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Research Article

Processing of Biodegradable Waste from Ceremonial Activities in Bali with Black Soldier Fly (BSF) Larvae

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Abstract

The conducted study aimed to analyze the waste processing process from traditional ceremonies in Bali by examining the composition of the waste generated. Since most of the waste generated during these ceremonies is a biodegradable organic material, it is feasible to use sustainable bioconversion techniques such as Black Soldier Fly (BSF) larvae to convert this waste into useful products. In the study, a feeding trial was conducted using a garbage blender consisting of banana fruit, rice, banana leaf, coconut leaf, and flower wastes. The BSF larvae were fed at a rate of 40 mg/larvae per day with a total of 200 larvae. The researchers measured the key processing parameters including overall degradation (OD), waste reduction index (WRI), and feed conversion efficiency (ECD) which resulted in values of 41.27±0.42%, 3.30±0.03 g/day, and 7.82±0.43%, respectively. The study found that the dry residue produced during the process was around 30-31% and met the minimum standards set for compost or biomass fuel. Additionally, the total mass of BSF larvae produced was around 16-18% in one cycle, which is a high protein source that can be used to feed animals.

Keywords: BSF larvae, waste conversion, waste reduction

1. INTRODUCTION

The composition of traditional ceremonial waste, which is dominated by organic matter, is indeed very the potential to be used as compost. The waste contains almost 79.13% of wet waste that has the potential to be processed into compost. In addition, there are also other compositions, such as plastic, cans, and paper [1]. However, efforts to reduce waste have not been extensively carried out except for waste collection and sorting activities. Thus, all waste is directly transported to the landfill. On the other hand, the use of waste from religious ritual activities, which consists of leftover canangs and ceremonies, is also one of the contributors to waste in landfills or water bodies [2]. On the other hand, the island of Bali has many temples and performs ritual activities regularly and generates waste from traditional ceremonial activities [3].

Various methods have been used to process traditional ceremonial waste, especially components of ceremonial waste. Waste left over from the ceremony can usually be converted by the bioconversion method. Several previous studies have recycled ceremonial waste into compost through the vermicomposting technique [4]-[6], as well as natural coloring agents, manures, and biofuels [7]. However, this technique is difficult to apply because of the complex nature of microorganisms. One alternative developed by the researchers is the processing offered by using Black Soldier Fly (BSF) larvae as an organic waste bioconversion agen [8,9]. BSF larvae are very suitable for a large volume reducer of organic waste due to their ability to reduce the pungent odor of waste decomposition [10]. Other studies have shown that BSF fly larvae are efficient as organic waste reducers because they can convert protein and lipid-rich biomass from their food substrate [11]. There are at least three products that are produced from the empowerment of BSF larvae, namely (1) larvae or pre-pupae BSF as an alternative source of protein for animal feed, (2) liquid resulting from the larval activity which functions as liquid fertilizer and (3) residual or dry organic waste that can be used as a fertilizer [12].

Previous studies have shown that BSF composting can effectively reduce the amount of waste and convert it into a valuable resource [10][13][14]. For example, a study conducted in Malaysia found that BSF larvae could effectively degrade food waste, producing compost with high nitrogen and phosphorus content [15]. Another

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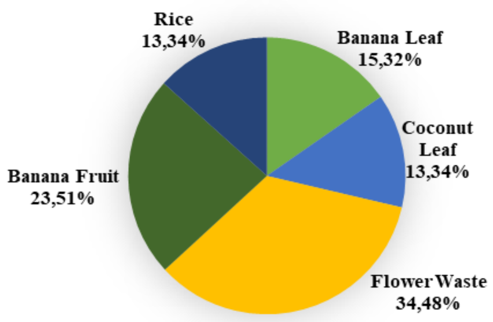

Figure 1. Composition of ceremonial waste in Bali used in processing with BSF larvae.

study conducted in China demonstrated that BSF composting could effectively reduce the volume of pig manure while producing high-quality compost [16]. The use of BSF for waste degradation has several advantages over traditional composting methods [13]. Firstly, the BSF larvae are highly efficient at breaking down organic material, resulting in faster composting times [17]. Secondly, BSF composting can reduce odors and attract fewer pests compared to traditional composting methods [18]. Finally, BSF larvae are a valuable source of high-quality protein and can be used as animal feed, reducing the reliance on soy and fish meal [19].

