International Journal of Public Health Science (IJPHS)
Vol. 13, No. 1, March 2024, pp. 311~318
ISSN: 2252-8806, DOI: 10.11591/ijphs.v13i1.22940

Waste processing without causing public health problems with black soldier fly bioconversion

Afifah Zahra[1], Herdis Herdiansyah[1], Suyud Warno Utomo[1], Nuraeni[2]
[1]School of Environmental Science, Universitas Indonesia, Jakarta, Indonesia
[2]Faculty of Public Health, Universitas Indonesia, Depok, Indonesia

Article Info

Article history:

Received Jan 9, 2023
Revised Sep 28, 2023
Accepted Oct 8, 2023

Keywords:

Bioconversion
Biomass
Black soldier fly
Feed nutrient
Waste processing

ABSTRACT

Bioconversion of black soldier fly (BSF) larvae is a method of processing organic waste that is environmentally friendly and has no impact on public health. This research aims to analyze the influence of the type of waste as a feed formulation on the effectiveness of organic waste processing with bioconversion of black soldier fly larvae. The research was conducted in Tubunan Village, Jepara Regency, the district with the second lowest waste processing in Central Java on 108 families. The initial procedure for this experimental research was carried out by sorting the types of waste (community waste, fish slaughter waste, and a mixture of both). Each type of waste is then given 1.5 grams of larvae/kg of waste. The larvae will be harvested after 20 days and weighed to record data on the increase in biomass and waste left behind. The collected data was then analyzed using SPSS through ANOVA and Kruskal Wallis tests. The results showed that the nutritional formulation of the feed had a significant effect on total larval biomass (p=0.0005) but had no significant effect on the waste reduction index (p=0.651) and feed conversion efficiency (p=0.180). In this study, processing organic waste with bioconversion of black soldier fly larvae reduced waste piles significantly (p=0.008). Thus, bioconversion waste processing using BSF can solve the waste problem at the research location. These findings can be considered in planning effective and efficient waste processing.

Corresponding Author:

Herdis Herdiansyah
School of Environmental Science, Universitas Indonesia
Salemba Raya UI Salemba Campus Street, Kenari, Senen, Central Jakarta City, Jakarta 10430, Indonesia
Email: herdis@ui.ac.id

1. INTRODUCTION

Waste is still a problem in Indonesia. In 2022, waste generation in Indonesia will reach more than 35,000,000 tons/year. This amount increased by 22.8% from the amount of waste generated in the previous year. 34.74% of them have not gone through processing. Food waste dominates. Meanwhile, based on sources, the majority came from households. Central Java has had the most significant incidents in Indonesia in the last three years. The 2022, this province will produce 5.7 million tons of waste [1]. Tubanan Village, Kembangan District, Jepara Regency, is one of the villages under the administrative area of Central Java Province. Jepara Regency generates 2.68 liters of waste/per person/day, with the highest percentage of waste types being organic waste, as much as 57% [2]. Furthermore, in 2020 Jepara Regency was the district with the second lowest managed waste after Grobogan Regency in Central Java, with a managed waste percentage of 18.84% [1]. According to previous observations, the problem in this research is Tubanan Village, Jepara Regency does not have a solid waste management system. Waste using the open dumping method without being processed first. Waste transported in a state has not been sorted by type. Some people manage their waste by throwing it directly into the environment or burning it. Therefore, there is a need for environmental management, including community-based waste management.

Several factors can encourage or hinder effective waste management, such as the number of family members, monthly income, level of education, waste management costs, lack of awareness of waste management, community willingness to participate in solutions, and other factors [3]. The accumulation of these factors shows the importance of low-cost waste management techniques that can overcome socio-economic barriers. Apart from that, waste management can also be done using easy processing techniques, thereby creating a desire for people to participate. It would be better if this processing could be done at the household level. Thus, it can utilize the available natural potential as well as possible. These problems need to be managed. Black soldier fly (BSF) can be one solution to the problem of waste, especially household organic waste.

