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Potential of Black Soldier Fly Larvae in Reduction Various Types Organic Waste

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ABSTRACT

As an organic waste reducer, Black soldier fly (BSF) larvae are an alternative in overcoming organic waste problems. Environmental conditions, larval density, amount of waste, time of waste application, and type of waste are reasons why the existing organic waste treatment with BSF larvae still needs to be improved. The main objective of this research is to develop the potential of black soldier fly larvae in reducing various types of organic waste (vegetable, fruit, restaurant waste, and mixed waste). To achieve the main objective of this study, the steps taken were analyzing the environmental conditions at the research site, the density of larvae in the reactor, the amount of organic waste, and the time of waste feeding on larval survival and the effectiveness of organic waste reduction. To implement the stage, sample preparation, selection of waste samples, making reactors, starting waste treatment, and measuring the results were carried out. It was found that BSF larvae at temperatures up to 34 °C, pH 8 with a larval density of 200 larvae, feeding 100–200 mg/larvae/day for 21 days were able to reduce organic waste by 84.5% with a waste reduction index value of 4.02%, a digested feed conversion efficiency value of 16.15% and a larval survival rate of 100%. Environmental conditions, larval density, amount of waste, time of waste feeding, and type of waste fed succeeded in reducing organic waste quickly compared to other organic waste treatments.

Keywords: environmental conditions, density, feeding, time, digested feed conversion efficiency.

INTRODUCTION

Currently, waste is a problem faced by almost all countries worldwide, not only in developing countries but also in developed countries, including Indonesia (Humairo and Aisah, 2022). Population growth, regional development, and economic growth are the reasons for the increase in waste generation, both organic and inorganic, which causes problems for the environment (Aprilia, 2021; Salam et al., 2022). Based on data compiled by KLHK in 2023, the amount of waste generated in Indonesia reached 23.19 million tonnes/year, with a composition dominated by organic waste, which reached 41.4%. Likewise, in the research location of Luwuk City where the composition of organic waste reaches 45%. Organic waste is composed of organic compounds that are degradable or easily and naturally decomposed (Palaniveloo et al., 2020). With its degradable nature, if waste is piled up, it causes unpleasant odor problems and disturbs the health of people living around it because it becomes a place for pathogenic organisms to grow. Leachate from landfills due to waste decomposition can pollute river water, well water, and groundwater (Priyambada et al., 2021; Oemar et al., 2023). In addition, organic waste also has the potential to cause greenhouse gas emissions to increase, which affects global warming; this condition emphasizes that organic waste management is essential and needs to be a significant concern (Arfidianingrum et al., 2023).

So far, there have been various kinds of organic waste processing, including anaerobic digestion technology that produces biogas (Davis et al., 2014), thermal conversion technology including pyrolysis, gasification, and incineration to produce electrical energy, gas, liquid (bio-oil and liquid smoke) and charcoal (Octaviani et al., 2024; Yuan and Hasan, 2022). However, applying these technologies has many challenges and obstacles, especially the composition of Indonesian waste, especially at the research location, which is still dominated by organic waste with a moisture content of 60–70% (Romianingsih, 2023). Large-scale implementation must also consider high investment and operating costs, equipment availability, availability of human resource managers, and emissions of air pollutants (Monita et al., 2017). So it is necessary to have a process that is not only environmentally friendly but also does not require a long time, does not require high costs, the availability of raw materials, and ease of processing operations, namely by utilizing black soldier fly larvae (Zahra et al., 2024). BSF larvae can degrade waste compared to other insects (Rahmawati and Rahayu, 2022).

Black Soldier Fly or often called "tantara hitam fly" (Hu et al., 2024) is a type of fly that has a lower risk of spreading disease than other types of flies (Wang and Shelomi, 2017). Black soldier fly larvae have an important role in solving the problem of organic waste because the process is environmentally friendly, and the remaining processing results are not disposed of in landfills because they can be organic compost (Siddiqui et al., 2022). Using larvae from these insects as waste processors is a promising opportunity because the harvested BSF larvae can be helpful as a source of protein for animal feed, so it can be an alternative feed to replace conventional feed (Mertenat et al., 2019; Siddiqui et al., 2024). Some of the other advantages of BSF processing are its fast life cycle (45 days on average), as can be seen in Figure 1 (Ferrarezi and Bailey, 2016), and the operation of the processing plant using affordable facilities with low costs. Therefore, it is suitable for implementation in small urban areas. The easily available feed source makes this cultivation one of the areas of good potential for the community. Therefore, this study aims to develop the potential of black soldier fly larvae in reducing organic waste.

