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Original Research Article

Utilization of Black Soldier Fly Larvae in Processing Expired Food Waste with Various Composition

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Abstract
The study aimed to evaluate the effectiveness of Black Soldier Fly (BSF) larvae in processing expired food waste with different compositions, including expired instant noodles, bread, and milk, compared to a cassava pulp control. A true experimental design using a Posttest Only Control Group and Complete Random Design was employed. Over 15 days, temperature, pH, moisture, and waste reduction were measured. The results indicated that BSF larvae were most effective in reducing waste when fed expired instant noodles, with a Waste Reduction Index (WRI) of 5.68%, followed by bread (5.61%) and milk (5.47%). The lowest WRI was observed in the cassava pulp control group (5.28%). Statistical analysis using One Way ANOVA showed significant differences in WRI values among the waste compositions, confirming that BSF larvae efficiently reduce organic waste, particularly expired food, offering a sustainable solution for waste management.

Keywords: Black Soldier Fly larvae; expired food; waste; organic waste management; waste reduction index

1. Introduction

Waste is an inevitable by-product of human activities, and its volume has surged dramatically in recent times due to rapid urbanization and global population growth (Minelgaitė and Liobikienė, 2019). In Indonesia, waste generation reached 35.93 million tons in 2022, as reported by the National Waste Management Information System under the Ministry of Environment. This increase in waste, particularly food waste, occurs both at the distribution and consumption levels. Food waste at the distribution level, such as expired products, primarily originates from traditional markets and supermarkets (Todd and Faour-Klingbeil, 2024). Proper management of expired food products is crucial, as careless disposal poses significant risks to public health. When food and its packaging are discarded without proper separation, organic waste becomes contaminated with plastic, leading to waste residues that cannot be recycled and ultimately end up in landfills. Organic waste disposed of in this manner contributes to the emission of methane gas, a potent greenhouse gas (Ugoeze et al, 2021).

One innovative approach to addressing organic waste management is the utilization of the BSF, scientifically known as Hermetia illucens. BSF larvae are highly effective in processing various types of organic waste due to their voracious appetite. They have shown great potential in bioconversion processes, turning organic waste into stable residues and larval biomass that can be repurposed for materials recovery (e.g., animal feed) and energy production (e.g., biodiesel) (Grossule and Lavagnolo, 2020). This makes BSF larvae a promising alternative to conventional waste management practices, offering a sustainable method to reduce the volume of organic waste.

BSF larvae are recognized as one of the most efficient insects for organic waste decomposition. They have been widely cultivated as bioconversion agents, capable of consuming a diverse range of organic materials, including food scraps (Abduh et al., 2022). Their ability to reduce organic waste by nearly 55% of its net weight without producing unpleasant odors further underscores their effectiveness (Salomone et al., 2017). Research indicates that the deployment of BSF larvae can enhance the decomposition process, making them an effective tool in waste reduction efforts (Kim et al., 2021).

In Indonesia, while there has been extensive research on the application of BSF larvae for processing fresh organic waste, there is a limited exploration of their use in managing waste from processed products, particularly expired food items (Josefin Purba et al., 2021). This study seeks to fill that gap by investigating the potential of BSF larvae to improve the organic waste reduction process when applied to expired food waste such as instant noodles, bread, and milk. The findings could be instrumental in developing a more efficient method for managing food waste, which remains a significant environmental challenge.

This research is particularly important as it introduces a novel approach to managing expired food waste, a growing environmental issue. By exploring the effectiveness of BSF larvae in decomposing expired food products, the study could lead to sustainable solutions in organic waste management. The results may not only help in reducing the environmental impact of waste disposal but also present an economically viable waste treatment method. Furthermore, this study could encourage the broader adoption of BSF larvae in waste management practices, especially in Indonesia, where waste management remains a critical concern.

Thus, this research offers a new perspective on utilizing BSF larvae as an innovative and sustainable method to manage organic waste, contributing to both environmental sustainability and economic development in waste management sectors.