BSF lives globally, especially in tropical and warm climates. BSF are voracious consumers of decaying plants and animals [4]. The benefit of using BSF is that it can reduce piles of organic waste by up to 80%. Bioconversion processing with BSF can reduce the number of pathogenic bacteria in organic waste, such; as Escherichia coli and Salmonella spp, so that it can avoid diseases due to waste contamination [5]–[9]. Apart from that, black soldier flies are the most promising waste processing tool because of their ability to process and convert waste into economic value [10]. Processing bioconversion waste with BSF can produce fertilizer and feed with economic value and form a circular economy for society. In addition, the method of processing bioconversion waste with BSF larvae does not produce leachate, reduce the mercury and does not cause odor and gas emissions [11]–[15].

To get the maximum benefit, we must pay attention to the supporting factors BSF is an insect that lives in extreme environmental conditions. However, in conducting bioconversion processing, several factors influence the development of the BSF: temperature, nutrition of food sources, and humidity [16]–[20]. BSF can optimize the extraction of organic waste into biomass when the substrate composition is suitable [21]. Research related to the different types of feed nutrition formulas shows that the different types of waste as feed nutrition formulas have a significant impact on the effectiveness of waste processing and showed a result that BSF need a complete nutrition [22]. Waste management using BSF also does not require much time. This reason can answer the problem of people's reluctance to manage waste because it takes up time [3].

In the research conducted on the formulation of feed nutrients, the research focuses on comparing the differences in feed treatment with one of the indicators of processing effectiveness [23], [24]. There has been no research comparing differences in feed treatment with overall processing effectiveness (waste reduction index, larval biomass produced, and feed conversion efficiency). Meanwhile, it is essential to analyze the results of the intervention for all the results that appear simultaneously. This study compares differences in feed treatment with processing effectiveness based on waste reduction index, larval biomass produced, and feed conversion efficiency. The results of this study can be used as a reference for the community to conduct waste processing or in breeding BSF. Thus, we will know whether the formulation of feed nutrients significantly affects the effectiveness of processing and what nutritional formulation of feed is suitable for BSF. This research will provide an overview of the efficiency of appropriate feed conversion based on three feed formulations: community waste, fish slaughter waste, and mixing the two. In the end, it will be a reference, especially for people living in coastal areas, to mix fish slaughter waste and community waste or separate the two when managing them by breeding black soldier flies. These findings will encourage increased efficiency in waste management time, improve management economics, and reduce potential public health problems.

2. METHOD

2.1. Study area

The research was carried out for three months, from October 2021 to December 2021. This research was carried out in RW 5, Tubanan Village, Jepara Regency, Central Java, Tubanan Village, consisting of 7 RW and 43 RT with a total of 4,300 households and a total population of 11,388 residents as presented in Figure 1. The population in this study is all people who live in Tubanan Village, Jepara Regency, Central Java Province. The number of samples taken is based on calculating the slovin formula with a 90% CI, as in (1).

$$n = \frac{N}{1+Ne^2} \quad (1)$$

N = Total population
E = Degree of error
N = number of samples

Based on the preliminary survey data collection, the total population of Tubanan Village is 4,300 families. Then obtained, a sample of 98 families was. To anticipate dropouts, the researchers added 10% of the minimum sample size to obtain a minimum sample of 108 families.