There have been many studies on black soldier fly larvae processing organic waste. However, the efficiency differs due to a need for more attention to environmental conditions (temperature, pH, feed conditions), larval density, amount of waste, time of waste feeding, and type of waste. As a form of improvement, in this study, an experiment was carried out, which was preceded by preparing a larval breeding reactor adjusted to the

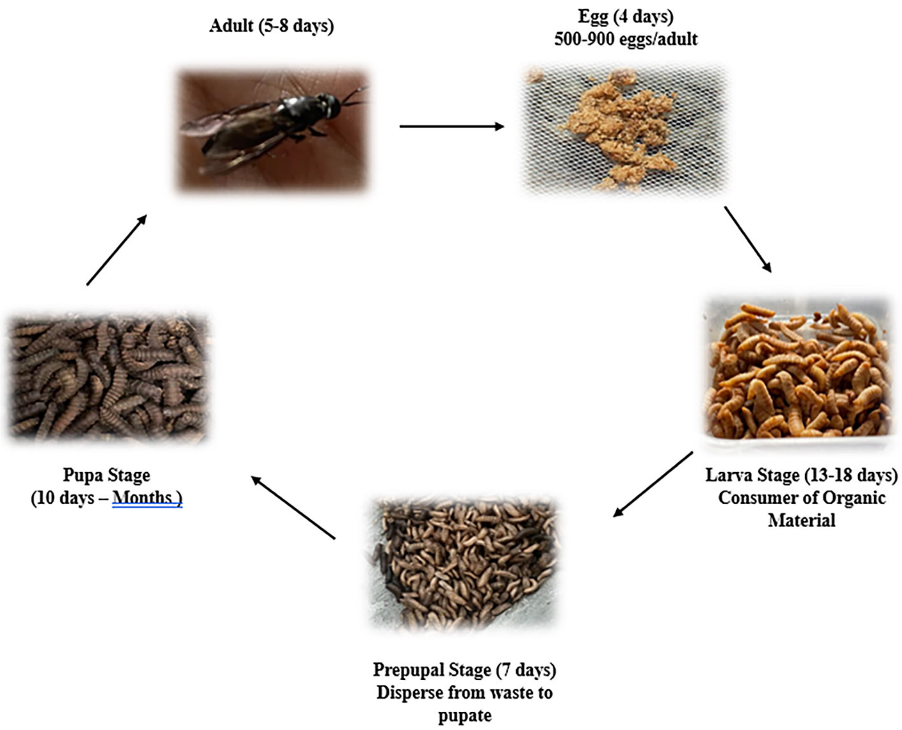

Figure 1. The life cycle of black soldier fly larvae

density of larvae, preparing samples adjusted to the needs of larvae and the frequency of feeding, measuring and adjusting temperature and pH.

MATERIAL AND METHODS

Larvae breeding reactor, waste storage barrel, gauze covering the reactor, digital scale, gloves, pH moisture-meter, temperature monitoring hygrometer, five day-old BSF larvae, vegetable waste from the market, fruit waste from the market, food waste from restaurants, mixed waste.

Matrix research

Table 1 shows the research matrix used in this study. There are eight types of variations, with two repetitions of each treatment.

Scale of research

This research was conducted on a laboratory scale located in Luwuk City, Banggai Regency, Central Sulawesi. This study used 16 small reactors for larval breeding and 8 large reactors to store small reactors. Furthermore, there are four types of waste used, namely vegetable waste, fruit waste, restaurant waste, and mixed waste. This type of waste is selected based on the large composition of waste found in Luwuk City. This study was conducted for 21 days using 200 BSF larvae/reactor with the amount of feed given 100 mg/larvae/day with a frequency of feeding every one day and the amount of feed given 200 mg/larvae/day with a frequency of feeding every three days. Furthermore, measurements of the acceleration of waste reduction were observed every 24 hours by considering environmental conditions such as temperature in the reactor, pH in the waste, and the condition of the waste given, namely chopped and mashed first.

Research reactor preparation

This study used a two-layer reactor. The first reactor used a plastic container measuring 17 × 12 × 5.5 cm with a representative larval density of 1 larva/cm^2, and the second reactor used a plastic container measuring 55 × 35 × 16 cm. Both reactors were designed to prevent BSF larvae from escaping during the feeding and environmental adaptation (Madu et al., 2022). Figure 2 illustrates the BSF larvae rearing reactor and Figure 3 illustrates the reactor layout.