2. Method

The research employs a true experimental design, specifically utilizing a Posttest Only Control Group method and complete random design technique. The study focuses on the BSF larvae sourced from Srikandi Maggot Klaten, with samples comprising BSF larvae. Four treatment groups are established: organic waste mixed with expired instant noodles, organic waste mixed with expired bread, organic waste mixed with expired milk, and cassava pulp as the control. Sample size determination is based on the Federer formula, leading to six replications per treatment. Each replication involves 1 gram of BSF larvae per container. Data collection involves the use of digital scales, soil survey instruments, and a soil meter 3 in 1. Research materials include expired food (noodles, bread, milk) from Klaten Regency Main Waste Bank, as well as organic waste, cassava pulp, and coconut pulp. For data analysis, SPSS will be employed to perform statistical tests and model the decomposition process, allowing for a comprehensive evaluation of the effectiveness of BSF larvae in reducing various types of expired food waste.

3. Result

The results of the research that has been carried out for 15 days of observation obtained data on the results of temperature, pH, moisture, and waste reduction The condition of the media that was measured was temperature, pH, and moisture measured using a soil survey instrument and a 3 in 1 soil meter as a result of measuring temperature, pH, and moisture.

3.1. Temperature

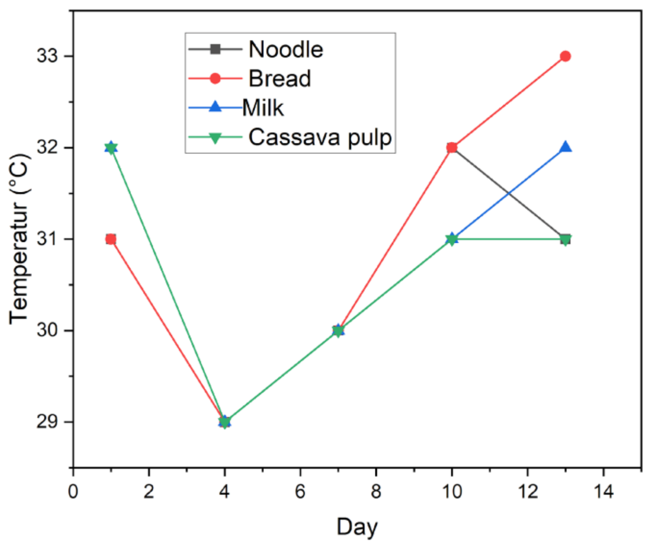

Figure 1. Temperature of BSF Larvae Media

The temperature measurements across all four waste composition groups displayed similar results. The average medium temperature recorded was 31°C. Observations noted a minimum temperature of 29°C and a maximum of 33°C. The graph confirms that the medium's temperature consistently ranged between 29°C and 33°C, indicating stability across the different waste composition variations. This consistent temperature range supports the optimal conditions for Black Soldier Fly larvae to effectively process the expired food waste, as depicted in the residual plot analysis.

2.2 pH

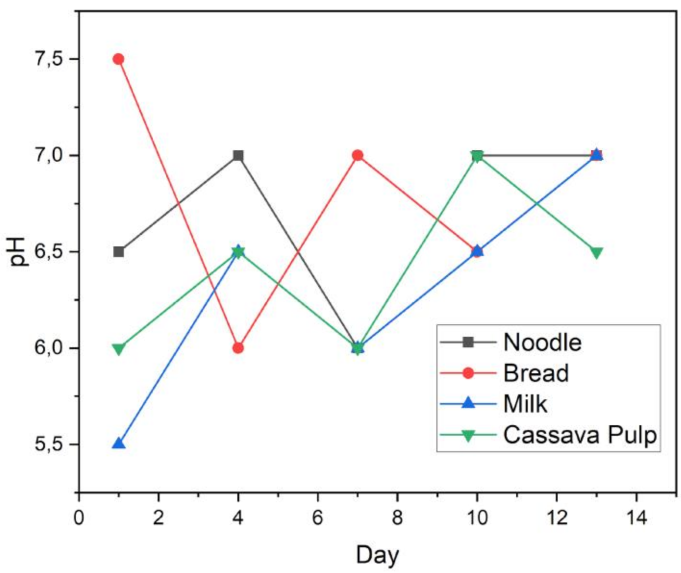

Figure 2. pH of BSF Larvae Media

The data presented in Figure 2 indicates that the average pH level of the media used was 6.5. The pH values recorded in the BSF larval media ranged from a minimum of 5.5 to a maximum of 7.5.

