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Design of A Canteen Organic Waste Management System Using Black Soldier Fly at Universitas Jambi

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Abstract: Universitas Jambi adopted the Green Campus concept and joined the UI Green Metric as a commitment to environmental sustainability. One crucial step is the management of solid waste, particularly organic waste. In 2023, Universitas Jambi generated 835.7 kg of organic waste per day; however, its management at the Temporary Disposal Site remains suboptimal. This study aimed to measure the amount of organic waste from canteens in the Mendalo Campus area, evaluate the effectiveness of the Black Soldier Fly (BSF) method, and design a sustainable organic waste management system. The results show that the BSF method can reduce waste by up to 77.5%, with a Waste Reduction Index (WRI) of 5.16% and an Efficiency Conversion Degree (ECD) of 9.15%. BSF larvae have proven to be effective in processing various types of organic waste, making this bioconversion technique widely applicable at the Universitas Jambi. The proposed management system includes waste collection from sources, transportation, and processing using BSF to enhance the efficiency of organic waste management.

Keywords: Black Soldier Fly; Universitas Jambi; Organic Waste; Waste Management

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1. Introduction

The environmental management approach based on the Green Campus concept includes the handling of organic, inorganic, and hazardous wastes generated from academic community activities on campus. This approach aligns with Law No. 18 of 2008 on Waste Management, which covers waste collection, transportation, and disposal processes. However, the primary challenges in campus waste management generally include inadequate infrastructure, limited effective management systems, and high costs associated with certain waste treatment methods. These issues are also experienced by Universitas Jambi.

In 2023, the total waste generation at Universitas Jambi reached 1023.239 kg/day, with organic waste as the largest component, amounting to 835.7 kg/day (66.94%) [1]. Given the continuous increase in waste production, the condition of the Temporary Disposal Site (TPS) at Universitas Jambi requires greater attention. Unfortunately, the university's waste management system still faces challenges, particularly in handling organic waste at TPS, where waste is often improperly disposed into the drainage system or left to accumulate without effective treatment. This situation can lead to flooding, deteriorating sanitation quality, increased disease risk, and acceleration of global warming [2].

Therefore, an efficient, sustainable, and economically valuable organic waste management approach is required. Biological solid organic waste management includes several methods such as composting (w h e r e organic waste is decomposed by microorganisms into compost fertilizer), biopore holes (which enhance water infiltration and organic waste decomposition within the soil), and the use of Black Soldier Fly (BSF), which consumes organic waste. Although composting and biopore holes are viable alternatives, these methods require a significant amount of time to produce optimal results. Meanwhile, organic waste continues to accumulate on campus, necessitating a faster and more efficient waste treatment approach.

Organic waste processing using BSF-based biological systems in campus areas offers several advantages. BSF larvae have the ability to rapidly decompose organic waste, with a reduction rate of up to 50% in a short period [3]. Another advantage is that the decomposition process using BSF can be carried out daily. This is because BSF larvae are decomposers that require direct nutrients from organic waste. Additionally, BSF larvae do not transmit diseases and only consume organic waste such as food scraps, fruits, and vegetables, making them a safer option for waste management applications [4].

Previous studies have demonstrated that BSF larvae can reduce organic waste by up to 50% in a relatively short time. Two experiments involving different amounts of organic waste confirmed this finding. In the first experiment, an initial waste mass of 50.76 kg was processed, with BSF larvae consuming 1.1 kg/day over 21 days, resulting in a Waste Reduction Index (WRI) of 14.4%, equivalent to a reduction of 24.86 kg of waste, and producing a biomass yield of 0.19 grams per larva [5]. In the second experiment, with an initial waste mass of 41 kg, BSF larvae consumed 18.67 kg of waste, yielding a WRI of 2.17% and leaving 22.33 kg of residue [6]. These findings indicate that the BSF method can significantly reduce the amount of organic waste sent to final disposal sites.

