FW#2) observed for 14 days.

As per Table 1, the percent reduction on a wet matter basis of FW#1 is 62.6%, and FW#2 is 62.0%, while the percent reduction in the dry matter basis is 61.8% for FW#1 and 61.4% for FW#2. The waste reduction per day (WRI) of FW#1 is 4.5%/day, while FW#2 is 4.4%/day. Based on the dry matter basis, the WRI value of FW#1 and FW#2 is in the same value of 4.4%/day. The difference between the reduction and the WRI considering the moisture content due to the evaporation. Additionally, the fresh matter consumption rate (FMCR) value showed the larvae consumption rate in consuming fresh waste at a particular time, where the FMCR value of food waste from FW#1 is 25.1 mg/larvae/day and at FW#2 is 19.8 mg/larvae/day. The type of waste influenced the fresh consumption rate significantly ($p=0.021 < 0.05$, $R= 0.878$). The waste from FW#1 is rice waste, which is more tender than FW#2, which contained meat and bone waste. The highest percentage of dry matter reduction (DMR) is from FW#2, with a value of 65.7%, and the DMR value of FW#1 is 61.3%. The DMR value represents how effectively the degraded substrate is converted into larvae biomass [24].

Table 1 Bioconversion performance based on bioconversion characteristics parameters value

Food Waste Characteristics	Experimental Diets	
	FW#1	FW#2
Food Waste Reduction in the wet matter basis (%)	62.6 ± 3.1	62.0 ± 2.6
Waste Reduction Index in the wet matter basis (%/day)	4.5 ± 0.2	4.4 ± 0.2
Food Waste Reduction in the dry matter basis (%)	61.8 ± 5.1	61.4 ± 4.7
Waste Reduction Index in the dry matter basis (%/day)	4.4 ± 0.4	4.4 ± 0.3
Fresh Matter Consumption Rate (mg/larvae/day)	25.1 ± 2.1	19.8 ± 2.9
Dry Matter Consumption Rate (mg/larvae/day)	15.5 ± 3.0	13.1 ± 3.2
Dry Matter Reduction (%)	61.3 ± 7.2	65.7 ± 8.8
Efficiency of Conversion of Digested Feed (%)	38.5 ± 3.1	47.7 ± 8.5

The dry matter consumption rate (DMCR) value represents the larvae consumption rate in consuming dry waste at a particular time. The DMCR value of FW#1 is 15.5 mg/larvae/day, while FW#2 is 13.1 mg/larvae/day. The DMCR value is lower than FMCR because the FMCR calculation uses fresh waste that still contains water, whereas the DMCR calculation uses the form of dry waste. Finally, the ECD value of FW#1 is 38.5%, and FW#2 is 47.7%. The ECD value indicates that the efficiency of waste consumption by larvae is higher in FW#2. Other studies [14,25] showed that food waste is reduced by 54.5%, and the WRI of mixed food waste is 2.8%/day and 4.3%/day using 200 larvae. Therefore, utilizing 0.5 g of BSF eggs for food waste management is more effective because have higher bioconversion characteristics value.

3.3. *Black Soldier Fly Larvae Produced*

The total fresh larvae mass is determined by measuring the harvested larvae from 0.5 g rearing on the 14th day that is retained on the mesh. The average results of fresh larvae harvested on the 14th day from 0.5 g of BSF eggs presented in Table 2 that shows the fresh larvae produced from FW#1 diet are 629.8 g, while FW#2 had 794.1 g. This result indicates that FW#2 had a higher larvae biomass than FW#1. There is a very significant correlation between the type of food waste and the fresh larvae mass ($p = 0.021 < 0.05$, $R = 0.878$). This outcome suggests that food waste influences the larvae mass produced. Diverse waste diets contain more nutrients to produce many larvae biomass [26]. As a result, the larvae biomass produced by FW#2 is greater than FW#1 because FW#2 contained leftover rice, vegetables, and side dishes, indicating a more varied waste diet than FW#1, which consisted of leftover rice. The nutritional content of BSF Larvae in Table 2 is analyzed by testing samples in duplicate.