2.3 Moisture

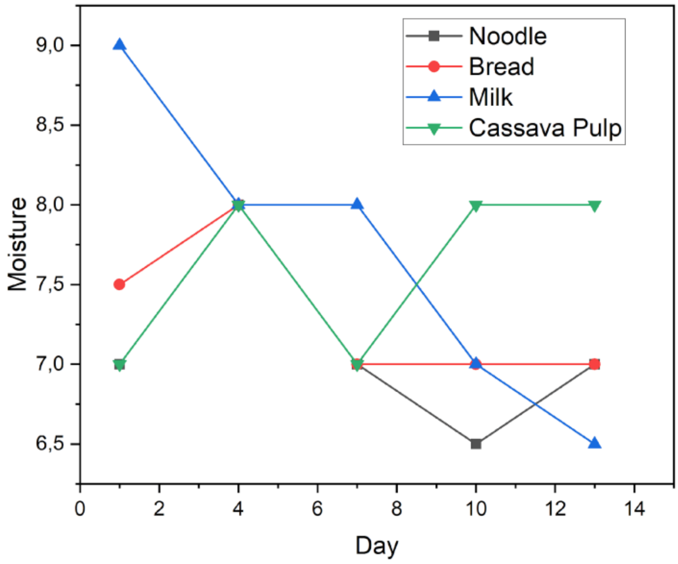

Figure. 3 Moisture of BSF Larvae Media

Moisture measurement using a 3 in 1 soil meter obtained results that showed that the differences in waste composition are not very different. The average moisture is 7, with a minimum moisture of 6.5 and a maximum moisture of 9. The 3 in 1 soil meter, which is a tool used in measuring the moisture of BSF larval media, classifies moisture into three levels: dry ranges from 1-3, moist ranges from 4-7, and wet ranges from 8-10. The results of the study showed that the moisture of BSF moist larval media was in the moisture category.

2.4 Waste Reduce Index

Table 1. Results of the waste reduce index calculation

Replication	Contact length (days)	Waste Reduction Index (%)			
		Noodle	Bread	Milk	Cassava pulp
1	15	5.73	5.6	5.4	5.33
2	15	5.67	5.73	5.53	5.33
3	15	5.8	5.67	5.33	5.27
4	15	5.67	5.6	5.53	5.2
5	15	5.6	5.6	5.4	5.27
6	15	5.6	5.47	5.6	5.27
Average Waste Reduction Index		5.68	5.61	5.47	5.28

Based on Table 1 about the observation of the waste reduction index after being treated based on each variation of waste composition, it can be seen that the highest WRI in the variation of organic waste mixed with expired instant noodles with an average WRI of 5.68%, then in the variation of organic waste mixed with expired bread with an average of 5.61%, in the variation of organic waste mixed with expired milk on average The WRI was 5.47%, and the lowest WRI value was in the cassava pulp control group with an average WRI of 5.28%. The results of the WRI show that the feeding given using a variety of expired food waste mixtures is more optimal compared to feeding the control group using cassava pulp.

Table 2. Normality test results

	Composition of Waste	p value
WRI	Noodle	0.450*
	Bread	0.515*
	Milk	0.507*
	Cassava pulp	0.201*

*significant at $p>0.05$

The results of the WRI data normality test showed that the significance value of the variation of organic waste mixed with expired instant noodles was $p=0.450$, the variation of organic waste mixed with expired bread was $p=0.515$, the variation of organic waste mixed with expired milk was $p=0.507$, and the variation of the cassava pulp control group $p=0.201$. From the four data groups in the results of the data normality test, $p>0.05$ was obtained, which shows that the data is distributed normally.

Table 3. Homogeneity test results

	Composition of Waste	p value
WRI	Noodle	0.236*
	Bread	0.261*
	Milk	0.269*
	Cassava pulp	0.242*

*significant at $p>0.05$

The variant homogeneity test uses the Levene homogeneity test. Based on the results of the homogeneity test, a value of $p>0.05$ was obtained which showed that the data was homogeneous, because the data was homogeneous, a follow-up test was carried out with the One Way ANOVA test.