BSF larvae have an effective life cycle for reducing organic waste. At 5-10 days old, larvae begin to develop and reach a lifespan of 14-27 days. Optimal BSF larval growth occurs at a temperature of 27.6°C – 29.3°C and a pH of 6-7, with body sizes reaching up to 2.5 cm in length and 0.5 cm in width. Research conducted by Oktavia and Rosariawari demonstrated that the effectiveness of the BSF method can be assessed based on the generated residue, which ranges between 65.5% and 78.9% of the waste. This residue contains essential elements such as total nitrogen (N), total carbon (C), and the C/N ratio, which align with the quality standards specified in SNI-19-7030-2004 for compost or organic matter reduction. As a result, the residue produced by BSF can provide added value as organic compost fertilizer [7].

Based on the issues outlined, this study aims to measure the volume of organic waste generated from canteens at the Mendalo Campus of Universitas Jambi and evaluate the effectiveness of the BSF method in reducing organic waste based on quantitative parameters. Furthermore, this study will calculate the Waste Reduction Index (WRI) and Efficiency Conversion Degree (ECD) to assess the success of the BSF method in organic waste management. The research also seeks to design an optimal organic waste management system utilizing BSF as a sustainable solution.

This study is focused on the Pinang Masak Mendalo Campus environment, with organic waste samples specifically collected from campus canteens. The results of this research are expected to provide valuable information and effective solutions for organic waste management and processing at Universitas Jambi.

2. Method

Data collection was conducted through primary sources. Primary data refers to specific information regarding organic waste production obtained directly from the research site, namely the Pinang Masak Campus Canteen at Jambi University. This includes experimental data such as the weight of BSF, the amount of processed waste, and quantitative data on the efficiency of waste conversion into biomass.

2. 1 Sampling of Organic Waste

This study was conducted over a period of seven months, from January 2024 to July 2024, at the Pinang Masak Campus of Jambi University, located on Jl. Jambi-Muaro Bulian KM 15, Mendalo Darat, Jambi Luar Kota Subdistrict, Muaro Jambi Regency, Jambi Province. The faculty canteen at the Pinang Masak Mendalo Campus was selected as the sampling site for this study as depicted in **Figure 1**.