Preparation of waste samples

In the sampling process, the market waste was taken using plastic bags. The organic waste collection process in the market was carried out randomly. The waste in the trash cans is of various types or mixed with inorganic waste until it is sorted first and obtained fruit and vegetable waste consisting of several types of domain fruits such as papaya, banana, mango, orange, grapes, avocado, dragon fruit, and durian. The dominant vegetable wastes obtained were dalundung vegetables, biot vegetables, kale, cabbage, carrots, mustard greens, bitter melon, and papaya leaves. Waste in restaurants is collected using buckets stored in several restaurants and then collected into the bucket. In the research location, several restaurants are lined up along the beach, commonly

Table 1. Research matrix

Reactor code	Waste type	Number of larvae	Feeding frequency	The amount of waste given	Number of repetitions
S.B1	Fruit waste	200	Once a day	100 mg/larvae	2
S.S1	Vegetable waste	200	Once a day	100 mg/larvae	2
S.RM1	Restaurant waste	200	Once a day	100 mg/larvae	2
S.C1	A mixture of 3 waste	200	Once a day	100 mg/larvae	2
S.B2	Fruit waste	200	Once in 3 days	200 mg/larvae	2
S.S2	Vegetable waste	200	Once in 3 days	200 mg/larvae	2
S.RM2	Restaurant waste	200	Once in 3 days	200 mg/larvae	2
S.C2	A mixture of 3 waste	200	Once in 3 days	200 mg/larvae	2

Note: S.S1 = vegetable waste1; S.B1 = fruit waste 1; S.RM1 = restaurant waste 1; S.C1 = mixed waste 1; S.S2 = vegetable waste 2; S.B2 = fruit waste 2; S.RM2 = restaurant waste 2; S.C2 = mixed waste 2.

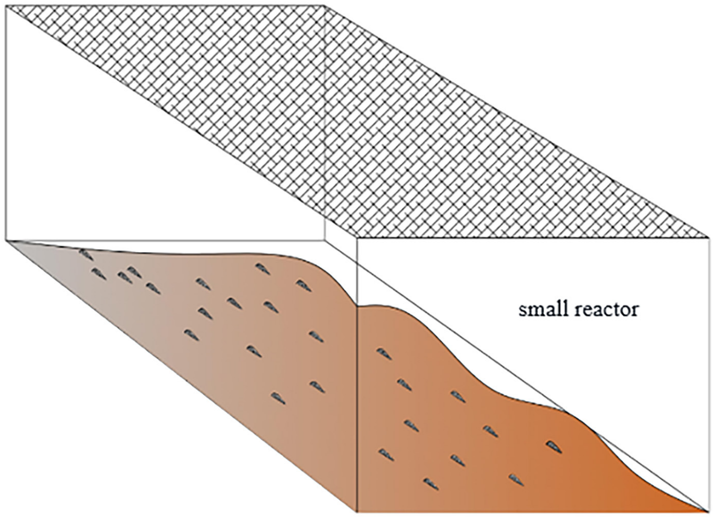

Figure 2. BSF larvae breeding reactor

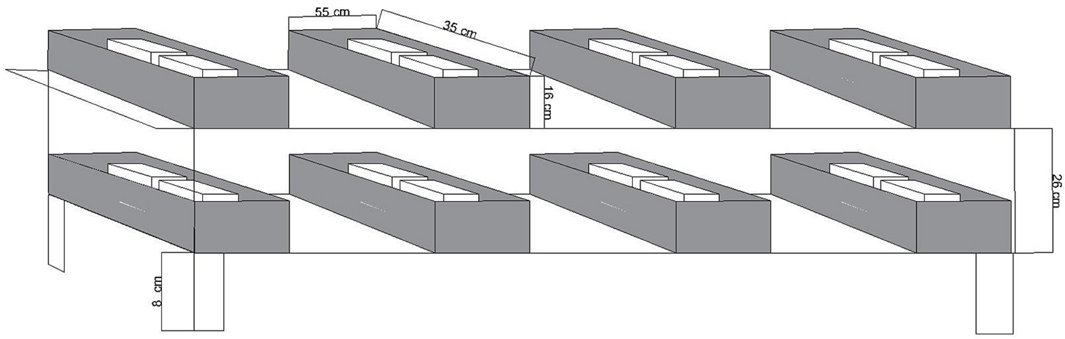

Figure 3. The layout of the reactor

known as Kadompe Restaurant, and the restaurant is one of the icons in the research location. The types of organic waste obtained from Kadompe restaurants are food waste, namely rice, grilled fish, dabu-dabu chili, fried biot, stir-fried kale, onyop, sinole, jepa and fried banana.

After the waste is collected, the waste is washed first to remove dirt and chemicals contained in the waste (Permana et al., 2021) and then chopped and mashed. The chopping and smoothing of this sample is done with the aim that the BSF larvae are more accessible to process because the smaller the size of the material, the faster and better the processing process will be because BSF larvae move more quickly on soft materials compared to soft materials with larger sizes (Yulianingsih and Yani, 2023).

Reactor operating process

The five day-old hatched larvae were counted manually and put into each reactor at the rate of 200 per reactor. Then, the reactors were coded according to Table 1. The maggot observation process was carried out every three days. Larvae were manually separated from the waste with tweezers. Then, the remaining waste in the reactor and the separated maggot were weighed using a digital scale. Ten larvae were weighed, representing 10% of the total number (Pérez-Pacheco et al., 2022). The weighed larvae were then marked with colored paint so that it was known which maggot was being measured. The temperature and pH of the reactor were also measured as controls.