In this study, the aim was to investigate the potential of using BSFL to biologically convert the waste generated from traditional ceremonies in Bali. The present work aimed to identify the effectiveness of BSF larvae in converting waste into valuable products, such as compost and animal feed, which can be further utilized. By conducting this study, the researchers aimed to provide a reference for waste management practices in Bali and promote the use of sustainable methods for waste disposal. Therefore, the results of this study can contribute to the development of more effective and sustainable waste management practices in Bali.

2. MATERIALS AND METHODS

2.1. Preliminary Research

Preliminary research was conducted to obtain supporting data needed in the study. The data are waste characteristics in the form of waste composition data, water content, calorific value, initial pH, and the value of carbohydrate, protein, and fat content of ceremonial waste. The water content of the waste was obtained from the measurement of the dry weight of the waste. The moisture content needs to be known to calculate the wet weight of larval food requirements for each type of waste. Dry weight measurement was carried out by heating in an oven for 1 day at a temperature of 105 °C. Measurement of the initial pH of the waste is needed to determine the effect of the decomposition of BSF larvae on the pH of the waste. It is necessary to test the carbohydrate, protein, and fat content of the initial waste to determine the effect of the decomposition of BSF larvae.

2.2. Experiment Set-Up

In this study, the waste from traditional ceremonies in Bali was collected and homogenized, and then placed into plastic containers with small holes for air circulation. To prepare the substrate mixed with waste from traditional ceremonies, a mixture of organic waste such as vegetables, fruits, and rice was collected from the market and mixed with the waste generated from traditional ceremonies. The waste from traditional ceremonies included offerings made from organic materials

Table 1. Initial Characteristics of Ceremonial Waste in Bali in Processing with BSF Larvae.

Parameters	Quality
Moisture Content	54.2±0.4%
Caloric Value	2413±64.1 kcal/kg
pH	6.8±0.6
Carbohydrate	8.19%
Protein	3.85%
Fat	0.39%
Ash	0.41%

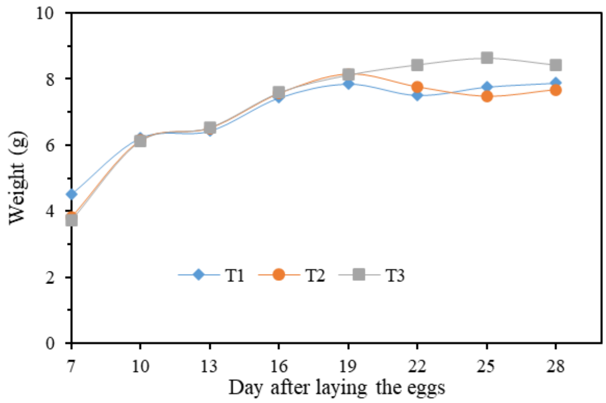

Figure 2. Increasing BSF larvae mass in Bali used in processing with BSF larvae (T1, T2 and T3 indicated Trial 1, 2, and 3 respectively).

such as flowers, leaves, and fruits, as well as burnt incense and ceremonial leftovers. The organic waste and traditional ceremony waste were mixed in a ratio of 1:1 (based on weight) to obtain a homogenous substrate. The substrate was then placed in plastic containers with a perforated lid and left for 3 days to allow microbial activity to begin.

BSF eggs were introduced into each container, and the containers were then covered with a net to prevent the escape of the larvae. The containers were placed in a laboratory at room temperature (± 28 °C) and were regularly checked and maintained for moisture content. The samples were collected at regular intervals for analysis of physical and chemical parameters, such as pH, moisture content, and nutrient content. The experiment was conducted in triplicate to ensure the consistency and accuracy of the results.

Thorough mixing is an important step to ensure that the sample of waste for BSFL breeding is homogenous. Thorough mixing of the waste material helps to ensure that all parts of the sample have a similar composition, which is important for obtaining reliable and consistent results in replicate trials. When preparing the waste material for BSFL breeding, it is recommended to mix the waste thoroughly to ensure that it is evenly distributed. This can be done using different methods such as shaking, stirring, or blending. For solid waste materials, a blender or other grinding device can be used to create a uniform consistency. Without thorough mixing, there is a risk of uneven distribution of nutrients and other components in the waste material, which can result in inconsistent growth and development of the BSFL.