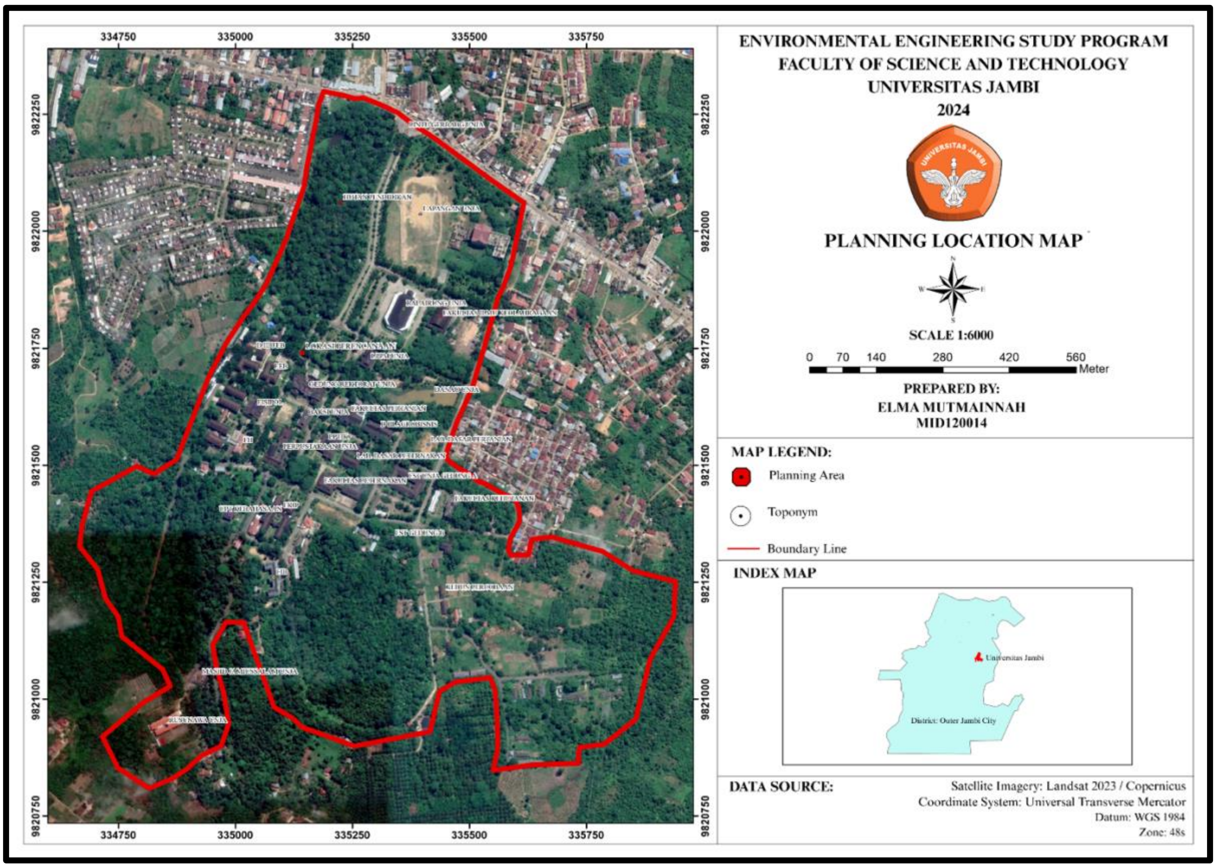

Figure 1. Research Location Map

The sampling method employed was non-probability sampling, utilizing the Slovin formula. This approach was based on the known population size and the sampling criteria or specific considerations [8]. The Slovin formula used is shown in **Equation (1):**

$$n = \frac{N}{N\,(e^2) + 1} \tag{1}$$

Description:

n = Sample size

N = Population size

e = Margin of error (sampling error tolerance). The standard values for *e* in the Slovin formula are *e* = 0.1 (10%) for larger populations (more than 100) and *e* = 0.2 (20%) for smaller populations (less than 100).

The total population in this study comprised 40 canteens, distributed across 5 clusters or points. Accordingly, a 20% or 0.2 margin of error was applied, and the results were rounded for alignment. Therefore, the sample size used was calculated using **Equation (2):**

(2)

$$n = \frac{N}{N\,(e^2) + 1}$$

$$n = \frac{40}{40\,(0{,}2^2) + 1}$$

$$n = \frac{40}{2{,}6}$$

$$n = 15.3 \approx 16$$

Based on the calculation above, 16 samples or canteens from the total number of canteens at the Mendalo Campus of Jambi University will be used. The sampling was carried out using the quota sampling technique, which involves dividing the population into several clusters, with each cluster being represented by the same proportion as in the population [9]. Thus, each cluster will be allocated or have three (3) research samples taken.

2. 2 Small-Scale Experiment with BSF

The core phase of the study involved a small-scale experiment to process organic waste using Black Soldier Fly (BSF) larvae. The collected organic waste was weighed to determine its initial weight. Subsequently, the waste was chopped into small pieces to facilitate consumption by the BSF larvae. The larvae were placed in specially designed containers under controlled environmental conditions.

In this experiment, a digital thermohygrometer was used to measure the temperature and humidity during the process of Black Soldier Fly (BSF) larvae treating organic waste. The rearing cycle lasted 15 days, with an optimal temperature of around 30°C. This temperature supported a development period of approximately 28 days, with the best hatching rate of 80% observed at 30°C [10]. During the maintenance period, the larvae were gradually fed organic waste according to their consumption capacity. Environmental parameters, such as temperature and humidity, were monitored using a thermo-hygrometer to ensure optimal conditions for larval growth.

2. 3 Monitoring and Measurement

During the rearing cycle, periodic monitoring was conducted to measure the remaining waste weight to evaluate the waste reduction rate and to record changes in larval weight to assess biomass conversion efficiency. After the rearing cycle was completed, the collected data was analyzed to calculate the Waste Reduction Index (WRI) and the Efficiency Conversion Degree (ECD). These metrics were used to measure the extent of organic waste reduction by BSF larvae and the efficiency of waste conversion into larval biomass, respectively.