Data analysis

Waste reduction index

Waste reduction index (WRI) by calculating the waste reduction index value (Ayu et al., 2023).

$$D = \frac{W-R}{W} \tag{1}$$

where: D – total waste reduction (g), W – total amount of waste (g), R – total waste remaining after a specific time (g), WRI – waste reduction index (%/day), t – total feeding time of waste larvae (days).

Efficiency of conversion digestedfeed

The efficiency of conversion digestedfeed (ECD) formula for calculating the conversion efficiency of larva digested feed (Pas et al., 2022) where:

$$ECD = \frac{B}{1-F} \times 100\% \quad (2)$$

where: ECD – efficiency of digestible organic waste consumption (%), B – weight gain of larvae during larval feeding period (mg), obtained by subtracting the final weight minus the initial weight of larvae (mg), I – amount of organic waste consumed, obtained by subtracting the initial weight of organic waste feed minus the final weight (mg), F – weight of residual organic waste and excretion products (mg).

Larva weight

Larval weight gain (Guidini Lopes et al., 2023), larval weight, or larval weight (mg), was calculated to determine the trend of larval development. The measurement result is the final larval weight minus the initial larval weight.

Survival rate

SR (survival rate) to identify the survival rate of BSF larvae (Ewald et al., 2020)

$$SR = \frac{y}{z} \times 100 \quad (3)$$

where: SR – survival rate (%), y – number of larvae alive at the end of the study (larvae), z – number of larvae alive at the beginning of the study (larvae).

This study used statistical analysis using two-way ANOVA to determine the effect of variations in waste type, frequency of feeding, and amount of feed on waste reduction and waste reduction index.

RESULTS AND DISCUSSION

pH

The pH measurement was carried out every day using a pH moisture meter. Where the results of the pH parameter test for 21 days of average research with two repetitions can be seen in Figure 4 below. The maximum pH in this study was 8, and the minimum pH was 5.5. According to (Firdausy et al., 2021), BSF larvae can eat almost all types of organic waste variations due to their wide tolerance to food pH, so the results of this

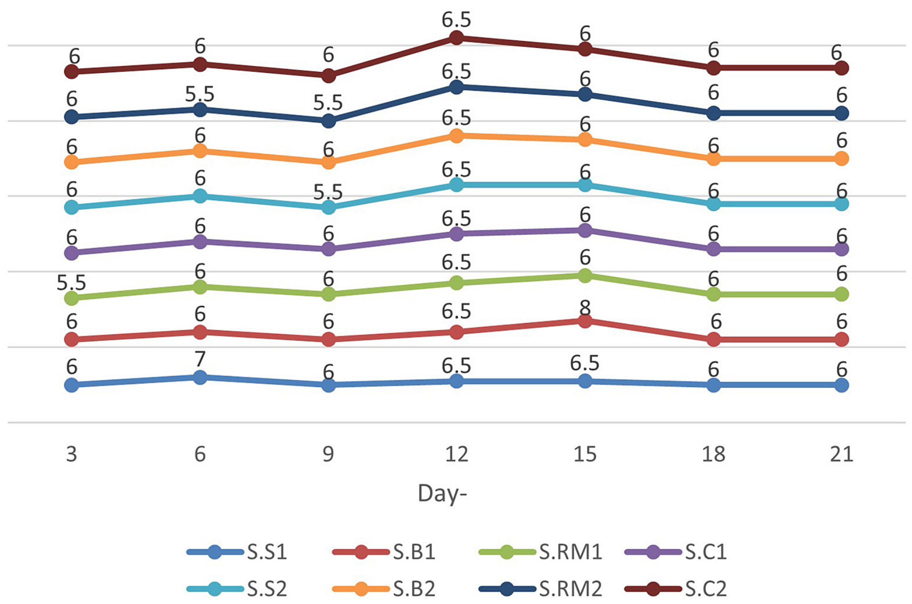

Figure 4. Degree of acidity (pH) (S.S1 = vegetable waste 100 mg/larva/day; S.B1 = fruit waste 100 mg/larva/day; S.RM1 = restaurant waste 100mg/larva/day; S.C1 = mixed waste 100 mg/larva/day; S.S2 = vegetable waste 200 mg/larva/3 days; S.B2 = fruit waste 200 mg/larva/3 days; S.RM2 = restaurant waste 200 mg/larva/3 days; S.C2 = mixed waste 200 mg/larva/3 days)

study also confirm that BSF maggots can still survive and remain capable of breaking down organic waste with a vulnerable pH of 5–8. According to Eawag (2017), maggots or BSF larvae can eat almost all types of organic waste due to their ability to tolerate food pH.