Regular monitoring of the moisture content of the waste material is necessary to ensure that it remains within the optimal range. Moisture content can be monitored using a moisture meter or by conducting simple moisture tests such as the squeeze test or visual inspection. Thorough mixing also can help distribute moisture evenly throughout the material. This can be achieved using mechanical hand mixing.

2.3. BSF larva breeding

BSF breeding is performed by providing a reactor where eggs grow, a reactor where larvae grow, and cages for the reproduction of adult flies. The reactor volume used is 1 L with a media height

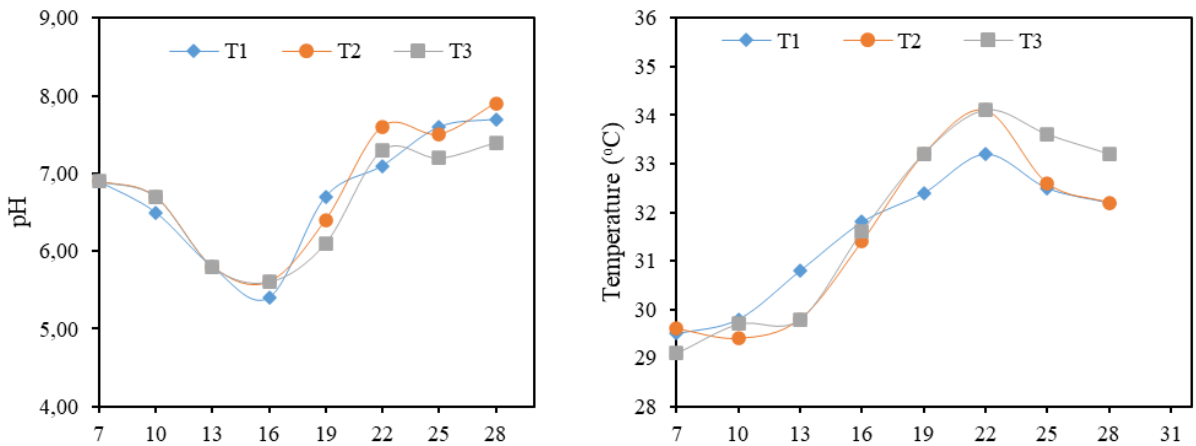

Figure 3. Change of pH and temperature of feed-in processing with BSF larvae (T1, T2 and T3 indicated Trial 1, 2, and 3 respectively).

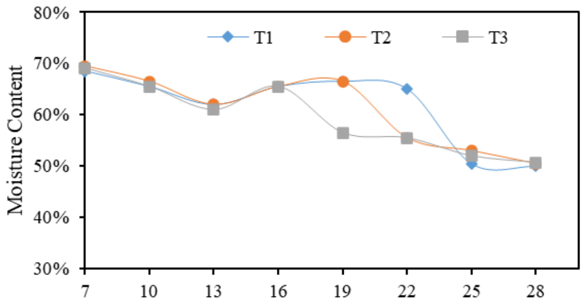

Figure 4. Change of Moisture Content of Feed in Processing with BSF Larvae (T1, T2 and T3 indicated Trial 1, 2, and 3 respectively).

of 5 cm. As a medium for eggs to be provided, wooden sticks are provided with holes on the sides or by using cardboard that is pasted in several layers. Eggs that have been laid by mature BSF in the media are then placed in an empty reactor and marked based on the time of collection. Media eggs are checked every day, to check when the eggs have hatched. BSF larvae begin to be fed when the eggs that hatch in the reactor have hatched into larvae. Each reactor used is filled with larvae with the same hatching date so that the larval age of each reactor can be known.

Feeding the BSF larvae was adjusted to the food needs based on dry weight, which was an average of 40 mg/larva per day [20], the daily waste requirement could be calculated based on the wet weight of the waste from the ceremony. The number of larvae put into the reactor is 200 tails. So that the dry weight of the waste from the ceremony that is needed every day is 8 g. However, because the experiment will be carried out with three replications, the food portion, and the number of BSF larvae are three times that amount.