The formula for calculating WRI is shown in **Equation (3) - (5):**

$$D = \frac{W - R}{W} \tag{3}$$

$$WRI = \frac{D}{t} \times 100 \tag{4}$$

Description:

W = Total waste amount (mg)

R = Remaining waste/residue (mg)

D = Total waste reduction (mg)

t = Total time for larvae to process waste (days)

WRI = Waste Reduction Index (%)

The formula for calculating ECD is as follows:

$$EDC = \frac{B}{(I - F)} \times 100 \quad (5)$$

Description:

EDC = Waste consumption efficiency (%)

B = Larval weight increase (final weight – initial weight of larvae) (mg)

I = Total waste consumed (initial weight – final weight of waste) (mg)

F = Weight of residue generated (mg)

The collected data will be processed using Microsoft Excel 2010. The analysis results aim to determine the volume and weight of solid organic waste produced, as well as the effectiveness of its processing using BSF. Additionally, a waste management plan for Jambi University will be developed, detailing the collection and transportation of waste and the layout of waste processing using BSF in AutoCAD 2022. The analysis results will then be presented in a structured format and summarized in a final report to provide a comprehensive overview of the role of BSF in reducing organic waste. The **Figure 2** illustrates the research stages from start to finish.

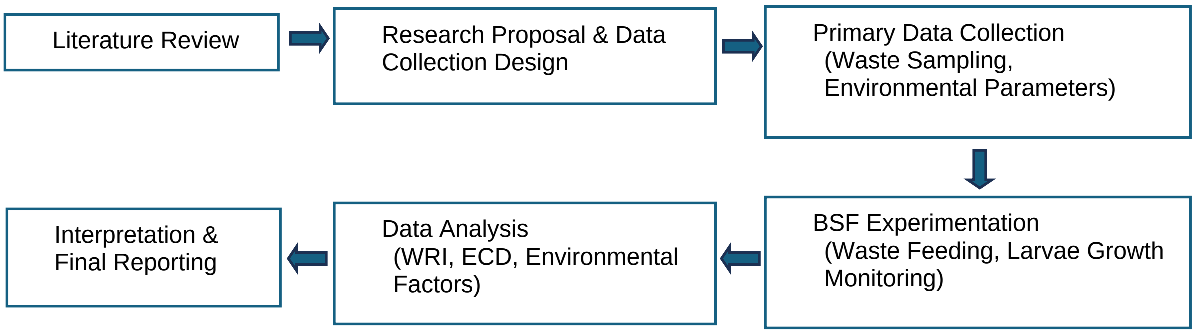

Figure 2. Research Stages

3. Results and Discussion

3. 1 Estimation of Organic Waste Output

In this study, calculations were conducted to design a system that can be utilized for waste management. The data collected included organic waste generation from canteens over a period of eight days, following SNI 19-3964-1994. Subsequently, the effectiveness of organic waste processing using Black Soldier Fly (BSF) larvae was evaluated over a 15-day period by calculating parameters such as the total waste processed, total reduction, residual waste, Waste Reduction Index (WRI), and Efficiency Conversion Degree (ECD), as depicted in **Table 1.**

Table 1. Organic Waste Generation from the Canteen at Universitas Jambi

Faculty	Population Count	Organic Waste Generation (Sample) (Kg/day)	Organic Waste Generation (Population) (Kg/Day)	Average Organic Waste Generation (Population) (Kg/Day)
FST	8	33.9	271.2	33.9
FH	6	10.6	65.4	8.18
FKIP	12	11.2	134.4	16.8
FAPERTA	9	15.7	141.3	17.66
FEB	5	14	70	8.75
		Total		85.29

According to Table 1, waste generation measurements were carried out at five different locations, namely the canteens of the Faculty of Science and Technology (FST), Faculty of Law (FH), Faculty of Teacher Training and Education (FKIP), Faculty of Economics and Business (FEB), and Faculty of Agriculture (FAPERTA), over a period of eight days. These measurements were conducted in accordance with SNI 19-3964-1994, which outlines the Sampling and Measurement Methods for Municipal Solid Waste Generation and Composition. The collected data included weight, volume, density, and daily waste generation from each measured location.

The total organic waste generation from the sampled canteens at Universitas Jambi was 51.5 kg/day, with an average of 6.42 kg/day. Consequently, the total waste generation from the entire population reached 411.1 kg/day, with an average of 85.29 kg/day. The organic waste consisted of both wet and dry waste, including food scraps (processed and unprocessed) and kitchen waste such as eggshells and herb stems.