Table 3. One Way ANOVA WRI test results

	Composition of Waste	N	Mean	p value
WRI	Noodle	6	5.68	0,001*
	Bread	6	5.61	
	Milk	6	5.47	
	Cassava pulp	6	5.28	
	Total	24		

*Significant at $p<0.05$

Based on the results of the analysis in Table 2 with the One Way ANOVA test, a value of $p=0.001$ ($p<0.05$) was obtained, which shows that there is a difference in the WRI value by BSF larvae in each variation of waste. To find out which groups have differences, a post hoc analysis was conducted.

Table 5. Post hoc analysis of WRI comparison between groups

Composition of Waste	Average difference	p value
Noodle and Bread	0.07	0.504
Noodle and Milk	0.21	0.001*
Noodle and cassava pulp	0.40	0.001*
Bread and Milk	0.15	0.026*
Bread and cassava pulp	0.33	0.001*
Milk and cassava pulp	0.19	0.004*

*Significant at $p<0.05$

Based on Table 5, the results of the analysis of the difference in each variation of waste have different p values, the comparison between the provision of variations of organic waste mixed with expired instant noodles and the variation of organic waste mixed with expired bread obtained a value of p=0.504 (p>0.05) which shows a significant difference between the two variations, the comparison between the provision of variations of organic waste mixed with expired instant noodles and variations organic waste mixed with expired milk obtained a value of p=0.001(p<0.05) which showed a significant difference between the two variations, the comparison between the giving of organic waste variation mixed with expired instant noodles and the variation of cassava pulp waste in the control group obtained a value of p=0.001 (p<0.05) which showed a significant difference between the two variations. The comparison between the giving of variations of organic waste mixed with expired bread and the variation of organic waste mixed with expired milk obtained a value of p=0.026 (p<0.05) which showed a significant difference between the two variations, the comparison between the giving of variations of organic waste mixed with expired bread and cassava pulp the control group obtained a value of p=0.001 (p<0.05) which showed a significant difference between the two variations. Finally, the comparison between the variation of organic waste mixed with expired milk and the variation of cassava pulp in the control group obtained a value of p=0.004 (p<0.05) which showed a significant difference between the two variations. Thus, the difference between the WRI value groups was obtained between the groups of noodles with milk, noodles with cassava pulp, bread with milk, bread with cassava pulp, and bread with cassava pulp.

4. Discussion

The temperature of the BSF larvae media ranges from 29-33°C based on the results of the study which can be seen in Figure 1., this shows that the temperature condition of the media in the study is still normal. BSF larvae can develop at an optimal temperature between 28-35°C. BSF larvae will not be able to survive at temperatures less than 7°C at temperatures over 45°C (Shumo et al., 2019).

The decomposition process of waste with BSF larvae requires a temperature of 28ºC-35ºC (Yuwono et al., 2021). A lower BSF larval temperature of 27ºC will slow down the life cycle and growth of BSF larvae compared to a slightly higher temperature of 30ºC. BSF larvae will not be able to survive at 36ºC. This indicates that temperatures higher than 36ºC are not suitable for the survival of BSF larvae (Abduh et al., 2022). Based on all the results of temperature measurements, nothing has crossed the maximum limit of the temperature at which larvae can live. So it can be said that the temperature can be maintained according to the needs of the larvae to live

The measurement results of Figure 2 show the average pH of the media used, which is 6.5. The minimum pH in BSF larval media was 5.5 and the maximum pH was 7.5. BSF larvae have a wide tolerance to food pH, BSF larvae can eat almost any type of organic waste. BSF larvae can survive and decompose organic waste with a vulnerable pH of 4-8 (Amrul et al., 2022)

The moisture of the BSF larval media in Figure 3 is moist which means in the damp category. Optimum BSF larvae live with a moisture of around 60-70% (Nairuti et al., 2022). On the first day of milk waste composition, the moisture showed wet, this was because the moisture content on the first day was more so that the moisture became high. The increase in moisture content in waste is caused by the leachate circulation process carried out to control waste that is not in line with the consumption of BSF larvae (Grossule et al., 2023). The water content in the larval food medium must be sufficiently moist (60–90) so that the BSF larvae can digest it easily (Nairuti et al., 2022)