2.4. Measurement of BSF Larval Mass Growth, pH, Temperature, and Moisture Content

Measurement of larval body weight was carried out every three days from the beginning to the end of the running time. At the beginning and end of the experiment, the total growth weight of the larvae was weighed (200 larvae). Measurements were carried out every 3 days on 10% of the number of larvae (20 tails) only [21], as a representation of the increase in overall larval weight in one reactor. The samples left in the reactor until the last day of the experiment will be used as residual data. The residual data obtained will be used to calculate the level of waste reduction that has been carried out by BSF larvae during the experimental period [20]. During the study, it was not certain that all larvae would survive to the end, where some larvae may die before the larvae reach the prepupa stage [22]. If this happens, the dead larvae do not need to be removed from the reactor. However, when mortality reached more than 50% (within a few days of the study) the experiment was stopped, as this indicated that the food provided was not suitable for the larvae. The death of larvae during the experiment can also be caused by too high temperatures in the study site or the presence of toxic substances in the food given [20].

The results of the mass measurement can also produce data that shows the mass balance of processing waste from ceremonies with BSF. The parameters are overall degradation (OD) waste reduction index (WRI) and feed conversion efficiency (ECD), which are calculated using equations 1-3.

Overall degradation (OD) =

$$\frac{Total\ dry\ feed\ offered (g) - Dry\ residue\ remained\ (g)}{Total\ dry\ feed\ offered\ (g)} \quad \textbf{(1)}$$

Waste reduction index (WRI) =

$$\frac{Total\ dry\ feed\ offered\ (g) - Dry\ residue\ remained\ (g)}{Rearing\ duration\ (day)} \quad \textbf{(2)}$$

Table 2. Parameters of waste processing results with BSF larvae.

Parameters	Unit	T1	T2	T3	Average	Standard Deviation
Total dry feed offered	g	248.00	248.00	248.00	248.00	±0
Dry residue remained	g	144.50	145.90	146.50	145.66	±1.04
OD	%	41.73	41.15	40.92	41.27	±0.42
WRI	g/day	3.34	3.29	3.27	3.30	±0.03
ECD	%	7.61	7.53	8.31	7.82	±0.43

***Note:** T1, T2 and T3 indicated Trial 1, 2, and 3 respectively.*

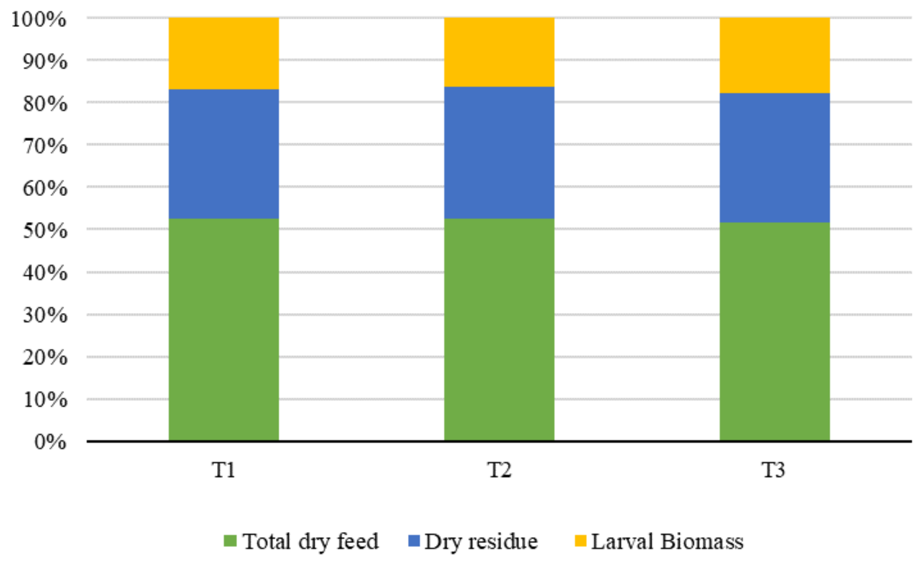

Figure 5. Mass composition in waste processing with BSF larvae (T1, T2 and T3 indicated Trial 1, 2, and 3 respectively).

The efficiency of conversion of digested feed (EDC)

$$= \frac{BSF\ Larvae\ biomass\ (g)}{Total\ dry\ feed\ offered\ (g) - Dry\ residue\ remained\ (g)} \quad \textbf{(3)}$$

Temperature, pH, and moisture content are essential parameters that can affect the growth of BSF larvae. Thus, periodic measurements are needed following the measurement of the body weight of BSF larvae. This measurement is carried out with calibrated tools such as pH meters, digital thermometers, and moisture meters.