3. 2 Effectiveness of Organic Waste Treatment

In this study, after Black Soldier Fly (BSF) eggs hatched and developed into larvae, the larvae were transferred to a special container measuring 85×45×25 cm and fed with organic waste such as leftover rice, vegetables, fruits, and bread. The feeding process started on day 7 and continued until day 21, just before the larvae entered the pre-pupae phase. This feeding phase aimed to meet the nutritional requirements of BSF larvae, particularly protein and fat. According to Ridwan et al. (2021), organic waste contains approximately 35% protein and 30% fat, which are essential for BSF larval growth [11]. Over a 15-day period, a total of 4325 grams of organic waste was provided, with an average processing time of 588.6 minutes per batch. The decomposition process was influenced by larval age and feed type, including the texture of the feed, which affected the speed of waste reduction [12]. In this study, the waste was not pre-processed or ground, resulting in a longer processing time for the larvae (**Table 2**).

Table 2. Effectiveness of Organic Waste Processing Using Black Soldier Fly Larvae

Larval Weight Gain (g)	Total Waste Processed (g)	Waste Reduction (g)	Residual Waste (g)	ECD (%)	WRI (%)	Duration (Days)
217	4325	3348	977	9.15	5.16	15

The bioconversion results indicated that BSF larvae not only decompose organic waste but also produce residues or substrates that are easily crumbled, resembling soil. These residues consist of feces and undigested food fibers and contain important nutrients such as total nitrogen (N), total carbon (C), C/N ratio, phosphorus, and potassium. These residues have the potential to be used as fertilizer or compost, following SNI 19-7030-2004 standards [7]. Residue harvesting was conducted on days 9, 12, 15, 18, and 21, with a total residue yield of 977 grams, approximately 22.5% of the organic waste provided.

Based on the findings, BSF larvae successfully processed 3348 grams of organic waste, which accounted for 77.5% of the total waste provided within 15 days. This high reduction rate demonstrates the efficiency of organic waste management, particularly within a campus environment. These results align with Oktavia (2020), who reported that the optimal waste reduction percentage by BSF larvae ranged between 65.5% and 78.9% [7]. This emphasizes the importance of consistent and evenly distributed feeding to achieve optimal bioconversion outcomes.

The Waste Reduction Index (WRI) value of 5.16% indicates that this system has significant potential to reduce waste volume efficiently within a relatively short time. This value reflects the effectiveness of BSF larvae in processing organic waste into a more manageable residue. From a sustainability perspective, reducing waste volume through this method can help minimize landfill dependency and promote environmentally friendly waste management. A previous study by Dewi et al. (2023) reported a WRI value of 4.75% for organic waste processing in restaurants, which closely aligns with the findings of this study [13]. The BSF method has distinct advantages in rapidly reducing organic waste since BSF larvae directly consume organic waste as a nutritional source, utilizing enzymatic activity to efficiently break down complex organic matter. Additionally, the relatively short larval life cycle (15-21 days) enables faster waste processing compared to traditional composting methods, which can take weeks to months to achieve a similar level of decomposition.

Furthermore, the Efficiency Conversion Degree (ECD) of 9.15% indicates that BSF larvae have a strong capacity to convert organic waste into biomass. The resulting biomass can be utilized as animal feed or an alternative protein source. This efficiency highlights the great potential for scaling up BSF-based waste management, both on campus and in broader communities. The findings are consistent with Afia et al. (2022), who reported a maximum ECD value of 5.98% for steamed mustard greens mixed with fermented leftover rice (M1) and a minimum value of 4.93% for steamed mustard greens mixed with papaya waste [14]. These results suggest that variations in organic waste composition, such as rice leftovers, fruits, and vegetables, contribute positively to conversion efficiency. However, hard or coarse-textured waste, such as fruit peels, requires more time to decompose, reducing overall efficiency. In this study, an ECD of 9.15% suggests that conversion efficiency is relatively high, yet harder waste textures remain a challenge. Additionally, the low nutritional content of waste materials, as explained by Nugraha (2019), may cause larvae to consume more feed to meet nutritional needs, ultimately lowering ECD values due to suboptimal energy production [15]. According to Ahmad (2001), low Efficiency of Conversion Digested Feed in BSF larval growth is directly proportional to feed quality; the lower the feed quality, the lower the ECD value [16]. Thus, although this study presents a relatively high ECD value, waste quality and texture remain key factors in determining conversion efficiency in BSF-based waste management, particularly in a campus setting.