Temperature

Temperature measurements were taken using a digital thermometer with units of degrees Celsius (0C). Room temperature data also affects the growth and development of BSF larvae. The average temperature parameter test results with two repetitions can be seen in Figure 5.

The temperature measurement results were in the range of 30–34 °C, which means that BSF larvae can grow and develop at temperatures up to 34 °C. This is very suitable for the research location in an area traversed by the equator, where sunlight illuminates almost all year round. Measuring and controlling temperature is crucial because it is one-factor affecting larval life. The results of this study are reinforced by the statement that larvae can develop and perform well at optimal temperatures between 27–36 °C (Opare et al., 2022).

Weight of larvae

Measurement of larval body weight gain was carried out every day and every 3 days. The Larval body weight gain was measured every day and every three days. The data obtained is the wet weight of the larvae. Data on larval body weight gain is needed to see how the larvae's ability to decompose organic waste is seen from the increase in larval weight during the rearing period. Measurements were taken using digital scales. Weighing was only carried out on 10% of the total number of larvae as a representative of the total weight of larvae in each reactor (Permana et al., 2021). The average larval weight data were obtained from the study results with two repetitions, as shown in Figure 6.

Based on the data above, the average larval weight gain increased until the 21st day of the end of the study. The most significant increase in larval weight occurred in the S.C1 variation, which is restaurant waste with a feeding rate of 100 mg/larvae/day and the provision of waste once a day, where the larval weight was from 0.45 g to 5.84 g. This good larval weight gain is due to adequate nutrients for larval growth. Larval weight increases with increasing rearing period (Hakim et al.,

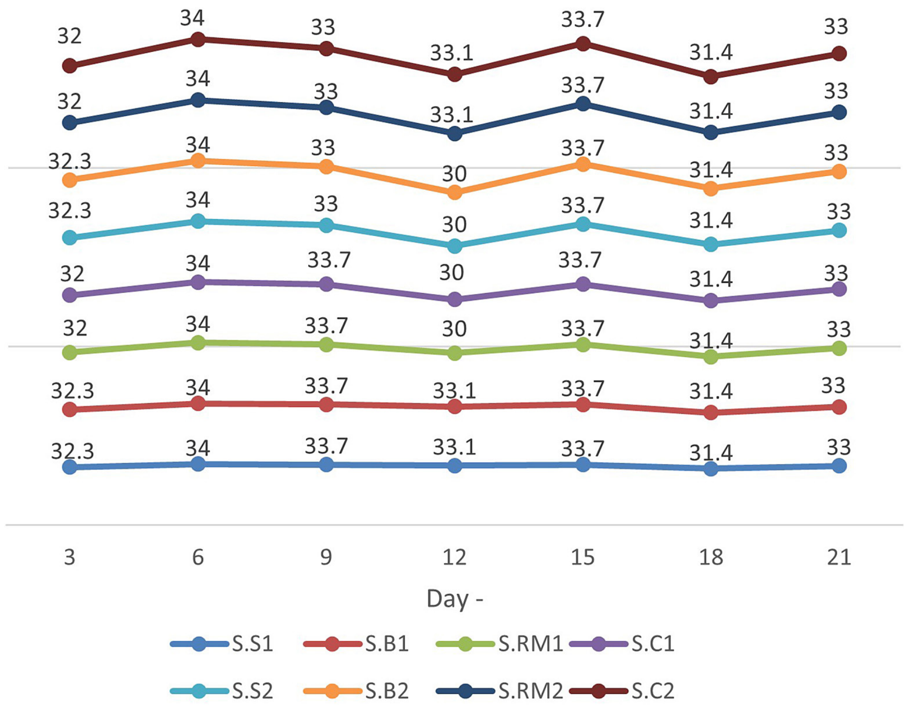

Figure 5. Temperature (S.S1 = vegetable waste 100 mg/larva/day; S.B1 = fruit waste 100 mg/larva/day; S.RM1 = restaurant waste 100 mg/larva/day; S.C1 = mixed waste 100 mg/larva/day; S.S2 = vegetable waste 200 mg/larva/3 days; S.B2 = fruit waste 200 mg/larva/3 days; S.RM2 = restaurant waste 200 mg/larva/3 days; S.C2 = mixed waste 200 mg/larva/3 days)