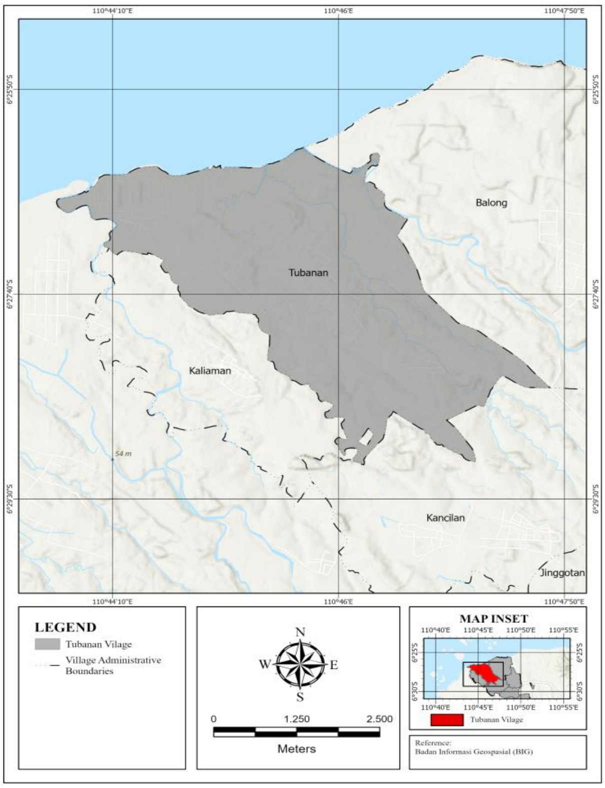

Figure 1. Map of Tubanan Vilage, Jepara Regency, Central Java

2.2. Procedures

The process of collecting research data began with asking the community to sort the waste in their respective homes and then transport it to the processing site. In addition, waste from the community's home environment and waste left over from cutting fish is transported to the processing site. After being transported, the waste will be re-selected to ensure no inorganic waste is mixed in, adjusted in size, making it easier to process, and the waste weighed. Furthermore, the waste was put in 3 different trays according to the type of feed (waste from the community, fish cutting waste, and mixed waste from the two). After that, the BSF, which had been set in advance for seven days, would be included. The larvae used were 1.5 g for 3 kg of waste. The processing took 20 days. After 20 days, the BSF larvae could be harvested. The larvae were weighed for the increase in biomass, and the waste remaining after the process was weighed. The remainder of the waste processing can be used as fertilizer or called KASGOT (ex maggot). After that, it was recorded as observation data, and statistical analysis was conducted.

2.3. Data analysis

Data collection based on waste type screening procedures, comparison of the number of larvae and weight of each type of waste, and time intervention can be a valid approach to collecting data. The data was then analyzed using SPSS statistical software. The Shapiro-Wilk normality test and Levene's Homogeneity of Variance test were respectively carried out to assess the normality and homogeneity of variance to meet the validity assumptions in conducting the ANOVA test. Data is normal if the results of the Shapiro-Wilk normality test have a p-value >0.05. Meanwhile, data is homogeneous if Levene's Homogeneity of Variance test results also have a p-value >0.05. Normal data will then go through ANOVA test analysis. In this study, we used the ANOVA test to determine the significance of the effect of bioconversion processing and reducing piles of waste. Meanwhile, the Kruskal Wallis test will be carried out on data that is not normally distributed. Kruskal Wallis analysis was used to determine fundamental differences between feed formulations and the waste reduction index (WRI), differences in feed nutritional formulations and total larval product biomass, and differences in feed formulations and feed conversion efficiency.

2.4. Ethical consideration

During the research, we asked for approval from all parties concerned, namely households in Tubanan Village. We explain the aim of the study by providing a crucial information sheet. Each household has the right to determine participation in the research. Household members who agreed to participate in this research then signed informed consent. In other words, all participants agreed to participate in this research.

3. RESULTS AND DISCUSSION

The increasing growth of the world's population is driving potential environmental problems, even though the role of the environment is vital in meeting human needs. Humans who are not wise in managing the environment will cause the environment to be damaged in terms of quality and quantity [25]. One of the environmental problems that is linear with population growth is waste. One type of waste that can cause environmental and public health problems is domestic waste. Previous research found that domestic waste is a source of contamination of water bodies and causes *E. coli*. This *E. coli* bacteria caused diarrhea in 2 family members in 5 households in the last six months [26]. Therefore, community participation in waste processing is a priority to solve the waste problem. BSF maggot cultivation can be a waste management technique at the household level, especially organic waste management [27]. Organic waste processing with BSF was conducted for two cycles. It used three different feed formulations: waste from the community, fish-cutting waste, and mixed waste from the two. The composition of the waste collected from the community was dominated by vegetable, fruit, animal feed waste, and carbohydrates from rice waste. Meanwhile, the composition of remain of the fish cutting was protein. The mixture of the two was a mixture of waste from the community and fish cutting. After doing research for two cycles, the results are shown in Tables1 and 2.

Table 1. Results of first cycle organic waste processing

	Processed waste	Residue	Total product biomass	Initial biomass	Waste reduction index	Processed feed conversion efficiency
Waste from the community	97.85 kg	39.4 kg	22.35 kg	18 g	59.73%	38.24%
Fish cutting waste	16 kg	4.9 kg	2.75 kg	3 g	69.38%	24.77%
A mixture of waste from the community and the remain of the fish cutting	22 kg	11.5 kg	4 kg	3 g	47.73%	38.09%