3. 3 Influence of Temperature and Humidity on BSF Development

The daytime temperature range optimal for BSF development was between 25°C and 36°C, with humidity levels between 55% and 90%. Nighttime temperatures ranged from 24°C to 30°C, with humidity levels between 75% and 97%. These environmental conditions were closely monitored and analyzed to determine their impact on the growth and development of BSF larvae (**Table 3 - 4**).

To evaluate the correlation between temperature, humidity, and larval development, a regression analysis was conducted. In this model, X_1 represents temperature, X_2 represents humidity, and Y represents the development of the BSF larvae. The regression test yielded a significance value, which indicated the extent to which temperature (X_1) and humidity (X_2) influenced BSF larval development (Y).

This analysis provides valuable insight into how environmental factors contribute to the efficiency of organic waste reduction by BSF.

Table 3. Results of the Regression Test for Daytime Temperature, Daytime Humidity, and BSF Weight

Model		*Unstandardized Coefficients* B	*Unstandardized Coefficients* Std. Error	*Standardized Coefficients* Beta	t	*Sig.*
1	(Constant)	355.882	637.101		0.559	0.583
	Daytime Temperature (°C)	-8.737	12.562	-0.301	-0.695	0.496
	Daytime Humidity (%)	0.559	3.776	0.064	0.148	0.884

Dependent Variable: BSF Weight
R^2 = 0.128
$F_{statistic}$ = 1.324
Sig = 0.291[b]

Table 4. Results of Regression Test for Night Temperature, Night Humidity, and BSF Weight

Model		*Unstandardized Coefficients* B	*Unstandardized Coefficients* Std. Error	*Standardized Coefficients* Beta	t	*Sig.*
1	(Constant)	-614.341	773.060		-0.795	0.437
	Night Temperature (°C)	4.368	16.832	0.079	0.259	0.798
	Night Humidity (%)	6.889	4.389	0.477	1.569	0.134

Dependent Variable: BSF Weight
R^2 = 0.180
$F_{statistic}$ = 1.976
Sig = 0.168[b]

The regression analysis results indicate that temperature and humidity have only a minor effect on the growth of Black Soldier Fly (BSF), both during the day and at night.

- The R^2 value during the day is 0.128 (12.8%), suggesting that only 12.8% of the variance in BSF growth can be explained by temperature and humidity, while 87.2% is influenced by other unexamined factors.
- The R^2 value at night is 0.18 (18%), indicating that 18% of the variance in BSF growth is affected by temperature and humidity, whereas the remaining 82% is attributed to other factors.
- All significance values for temperature and humidity during both day and night exceed 0.05, indicating that these variables do not have a significant impact on BSF growth in this analysis.

The temperature and humidity measurements during the study revealed that the daytime temperature ranged from 25–36°C and humidity from 55–90%, creating optimal conditions for larval growth. However, the regression analysis indicated that temperature and humidity had only a minor effect on the growth of BSF larvae, with R^2 values of 12.8% during the day and 18% during the night. This suggests that the primary factors influencing the effectiveness of bioconversion are the type and quality of the waste provided. These findings are consistent with the research by Firdausy et al. (2021), where a Two-Way ANOVA test showed that waste type, the size of the BSF habitat, and feeding frequency had a significant effect on larval growth (significance value < 0.05) [12].

These findings are relevant in the context of Universitas Jambi, where effective BSF management can be achieved by ensuring the proper management of waste types, the use of adequate cultivation areas, and consistent feeding schedules. Although temperature and humidity did not show significant effects, the success of the process is more influenced by these factors, which directly enhance the efficiency of BSF larval bioconversion in organic waste management on campus. In comparison, the research by Dewi et al. (2023) showed that stable environmental conditions could accelerate waste reduction by up to 80%, particularly when the waste texture was processed to be finer before being fed to the larvae [13]. The type of waste also plays a significant role; the study by Afia et al. (2022) found that waste with high nutritional content, such as steamed vegetables or rice leftovers, yielded higher ECD values than waste with high fiber content like fruit peels [14].