3. RESULTS AND DISCUSSIONS

The composition of the waste leftover from ceremonies in Bali is dominated by organic matter, which has the potential to be used as compost [23] [24]. The results of measurements were carried out by random sampling and proportionally at one of the temples in Denpasar City which produces the highest waste generation. This study only uses organic materials that are easily degraded. Therefore only 5 major compositions were used as feed for BSF larvae. The waste contains as much as 79.13% wet waste that has the potential to be processed into compost (Figure 1). In addition, there are also other compositions, such as plastic, cans and paper. People's behaviour in using disposable items when going to the temple, such as plastic, crackle, or paper is still very high, so the waste must be separated again if it is to be processed or recycled [25].

The data on carbohydrate, protein, and fat content obtained in this study are presented in Table 1. Gobbi et al. stated that the quality and quantity of food ingested by BSF larvae have an important influence on the growth and timing of larval development, survival, mortality and ovarian development of adult insects and determine the physiological and morphological development of adult BSF [26]. The content of protein, carbohydrates, and fat needed by BSF larvae have to be fulfilled in the body so that if these nutrients are not met, the body's health will be disturbed. Nutrition itself functions for the growth and development of organisms.

The growth of BSF begins when the eggs hatch into larvae. The results showed that more than 95% of the eggs hatched on the 3rd day after laying the eggs in the culture medium and entered the active feeding phase on the 7th day. Therefore, the mass measurement in this study began on the 7th day, when the weight of each larva was different. The larval phase lasts 12-18 days. During the feeding phase, the larvae grow in length and width, so that the mass in the processing of ceremonial waste until the pupa phase continues to increase (Figure 2). Ceremonial waste is an excellent medium to support the growth of BSF larvae because it has the

Table 3. Characteristic of dry residue.

Parameters	Unit	Average Value	Stdev	Standard
pH	-	6.25	±0.9	4-8
C-organic	%	40.7	±2.1	≥12
N-organic	%	2.015	±0.2	-
C/N	-	20.32	±2.8	10-25
Water Content	%	17.3	±1.4	13-20
Higher Heating Value (HHV)	kcal/kg	4163.5	±81.3	-

right nutritional content.

The temperature and pH of the media play an important role in the bioconversion process of organic waste by larvae in accelerating composting and supporting larval growth [27]-[29]. Measurements of the temperature and pH of the media began when the larvae were transferred to the treatment container. The temperature of the media in the three treatments ranged from 29.1-34.1 ^{o}C, and the pH of the media was 6.9-7.7 still in the neutral pH range (Figure 3).

During the degradation process of organic waste by BSFL, the pH trend observed is also influenced by the activity of microorganisms. The pH initially decreases because of organic acids being produced during the early stages of degradation [30]. These microorganisms produce organic acids as a by-product of their metabolism [31]. In the case of your study, the pH reached its minimum value (became more acidic) during days 15-17, which corresponds to the early stages of the degradation process. This suggests that the microorganisms responsible for the degradation of organic matter were active during this period and were producing organic acids, leading to a decrease in pH. As the degradation process continues and more organic matter is consumed by the BSFL, the production of organic acids slows down and the pH starts to increase. This increase in pH is due to the production of ammonia and other basic compounds because of microbial activity. These basic compounds come from the breakdown of proteins and amino acids in the waste material. This can make the environment more alkaline and lead to the pH reaching its maximum value (becoming more basic) during day 22, which corresponds to the later stages of the degradation process. It is important to monitor pH during the BSFL degradation process to ensure that the optimal conditions for microbial activity are maintained. A pH range of 7-8 is considered optimal for the BSFL gut microbiota, which will ensure efficient degradation of organic matter.

The moisture content of the waste media left over from the ceremony during the decomposition process has decreased continuously from around 70% to 50% on day 28 (Figure 4). In addition, in the composting process with BSF larvae, microorganisms can utilize organic matter if the organic material dissolves in water. A moisture content of 40–60% is the optimum range for microbial metabolism. If the moisture content is less than 40%, microbial activity will decrease and will be even lower at 15% moisture content. In contrast, if the Moisture content is greater than 60%, the nutrients will be leached, and the air volume will decrease, as a result, microbial activity will decrease, and anaerobic fermentation will occur which causes an unpleasant odor. Since the moisture content in the research process was well maintained, an unpleasant odor did not appear, and the decomposition process of organic matter was achieved.