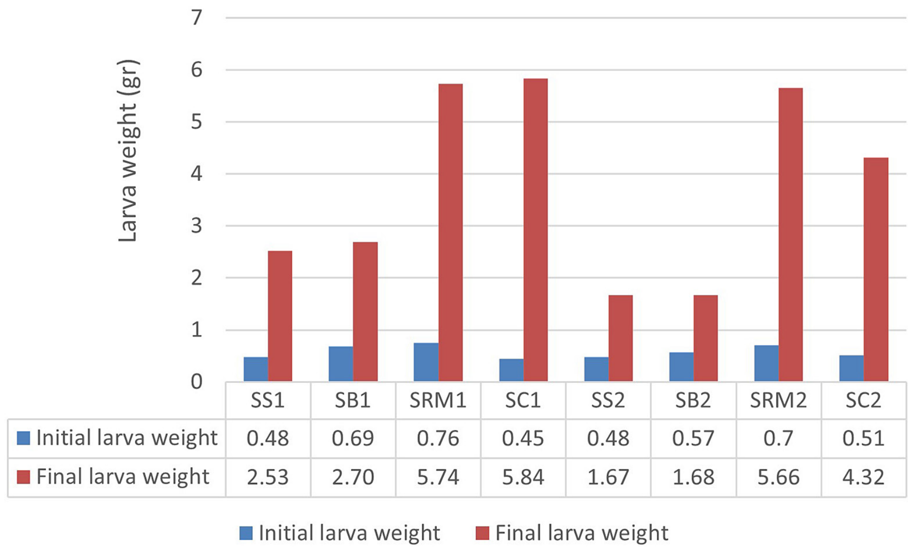

Figure 6. Results of larva weight assessment (S.S1 = vegetable waste 100 mg/larva/day; S.B1 = fruit waste 100 mg/larva/day; S.RM1 = restaurant waste 100 mg/larva/day; S.C1 = mixed waste 100 mg/larva/day; S.S2 = vegetable waste 200 mg/larva/3 days; S.B2 = fruit waste 200 mg/larva/3 days; S.RM2 = restaurant waste 200 mg/larva/3 days; S.C2 = mixed waste 200 mg/larva/3 days)

2017). As with other types of animals, BSF larvae will adjust the rate of food absorption according to their nutritional needs and food availability. If the amount of food nutrients around them is lacking, BSF larvae will slow down their metabolism, which will disrupt larval development and cause the waste reduction rate to be inhibited.

The residual of organic waste

Determining residual waste is based on the amount of residue produced at the end of the study on day 21. The residual waste is measured based on the initial weight of the total organic waste given minus the total weight of the final organic waste given to the BSF larvae. The residual organic waste will be directly proportional to the weight growth of BSF larvae; the higher the waste reduction value, the higher the growth rate, as shown in Figure 6. Another factor determining the value of organic waste reduction is the mortality rate in the reactor, which will be discussed later. The residual waste value for 21 days of observation can be seen in Table 2.

Based on the research data from 8 treatments and two repetitions with a density of 200 larvae per reactor, the amount of feed given and the feeding time for 21 days show that the processing of BSF waste has the potential to reduce various types of organic waste which can be seen from the lack of residual processed waste. The waste that produced the most minor residue was in variation S.C2, from 200 g to 43.4–43.8 g. The waste that produced the most residue was in variation S.B1 from 400 g to 202–200.4 g. This also shows the larvae's preference for the type of waste provided. The residue from the processing results produced by BSF larvae is called kasgot (ex-manggot). Kasgot is the residue from BSF larvae bioconversion of organic waste (Sebayang et al., 2022). Kasgot can be used as a planting medium and organic plant fertilizer. BSF larvae kasgot is

Table 2. Total organic waste residue

Total feed residue (gr)	Number of repetitions	Variation							
		S.S1	S.B1	S.RM1	S.C1	S.S2	S.B2	S.RM2	S.C2
Initial feed	1	400	400	400	400	200	200	200	200
Final feed		190.9	200.4	174.4	167.7	47.2	66.5	44.6	43.8
Initial feed	2	400	400	400	400	200	200	200	200
Final feed		195	202	176.5	171.7	44.8	68.6	45.2	43.4

like compost that can be used for planting media in vegetable cultivation because it is a material that is rich in nutrients needed by plants so that it can produce optimal nutrient content if made into compost (Haryanto et al., 2023).

Waste reduction percentage

The effectiveness of using BSF larvae is determined by reducing food waste, as seen from the percentage of waste reduction. Based on the residual organic waste produced, the percentage of organic waste reduction by BSF larvae can be calculated, as seen in the graphs of the percentage of organic waste reduction by BSF larvae in Figures 7a and b.

Based on the research data from 8 treatments and two repetitions with four types of waste, a density of 200 larvae per reactor, the amount of feed given, and the feeding time for 21 days, it shows that this BSF waste treatment according to Figure 7 can reduce waste up to 84.5%. Based on statistical analysis, the significance value obtained for the effect of treatment (variation of waste type, feeding time, and amount of feed) on waste reduction (Sig.) < 0.05, thus indicating that there is a significant effect on the value of waste reduction. After 21 days of observation, significant results show that black soldier fly larvae have the potential to reduce various types of organic waste by paying attention to influencing factors so that the maximum results are achieved.