The value of the WRI is used to calculate the ability of BSF larvae to consume substrate by considering the time or period of feeding. A high WRI value means that the larvae's ability to reduce high bait is also high (Amrul et al., 2022). The WRI value indicates the efficiency of the larvae in reducing the given substrate, as well as indicating the effectiveness of the time required to reduce the substrate. The larger the WRI, the better the substrate reduction efficiency produced (Supriyatna and Putra, 2017). The difference in reduction in this study is influenced by the moisture content contained in the growth medium. Where high water content is also the cause of the lack of waste reduction by BSF larvae. The moisture content of organic waste greatly affects the performance of BSF larvae (Bekker et al., 2021).

BSF larvae can reduce organic waste at a higher rate compared to other types of reducing insects. The calculation of ability and speed of BSF larvae to consume substrates can be calculated using the value of the waste reduction index or WRI (Amrul et al., 2022). BSF larvae that have high reduction ability produce high WRI values (Tirtawijaya et al., 2024). The speed of reduction of organic waste by BSF larvae can be affected by the amount of substrate given and the water content contained in it. The smaller the amount of substrate provided, the more efficient it is for the BSF larvae to reduce it. If the amount of waste provided is high, it will result in a decrease in the WRI value (Amrul et al., 2022). The WRI value represents the efficiency of the larvae in reducing the substrate and the length of time it takes to reduce the substrate (Supriyatna and Putra, 2017).

BSF larvae do not have mouths that function to chew, so substrates that have small parts or even like porridge will make it easier for the larvae to absorb nutrients (Dortmans et al., 2017). A variety of organic waste mixed with expired instant noodles has a texture that is easy to mash, this is because the expired noodles used are soaked first and then mashed with a blender until the texture becomes porridge. Likewise, in the variation of organic waste mixed with expired bread the expired bread used is soaked and mashed until it becomes a porridge, and a variation of organic waste mixed with expired milk for expired milk is enough to be diluted because the milk used is powdered milk. Milk is one of the best mediums for the growth of pathogenic bacteria and fungi in humans, so dairy products must be destroyed as soon as they reach their expiration date (Yang et al., 2023). Meanwhile, the cassava pulp variation as a control for cassava pulp itself has a dense and hard texture, although the cassava pulp variation is also smoothed, the texture of the cassava pulp variation is not as smooth as the pulp in the organic waste variation mixed with expired instant noodles. Cassava pulp contains coarse fiber (Kotatha et al., 2023). BSF larvae have difficulty absorbing nutrients from cassava pulp.

The treatment group showed higher WRI values which means the high waste reduction ability of the control with cassava pulp. Treatment with a variety of expired noodles, bread, and milk waste and mixed with organic waste where expired noodles, bread, and milk are foods that have passed the expiration date listed on the packaging and are no longer safe for consumption. This is because, over time, the food can undergo chemical and physical changes that can support the growth of bacteria, viruses, or fungi. The organic waste used as a mixture comes from food waste, fruits, and vegetables that have decayed. The type of waste that is easy to reduce by BSF larvae is waste that has been fermented or that has undergone decay. The results of the research conducted by (Kim et al., 2021) the high WRI value in the treatment of fermented fruit because the waste has been decomposed by bacteria and has a soft texture, so that reduction becomes faster and easier. The high reduction rate is also due to the amino acid content that reshapes the fiber in the fermented fruit, making it easier for BSF larvae to absorb protein (Yuan and Hasan, 2022).

Waste that has entered the decay phase, so that the texture is softer and easier to digest, so that the palatability level of BSF larvae experiences an increase in the waste reduction value which affects the calculation of the WRI value. According to (Yuan and Hasan, 2022)spoilage is naturally caused by photosynthetic bacteria that produce amino acids, so the food juice contained in the feed is easier for the larvae to consume so that the level of palatability of the larvae in consuming the feed increases and affects the WRI value.