This research confirms that a varied organic waste composition, such as rice leftovers, vegetables, and fruits, can support the efficiency of BSF larval conversion. Therefore, managing the texture and nutritional content of the waste is a crucial factor in enhancing the success of waste processing using the BSF method.

3. 4 Design of the Organic Waste Management System at Universitas Jambi

Based on the research findings, the waste management system will be divided into four main components: waste sources, waste transportation, waste collection, and waste processing (**Figure 3**). At the waste source stage, separation between organic and inorganic waste is carried out in the cafeterias by providing designated containers such as bags and 10-20 liter bins for organic waste located behind the cafeterias. Awareness campaigns will be conducted in each cafeteria to ensure proper sorting of organic waste.

The system for collecting organic waste will be implemented daily in the late afternoon, between 15:30 and 16:00 WIB, to optimize the volume of waste collected and ensure that the collection fleet is exclusively used for organic waste, avoiding contamination with other waste types. The transportation route will start from the Faculty of Economics and Business (FEB), proceed to the Faculty of Agriculture (FAPERTA), Faculty of Science and Technology (FST), Faculty of Teacher Training and Education (FKIP), and finally the Faculty of Law (FH), before transporting the waste to the processing facility.

At the waste processing site, waste will be collected in three 40-liter bins located inside the management facility. The waste will then be sorted into two categories: waste that can be processed directly and waste that needs to be chopped or crushed before being fed to the BSF larvae for the bioconversion process. This system is designed to ensure efficient management of organic waste in the cafeterias at Universitas Jambi.

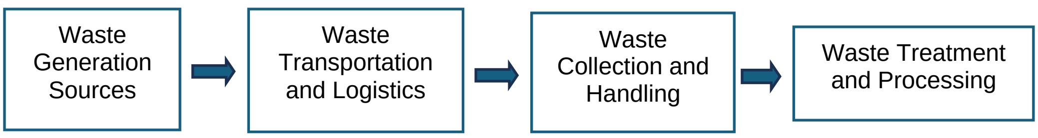

Figure 3. Flow of Organic Waste Management.

In the processing of organic waste, special attention is required, particularly in the design phase which necessitates accurate mapping of location points (**Figure 4**). The proposed site for the establishment of the organic waste processing system is an empty area near the UNJA student dormitory. This consideration is made to ensure that the location does not interfere with the academic activities of the university community.

Figure 4. Layout of Organic Waste Processing Site

The waste processing facility is designed with an efficient layout, consisting of four areas: waste processing, egg hatching, BSF rearing, and residue collection. The materials used are hollow steel measuring 50 mm × 50 mm, with iron mesh of 0.4 mm diameter and insect netting to prevent disturbances from animals. The processing house measures 350 × 300 × 400 cm to ensure that all processing activities can run smoothly (**Figure 5 - 6**).