In the first cycle, processing waste with waste feed from the community can produce total product biomass of 22.35 kg or 1241.67 g from every g of larvae used, reducing waste by 59.73%. Furthermore, waste treatment with fish cutting feed can produce total product biomass of 2.75 kg or 916.67 g from each g of larvae used, and it can reduce waste by 69.38%. Meanwhile, waste processing with a mixture of both feed produces total product biomass of 4 kg or 1333.33 g from each g of larvae used, and it can reduce waste by 38.09%. In the second cycle, processing waste with waste feed from the community can produce total product biomass of 10.15 kg or 751.85 g from every g of larvae used, reducing waste by 36.97%. Moreover, waste processing with fish cutting feed can produce total product biomass of 1.5 kg or 500 g from each g of larvae used, reducing waste by 55.67%. Meanwhile, processing waste with mixed feed produces total product biomass of 4.1 kg or 1366.67 g from each g of larvae used and can reduce waste by 15.4%.

Table 2. Results of second cycle organic waste processing

Second cycle	Processed waste	Residue	Total product biomass	Initial biomass	Waste reduction index	Processed feed conversion efficiency
Waste from the community	35.7 kg	22.5 kg	10.15 kg	13.5 g	36.97%	76.89%
Fish cutting waste	15 kg	6.65 kg	1.5 kg	3 g	55.67%	17.96%
A mixture of waste from the community and the remain of the fish cutting	31.86 kg	5.25 kg	4.1 kg	3 g	83.52%	15.4%

Based on the Table 2, it can be concluded that in both the first and second cycles feed formulation which produces the most significant biomass product is a mixed feed formulation between community waste and fish-cutting waste. Meanwhile, the highest waste reduction in the first cycle was in the formulation of fish-cutting waste, with a waste reduction index of 69.38%. In the second cycle, it occurred in the mixed waste feed formulation with a waste reduction index of 83.52%. For feed conversion efficiency in both the first and second cycles, the highest feed efficiency is shown in the waste feed formulation taken from the community, respectively 38.24% and 76.89%.

Furthermore, bivariate analysis was conducted to determine the effect of feed nutrition formulation on the effectiveness of organic waste processing with bioconversion of BSF larvae using Kruskall Wallis test analysis. Based on the Table 3 shows that the mixed waste and fish-cutting waste had the most significant average rating value of 4. It is because of different types of feed which produce the highest waste reduction index from the two cycles conducted. In the first cycle, giving the type of feed left over from fish cutting resulted in the most significant waste reduction index. In contrast, in the second cycle, the most extensive waste reduction index is produced by giving mixed types of feed.

Table 3. Results of Kruskall Wallis test analysis differences in feed formulation with WRI

Variable	Mean rank	p-value
Community waste	2.5	0.651
Fish cutting waste	4	
Mixed	4	

Based on the results of statistical tests as presented in Table 3, it is obtained p=0.651, which means that there is no significant difference in the average waste reduction index between the three types of feed nutrition formulations. In this study, community waste dominated by vegetables and fruit resulted in the lowest average rating of 2.5. However, this study is in line with other research, that feeding kitchen waste with a nutritional composition of waste rich in fat, protein, and carbohydrates can reduce waste by up to 89.66% [22]. The highest waste reduction occurred in feeding mixed waste between community waste and the rest of the fish slaughter in the second cycle at 83.52%. The results obtained from this study have exceeded the results obtained by previous studies. Other research found that the maximum waste reduction generated from bioconversion waste management with BSF is 80% [5], [28]. Another study resulted in a maximum waste reduction percentage of only 52% [29].

The difference in the results of the highest waste reduction in the first and second cycles causes a relationship between differences in feeding and the waste reduction index. Differences in the results of the highest waste reduction in the first and second cycles can be caused by differences in the ratio when feeding. According to another research result, the ratio of feeding differences in food waste has a significant relationship with the waste reduction index (p<0.05). In this study, feeding is highly dependent on the amount of waste generated by the community and the waste generated from slaughtering fish.

The effect of processing bioconversion waste with BSF on reducing the amount of organic waste was analyzed by using statistical tests. The results of the analysis are shown in Table 4. Based on the statistical analysis results, the average waste processed is 36.4, with a standard deviation of 31.24. The average residual waste after processing is 15.03, with a standard deviation of 13.64. It shows the difference in the average value of 21.37 with a standard deviation of 19.29. Statistical test results obtained a p-value of 0.008. Therefore, it can be concluded that there is a significant difference between the weight of waste before processing and the weight of remaining waste after processing. Moreover, this study's results align with another research result which shows that the use of BSF significantly affects the reduction of organic waste, with the highest percentage of waste reduction reaching 82.2% [9].