BSF larvae have demonstrated significant potential in waste reduction due to their efficiency in decomposing various organic materials. The study's findings highlight the crucial role of temperature, pH, and moisture in optimizing the larvae's ability to break down waste. These environmental factors, when maintained within suitable ranges, ensure that the larvae can effectively process and reduce the substrate provided to them (Siddiqui et al., 2024).

Temperature is a critical factor, as the larvae's growth and survival are highly dependent on maintaining a specific temperature range. In this study, the temperature was consistently within the optimal range of 29-33°C, which is ideal for the larvae's development. This temperature range ensures that the larvae remain active and can efficiently consume the organic material. Deviations from this range, particularly if temperatures rise above 36°C or fall below 27°C, would significantly hinder the larvae's ability to thrive and perform waste reduction tasks (Salam et al., 2022).

The pH level of the substrate also plays a significant role in the larvae's efficiency. With an average pH of 6.5, the conditions in the study were favorable for the larvae. A pH range between 4 and 8 is acceptable for BSF larvae, allowing them to process a wide variety of organic materials. The larvae's adaptability to different pH levels is advantageous in managing diverse waste streams, making them a versatile tool in waste management (Lopes et al., 2022).

Moisture content, as indicated by the study, is another essential factor. The larvae require a moist environment to efficiently digest and decompose organic waste. In this study, the moisture levels were kept within the optimal range, which is critical for the larvae's activity. On the first day, higher moisture content in certain substrates, like the milk waste, was noted. This was due to the initial water content, which, while high, still fell within the larvae's tolerable range. Proper moisture management is necessary to ensure that the waste does not become too wet, which could hinder the larvae's ability to process it effectively (Yang Xu, 2024).

The study also delved into the WRI, a key metric in evaluating the effectiveness of the larvae in breaking down waste. Higher WRI values indicate that the larvae are efficiently reducing the substrate over a specific period. The variation in WRI observed in the study suggests that factors like substrate type and moisture content directly impact the larvae's performance. Substrates that are easier to digest, such as those that have been pre-processed or fermented, tend to yield higher WRI values. This is because the larvae can more readily absorb nutrients from softer, more broken-down materials (Gonzalez-Piedra et al., 2021).

The physical characteristics of the substrates provided to the larvae also influence their waste reduction capabilities. In the study, expired food items like instant noodles, bread, and milk were processed into a soft, porridge-like consistency before being fed to the larvae. This made it easier for the larvae to consume and digest these materials, resulting in higher WRI values. On the other hand, harder, coarser substrates like cassava pulp proved more challenging for the larvae to process, leading to lower waste reduction efficiency (Lalander et al., 2019).

The findings emphasize the importance of substrate preparation and environmental management in maximizing the effectiveness of BSF larvae in waste reduction. By optimizing temperature, pH, and moisture levels, and by ensuring that the substrates are in a form that is easy for the larvae to digest, the efficiency of waste reduction can be significantly enhanced. This makes BSF larvae a promising solution for organic waste management, capable of handling a wide range of waste types under the right conditions (Debasree Purkayastha, 2022)

Overall, the study demonstrates that with proper environmental controls and substrate preparation, BSF larvae can be an effective tool in reducing organic waste. Their ability to process different types of waste efficiently, even under varying conditions, makes them a valuable asset in sustainable waste management practices.

5. Conclusion

The research conducted over 15 days provides valuable insights into the environmental conditions necessary for optimal BSF larvae activity, as well as their efficiency in reducing organic waste. The observed temperature, pH, and moisture levels were within the acceptable range for BSF larvae survival and waste decomposition. The temperature of the media remained between 29°C and 33°C, which is ideal for larvae development. The pH level, averaging around 6.5, was also suitable for the larvae to process organic waste efficiently. Moisture levels were classified as moist, which is conducive to the larvae's ability to digest the substrate.

Furthermore, the WRI results highlighted the larvae's effectiveness in reducing different types of organic waste. Variations in waste composition, particularly the combination with expired instant noodles, yielded the highest WRI, indicating superior waste reduction efficiency compared to other mixtures. The findings suggest that the texture and moisture content of the waste significantly influence the larvae's reduction capabilities. Overall, this study underscores the potential of BSF larvae as a sustainable solution for organic waste management, with specific environmental parameters playing a crucial role in optimizing their waste reduction performance.

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