Waste reduction index

The organic waste reduction value calculates the WRI value. The WRI value is a method used to determine the level of organic waste reduction at a specific time. The high WRI value is directly proportional to the level of waste consumption,

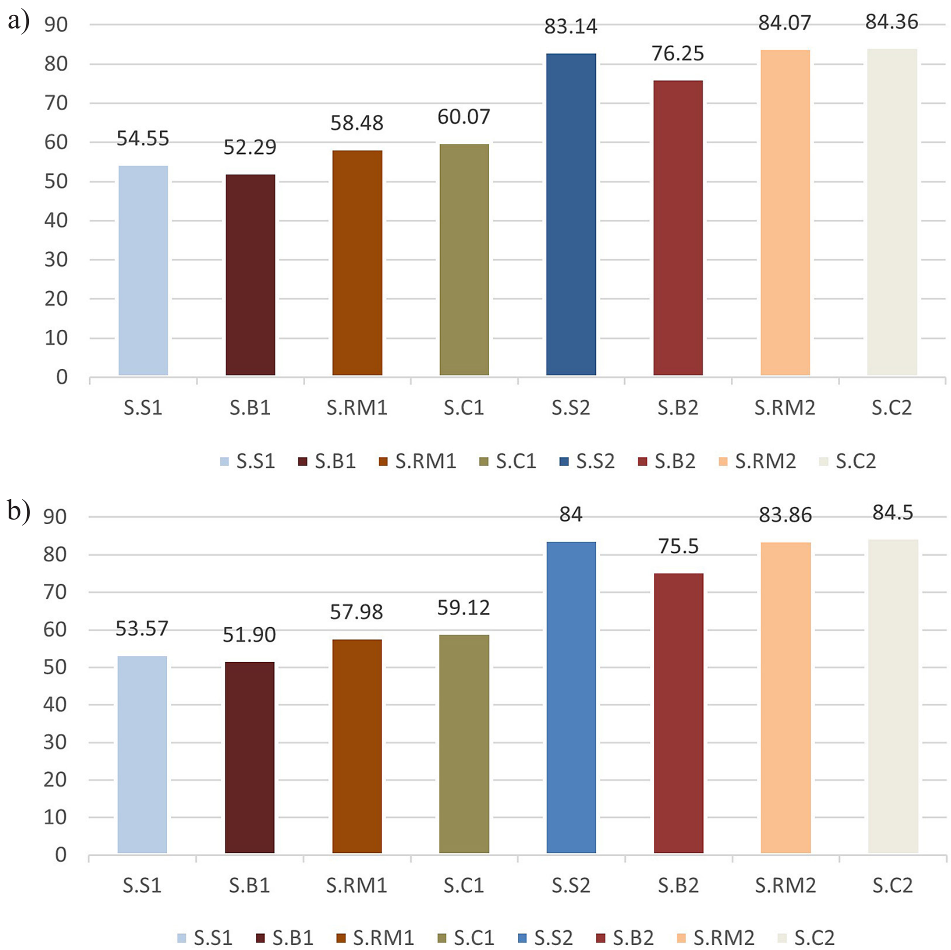

Figure 7. Results of waste reduction percentage at: a) repetition 1 b) repetition 2 (S.S1 = vegetable waste 100 mg/larva/day; S.B1 = fruit waste 100 mg/larva/day; S.RM1 = restaurant waste 100 mg/larva/day; S.C1 = mixed waste 100 mg/larva/day; S.S2 = vegetable waste 200 mg/larva/3 days; S.B2 = fruit waste 200 mg/larva/3 days; S.RM2 = restaurant waste 200 mg/larva/3 days; S.C2 = mixed waste 200 mg/larva/3 days)

meaning that the greater the WRI value, the greater the waste consumption given to BSF larvae. In determining the WRI value, the total reduction value of organic waste must first be known. The overall average WRI value of each replicate and treatment can be seen in Table 3. Based on Table 3, the highest average WRI value of 4.01–4.02% was obtained in the S.C2 waste variation. The eight treatments and two repetitions with four waste types, the density of 200 larvae per reactor, the amount of feed given, and the feeding time of 21 days show that the treatment of BSF waste shows the larvae's palatability/liking for the waste variation which causes the high WRI value. The soft condition of the feed, because it has been chopped and mashed, is also one factor that makes the larvae like the type of waste given, which increases the waste reduction value and affects the WRI value. The different WRI values are also caused by the age of the larvae because, by the time they enter day 15, they have entered the prepupae phase, which causes a lack of larval feed consumption to be reduced (Fakhrieza et al., 2023). Based on statistical analysis, the significance value obtained for the effect of treatment (variation of waste type, feeding time, and amount of feed) on WRI value (Sig.) < 0.05, thus indicating that there is a significant effect on WRI value.