Table 4. Analysis of the effect of bioconversion processing with reduction of waste piles

Variable	Average	Standard deviation	Standard error	P factor	N
Processed waste	36.4	31.24	12.75	0.008	6
Residue	15.03	13.64	5.57		

The results of the statistical analysis of the effect of differences in feed nutrient formulations with the total biomass of larval products are shown in Table 5. Based on the Table 5, it is found that mixed waste has the most significant average rating value of 36.5. Based on the results of statistical tests, p=0.0005, there is a significant difference in the average total product biomass between the three types of feed nutrient formulations. This research is in line with previous research, which found that the substrate type influences biowaste's bioconversion efficiency into larval biomass [30], [31]. According to another research, the nutrition soce of food that is easily digested by the BSF and can accelerate development is food that is rich in protein and carbohydrates [32]. The result is supported by research result that feeding rich in carbohydrates can accelerate development and produce total biomass of larval products [33]. Different results that fed mixed mackerel fish produced the highest larval biomass compared to feeding grains and sugar beets. Based on this research, protein provides the highest larval product biomass [34].

The results of this study produced different results from the studies mentioned above. The results were that the BSF requires complete nutrition in feed ingredients to increase the biomass of larval products. The same results of research that showed differences in the average total biomass of larvae at different feedings. The order of the smallest to the most significant product biomass produced from this research is fish slaughter residue, community waste, and mixed waste. This is because the rest of the fish cutting produces an unpleasant odor and invites more house flies to perch on the processing site so that the reduced waste is not in line with the increase in total product biomass. Meanwhile, house flies are not infested with waste that is dominated by vegetables, so it is well converted into larval biomass.

Table 5. Results of Kruskall Wallis test analysis differences in feed nutrient formulation with a total biomass of larval products

Variable	Mean rank	p-value
Community waste	19	0.0005
Fish cutting waste	8	
Mixed	36.5	

The results of the statistical analysis of the effect of differences in feed nutrient formulations with feed conversion efficiency are shown in Table 6. Based on the Table 6, it is found that waste from the community has the most significant average rating value of 5.5. Based on the results of statistical tests, p=0.180, there is no significant difference in the average feed conversion efficiency between the three types of feed nutrient formulations. This study does not in line with research result, that differences in feeding have a significant relationship to differences in feed conversion efficiency. The highest feed conversion efficiency was found in the provision of vegetable waste packs of 49.54% [35]. This is in line with the research results, namely that waste from the community dominated by vegetables and fruit produces the highest conversion efficiency in both the first and second cycles. This result in line with another research that kitchen waste with a nutritional composition rich in fat, protein, and carbohydrates can only produce a feed conversion efficiency of 16.65% [22].

Table 6. Results of Kruskall Wallis test analysis differences in feed formulation and feed conversion efficiency

Variable	Mean rank	p-value
Community waste	5.5	0.180
Fish cutting waste	2.5	
Mixed	2.5	

This can be caused by waste rich in fat and protein, especially animal protein, which produces a foul odor and can invite the presence of house flies to join the processing site. Thus, more waste is reduced, but not all of it is converted into biomass in larvae. Feeding vegetable protein can result in higher feed conversion efficiency. The relationship between different types of waste and feed conversion efficiency, which is not significant, can be caused by differences in the ratio of feed given. Using BSF significantly affects organic waste reduction. Feed conversion efficiency is obtained from the percentage ratio of biomass and the amount of reduced waste. Indirectly, the feed ratio difference also affects feed conversion efficiency [9].

4. CONCLUSION

Bioconversion of BSF larvae can make a significant difference in waste reduction. The type of waste used as nutritional feed formulation significantly influences total larval biomass, although it does not significantly influence the waste reduction index and feed conversion efficiency. However, bioconversion waste processing using BSF can be a solution because it can reduce waste well, especially in the mixture of fish slaughter and community waste. These findings can provide input for coastal communities that manage waste by using BSF larvae to mix fish and household waste. Mixing the two types of waste will be more effective than separating the two. Meanwhile, considering there is no waste processing system at the research location, these findings can be used as a reference for effective and efficient waste processing planning. Apart from the need to design a waste processing system, identifying community behavior in processing waste using BSF larvae is another critical need. Thus, further research will be able to elaborate on the behavioral determinant factors related to and most dominantly influence people's behavior in managing waste.