Moisture content is an important factor that affects the degradation process of organic waste by microorganisms, including those present in the gut of BSF larvae. If the moisture content is too low, microbial activity can be inhibited, and if it is too high, the waste can become waterlogged and anaerobic conditions can occur, leading to the production of unpleasant odors. In our study, the moisture content was well maintained, which means that the waste material provided an optimal environment for microbial activity, including the activity of the BSF larvae gut microbiota. This led to the efficient degradation of organic matter by the BSF larvae, and the production of an unpleasant odor was prevented. Maintaining an optimal

Table 4. Characteristic of BSF larvae mass.

Parameters	Quality
Caloric Value	3303±86.8 kcal/kg
Carbohydrate	5.19%
Protein	43.85%
Fat	24.39%
Ash	0.54%

moisture content also ensures that the BSFL larvae have access to water for hydration and digestion, which is important for their growth and development. Additionally, an optimal moisture content helps to regulate the temperature within the waste material, preventing overheating or cooling, which can also affect microbial activity.

The WRI value in this study shows a similar value where the standard deviation is only ±0.03 (Table 2). Consumption of excessive bait can cause the value of the percentage of bait consumed to the total bait to be lower. The test results show that the ECD value in each repetition is also not significantly different. The low amount of bait consumed resulted in a decrease in the amount of bait converted into BSF larvae biomass. The low value of ECD on the growth of insect larvae is related to the quality of the available bait.

The composition of the processing mass consisting of total dry feed offered, dry residue remaining, and total larval biomass from processing can be seen in Figure 5. The amount of processing results show a high dry residue composition of 30-31% while the total mass of BSF larvae can reach 16-18% in one cycle. Both products can be reused into materials of economic value. Therefore, it is necessary to further measure the quality of the residue product.

The compost produced by BSF larvae has the same characteristics, namely black, coarse texture, granular and has a distinctive odor of larval. While the crude residue is part of the organic waste that has a hard texture so that it cannot be digested by the larvae during the feeding phase. Larvae prefer organic waste that has a hard-to-soft texture [32]. The characteristic of dry residue is listed in Table 3.

The characteristic of BSF larvae mass is shown in Table 4. The protein content is a macro parameter contained in the body of BSF larvae. In this study, protein can reach 43.85%. Protein is a polypeptide macromolecule composed of several amino acids and connected by peptide bonds [33]. Protein consists of essential amino acids and non-essential amino acids. Protein functions as a building block and protective substance for the body and can also be a source of energy [34]. The energy contained in BSF larvae can reach 3303 kcal/kg. Energy itself is also formed by the presence of organic carbons in the feed [35]-[37]. The results of the calculations on the carbohydrate content test that have been carried out, the percentage of nutrients can be seen in Table 3, which is 5.19%. The carbohydrate content in BSF larvae is so low. The low carbohydrate content is because BSF larvae are the source of animal nutrition where the carbohydrate content is low. The amount of carbohydrates in animal nutrition is very small, which is less than 1% [38]. Carbohydrates themselves are contained in many portions of cereal (wheat, rice, corn, potatoes and others) as well as in grains. While the tang fat contained can reach 24.39%. Fat is a source of energy; the larvae will accumulate high-fat reserves in their bodies [39].

The standards for utilizing the residue produced during the BSFL degradation process can vary depending on the intended use. If the residue is to be used as solid fuel, the standard requirements may include a minimum heating value or higher heating value (HHV) to ensure that the fuel meets certain energy content requirements [36][37][40]. On the other hand, if the BSFL larvae are to be used as animal feed, the standard requirements may include a minimum protein content, which can vary depending on the type of animal being fed [10][41]. Other nutrient requirements may also need to be met, such as minimum levels of fat, fiber, and other essential vitamins and minerals [42][43]. It's worth noting that the specific standard requirements may vary depending on the location and intended use of the residue or larvae. It's important to consult with local regulations and guidelines to ensure that the standards are met for each specific application.

4. CONCLUSIONS

Based on the results of processing waste from the ceremony with BSF larvae with feeding consisting of banana fruit, rice, banana leaf, coconut leaf, and flower waste which are blended into one, the overall waste degradation is 41.27±0.42%. The final composition of dry residue is quite high, namely 30-31% while the total mass of BSF larvae can reach 16-18% in one cycle. The utilization of residue can be done with compost that has met the standard or can be used as solid fuel because it has low water content and sufficient heating value. In addition, the nutritional content of BSF larvae can be used as animal feed with high protein value.

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Conflicts of Interest

The author(s) declared no conflict of interest

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