The efficiency of digested waste

The efficiency of conversion of digestedfeed (ECD) value indicates the efficiency level in digesting and storing waste by BSF (Black Soldier Fly) larvae. The higher the ECD value, the greater the level of waste digested by the larvae. A high-quality substrate accelerates the development and growth of the larvae due to adequate nutrition (Mangunwardoyo et al., 2011). The growth of BSF larvae is influenced by external factors such as food availability and temperature in their breeding habitat. BSF larvae will continue to eat the food they like throughout their lifetime, so a stable food supply is essential. If the food in the growth medium runs out, BSF larvae will look for other locations, which can also cause death (Rofi et al., 2021). The ECD values for the four treatments can be seen in Table 4 based on the calculation of waste bioconversion efficiency.

The ECD value is one of the parameters to determine the larvae's ability to digest food. A high ECD indicates that the larvae are more effective at reducing waste to biomass (Rohmanna and Maharani, 2022). Feeding waste that the larvae do not like will cause a lot of waste that the larvae cannot consume, so the increase in BSF larval mass is not proportional to the amount of waste fed, leading to low ECD values.

Survival rate

The survival rate will directly affect the level of organic waste reduction provided in each reactor. This is caused by several factors, including the suitability of the food provided, the density of larvae in a breeding medium, the frequency of feeding, and the condition of the feed provided. This survival rate value will affect the ECD value. Survival rate can be calculated using formula 3. The results of the calculation of survival rate values of all treatments and replicates can be seen in Table 5. Some factors that can also affect the survival rate of larvae include environmental temperature (Josefin Purba et al., 2021). This is also reinforced by the results of this study, which, when referring to the study results, can be concluded that the substrate conditions and environmental temperature in the study are at the optimal point.

Table 3. Waste reduction index

Number of repetitions	Waste Reduction Index (WRI) %							
	S.S1	S.B1	S.RM1	S.C1	S.S2	S.B2	S.RM2	S.C2
1	2.59	2.48	2.78	2.86	3.95	3.63	4	4.01
2	2.55	2.47	2.76	2.81	4	3.59	3.9	4.02

Table 4. The efficiency of digested waste

Number of repetitions	The efficiency of conversion of digestedfeed (%)							
	S.S1	S.B1	S.RM1	S.C1	S.S2	S.B2	S.RM2	S.C2
1	7.00	7.12	10.06	14.26	4.01	5.45	12.67	16.15
2	7.21	7.92	9.99	14.66	3.88	6.04	12.82	15.59

Table 5. Survival rate percentage results

Number of repetitions	Survival rate larva BSF (%)							
	S.S1	S.B1	S.RM1	S.C1	S.S2	S.B2	S.RM2	S.C2
1	98	99	100	100	99	99	100	99
2	99	100	100	99	100	99	99	99

CONCLUSIONS

Based on the research conducted, BSF larvae have the potential to reduce various types of organic waste, as shown by the maximum reduction efficiency in reducing organic waste. Results After 21 days of observation showed that the potential of larvae in reducing organic waste can be seen from the increase in larval weight that occurs where at a density of 200 larvae with 100 mg/larva/day of vegetable waste 0.48 g to 2.53 g, fruit waste 0.69 g to 2.70 g, restaurant waste 0.76 gr to 5.74 g, mixed waste 0.45 to 5.84 g. At a density of 200 larvae, they give 200mg/larvae/3 days of vegetable waste 0.48 g to 1.67 g, fruit waste 0.57 g to 1.68 g, restaurant waste 0.7 g to 5.66 g, and mixed waste 0.51 to 4.32 g. Based on the survival rate, it is known that the average survival rate of each treatment is 99–100%. The most significant percentage of waste reduction was in the treatment of 100 mg/larvae/day mixed waste variation (S.C1) of 60.07%, in the treatment of 200mg/larvae/day mixed waste variation (S.C2) of 84.5%. Based on the waste reduction value, it is known that the WRI value is directly proportional to the percentage of waste reduction value where the most significant WRI value is in the treatment of 100 mg/larvae/day mixed waste variation (S.C1) WRI of 2.86% with an ECD value of up to 14.66%, in the treatment of 200 mg/larvae/day mixed waste variation (S.C2) WRI of 4.02% with an ECD value of up to 16.15%. To the best of the author's knowledge, the potential of larvae in terms of their effectiveness in reducing various types of organic waste is influenced by factors including optimal environmental conditions, the type and condition of the waste, the suitability of the larval density to the amount of feed provided and the frequency of feeding. However, this study did not measure the moisture content of the waste, which also affects the effectiveness of black soldier fly larvae in processing organic waste.

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