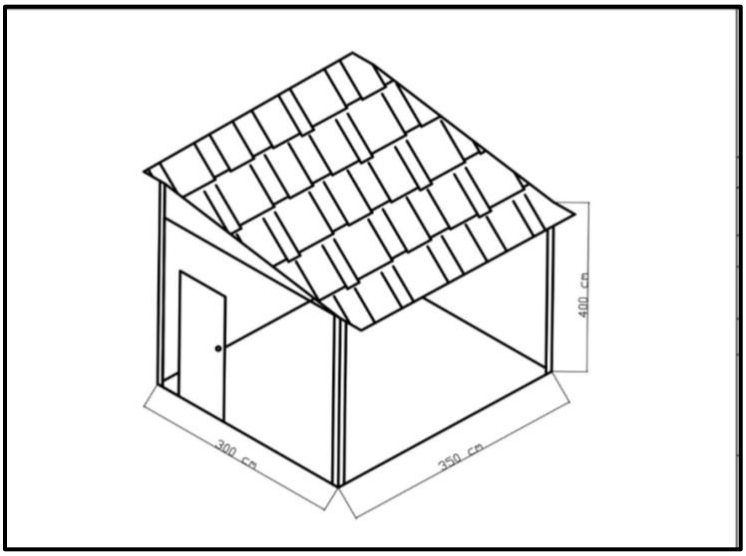

Figure 5. Design of Organic Waste Processing House

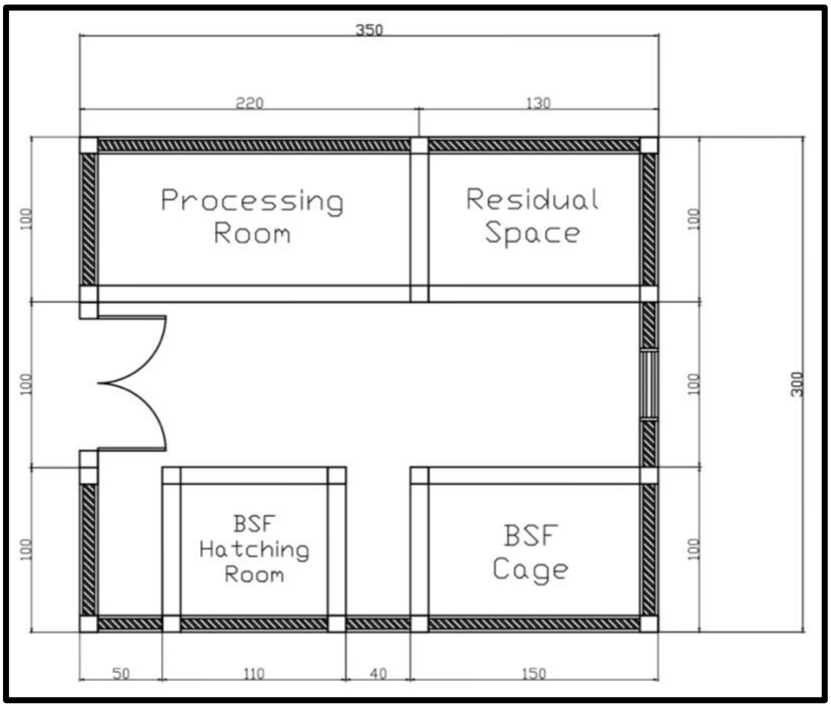

Figure 6. Layout Design of Organic Waste Processing House

The processing area is located near the entrance, with the hatching area facing the processing area, and the residue collection area situated close to the processing area to facilitate the separation of BSF larvae from the residues. The BSF rearing area is placed at the end of the room to avoid disturbances and receive morning sunlight. This design follows the principles applied by Murdowo (2020), who conducted a design study in the Bumi Siliwangi residential area [17]. With a short decomposition time and high effectiveness, this method is suitable for large-scale application on campus. The implementation of this system is expected to be part of the Integrated Waste Processing Site (TPST) program at Universitas Jambi, thereby reducing the volume of waste sent to landfills, improving campus environmental quality, and supporting sustainability through the production of high-quality organic fertilizers.

4. Conclusion

This study demonstrates the significant potential of Black Soldier Fly (BSF) larvae in improving organic waste management at Universitas Jambi. The average organic waste generated by the canteens is 6.42 kg/day, with a projected total of 85.29 kg/day across all canteens. BSF larvae processed 3348 grams of the total 4325 grams of waste provided, resulting in 977 grams of residue, achieving a waste reduction rate of 77.5%. The Waste Reduction Index (WRI) of 5.16% and an Efficiency of Conversion of Digested Feed (ECD) of 9.15% indicate that BSF larvae are highly effective in reducing waste while demonstrating excellent palatability to the various types of organic waste provided.

This research contributes to the optimization of organic waste management through BSF, highlighting the efficiency of bioconversion processes and the potential for large-scale waste reduction. The proposed design for the organic waste management system, located near the UNJA dormitories, consists of four primary zones: waste processing, egg hatching, BSF cages, and residue collection. This integrated system aligns with the Green Campus program and the management objectives of the Integrated Waste Treatment Facility at Universitas Jambi. However, the study has some limitations, including the use of a limited variety of organic waste types and a relatively small-scale research setup.

Further research should explore a wider range of waste compositions, different operational scales, and the long-term effects of BSF larvae on waste reduction efficiency.

Practical recommendations for future implementation include the construction of dedicated waste management facilities, training for waste handlers, and awareness campaigns aimed at encouraging proper waste sorting at the canteens. Additionally, collaboration with the Environmental Engineering study program and continued support from the university are crucial for the successful integration of BSF-based waste management into the university's broader sustainability initiatives.

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