Table 2 Fresh larvae produced from the bioconversion process

Experimental Diets	Average Fresh Larvae Mass (g)	The Nutritional Content of BSF Larvae	
		Protein (%)	Lipid (%)
FW#1	629.8 ± 21.2	32.5 ± 3.4	29.6 ± 2.0
FW#2	794.1 ± 112.0	36.4 ± 2.0	29.3 ± 0.6

The protein content of larvae given FW#1 is 32.5%, while that of FW#2 is 36.4%. The protein content of larvae supplied with FW#2 had a higher value than larvae given FW#1. The waste characteristics from FW#2 contained a mixture of vegetable and meat waste, which are protein sources. The lipid content of the larvae given the waste supply from FW#1 is 29.6% and 29.3% from FW#2. Another study showed that larvae fed food waste from the canteen, consisting of a mixture of vegetables, rice, and meat, have a high protein content of 36.1%, higher than the larvae that are only given the supply of vegetable waste, only 24.5% [27]. In addition, 14-day-old larvae are supplied with food waste in the form of leftover chicken meat, which has a protein content of 39.2% and a lipid content of 28.4% [28]. From this study, there is no significant correlation between the type of food waste, the protein ($p = 0.135 > 0.05$), and the lipid content of larvae ($p = 0.573 > 0.05$). Protein and lipid content of black soldier fly larvae depending on waste characteristics, feed rate, larvae age, and maintenance room air conditions.

3.4. *Compost Quality*

Waste bioconversion using BSF larvae produces nutrient-rich compost, offering environmental benefits. The utilization of BSF for bioconversion results in compost that mitigates the risk of spreading harmful substances, such as pesticides, in the environment, and serves as an economically valuable product for agricultural purposes [29]. In this study, the produced residue comprises large residue (dried rice and bones) and fine residue. The fine residue undergoes testing to evaluate the compost quality. The compost generated through a 14-day bioconversion process indicates that the compost derived from FW#1 weighed an average of 329.8 g, with the average value of large residue remaining at 109 g.

Table 3 Compost quality from the bioconversion process

Parameters	SNI 19-7030-2004 Standard	Value
Temperature (°C)	Groundwater temperature	27
Color	Blackish	Brownish
Nitrogen (%)	>0.4	2.96
Carbon (%)	9.8-32	49.59
C/N Ratio	10-20	17
Phosphorus (%)	>0.1	1.94
Potassium (%)	>0.2	0.95
Zink (mg/Kg)	<500	42.01
Iron (%)	<2	0.04

In contrast, the compost produced from FW#2 exhibited an average weight of 270.5 g, with the average residue value remaining at 214.3 g. The compost analyzed in this study is a blend of compost from FW#1 and FW#2, reflecting the outcomes of food waste bioconversion from diverse food sources. The physical parameter results of the compost, including temperature, are 27°C, and the color is brown. Furthermore, the compost's chemical composition reveals a carbon content of 49.59%, nitrogen at 2.96%, a C/N ratio of 17%, phosphorus at 1.94%, potassium at 0.95%, zinc at 42.01%, and iron at 0.05%. Table 3 illustrates the nutritional value of the compost based on the laboratory analysis results.

According to Table 3, the compost temperature conditions, as per SNI 19-7030-2004 standards, are below the recommended groundwater temperature, although the recorded 27°C adheres to the specified standards. The established standard [23] determined that optimal compost color is blackish, while the observed color of the bioconversion compost is brown. In addition, the prescribed range for carbon content, according to SNI 19-7030-2004, is 9.8-32%, while the bioconversion compost registers a higher carbon content of 49.59%. The elevated carbon content and brownish hue indicate that the compost is in an immature state, signifying incomplete degradation of numerous organic components and consequently extending the compost's maturation period. The value of carbon in compost has a strong relationship with its color, so if the carbon content is high, the compost is immature and brownish [30]. In Conclusion, almost all parameters in the compost resulting from the 14-day bioconversion using BSF larvae align with the specifications outlined in SNI 19-7030-2004.

4. Conclusions

Utilizing black soldier fly as a food waste management strategy has excellent performance. Different food waste characteristics produced varied results but similar values. The bioconversion utilizing 0.5 of BSF eggs for 3.4 kg of food waste gives the byproduct results, reducing the waste by more than 60%, producing fresh larvae with an average of 711.9 g and producing an average compost of 300.2 g. However, there are still wastes remain (dried rice and bones) with an average value of 161.7 g. Based on this study, the type of food waste influences larvae mass production ($p= 0.021 < 0.05$, $R=0.878$), but no correlation is observed for larvae nutritional content ($p >0.05$). The more varied content of food waste gives the best larvae production compared to food waste from rice waste. The 14 days bioconversion process produces compost meeting seven parameters appropriate with SNI 19-7030-2004, except for compost color and carbon content.

Conflicts of Interest

The authors declare no conflict of interest.

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