ACKNOWLEDGEMENTS

This research was funded by Internal Grant, School of Environmental Science, Universitas Indonesia 2022, with contract number PKS-0013/UN2.F13.D1/PPM.00.04/2022. We want to convey our gratitude and sincere thanks to Cluster Interaction, Community Engagement, and Social Environment, School of Environmental Science, Universitas Indonesia, who has helped with technical editing and reviewing articles.

REFERENCES

[1] Ministry of Environment and Forestry of the Republic of Indonesia, "Waste management work achievements," Ministry of Environment and Forestry of the Republic of Indonesia. Accessed: Sep. 20, 2023. [Online]. Available: https://sipsn.menlhk.go.id/sipsn/

[2] Directorate General of Public Works and Housing Infrastructure Financing of the Republic of Indonesia, "Recapitulation of provincial waste data," Directorate General of Public Works and Housing Infrastructure Financing of the Republic of Indonesia. Accessed: Sep. 20, 2023. [Online]. Available: https://data.pu.go.id/dataset/tempat-pemrosesan-akhir-tpa.

[3] T. M. Abir, M. Datta, and S. R. Saha, "Assessing the factors influencing effective municipal solid waste management system in barishal metropolitan areas," *Journal of Geoscience and Environment Protection*, vol. 11, no. 01, pp. 49–66, 2023, doi: 10.4236/gep.2023.111004.

[4] A. U. Farahdiba, I. D. A. A. Warmadewanthi, Y. Fransiscus, E. Rosyidah, J. Hermana, and A. Yuniarto, "The present and proposed sustainable food waste treatment technology in Indonesia: A review," *Environmental Technology & Innovation*, vol. 32, p. 103256, 2023, doi: 10.1016/j.eti.2023.103256.

[5] S. N. Rindhe *et al.*, "Black soldier fly: a new vista for waste management and animal feed," *International Journal of Current Microbiology and Applied Sciences*, vol. 8, no. 01, pp. 1329–1342, 2019, doi: 10.20546/ijcmas.2019.801.142.

[6] L. W. Bessa, E. Pieterse, J. Marais, and L. C. Hoffman, "Why for feed and not for human consumption? The black soldier fly larvae," *Comprehensive Reviews in Food Science and Food Safety*, vol. 19, no. 5, pp. 2747–2763, 2020, doi: 10.1111/1541-4337.12609.

[7] I. G. Lopes, C. Lalander, R. M. Vidotti, and B. Vinnerås, "Reduction of bacteria in relation to feeding regimes when treating aquaculture waste in fly larvae composting," *Food Microbiology*, vol. 11, no. 1616, 2020, doi: 10.3389/fmicb.2020.01616.

[8] T. Klammsteiner, V. Turan, M. F. D. Juárez, S. Oberegger, and H. Insam, "Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization," *Agronomy*, vol. 10, no. 10, 2020, doi: 10.3390/agronomy10101578.

[9] N. Fadhillah and A. Y. Bagastyo, "Utilization of hermetia illucens larvae as a bioconversion agent to reduce organic waste," *IOP Conference Series: Earth and Environmental Science*, vol. 506, no. 1, pp. 0–11, 2020, doi: 10.1088/1755-1315/506/1/012005.

[10] B. D. Bajra *et al.*, "Determination of black soldier fly larvae performance for oil palm based waste reduction and biomass conversion," *Journal of Environmental Management*, vol. 343, p. 118269, 2023, doi: 10.1016/j.jenvman.2023.118269.

[11] F. K. Attiogbe, N. Y. K. Ayim, and J. Martey, "Effectiveness of black soldier fly larvae in composting mercury contaminated organic waste," *Scientific African*, vol. 6, no. 1, 2019, doi: 10.1016/j.sciaf.2019.e00205.

[12] M. S. Ayilara, O. S. Olanrewaju, O. O. Babalola, and O. Odeyemi, "Waste management through composting: Challenges and potentials," *Sustainability (Switzerland)*, vol. 12, no. 11, pp. 1–23, 2020, doi: 10.3390/su12114456.

[13] V. Paolini, F. Petracchini, M. Segreto, L. Tomassetti, N. Naja, and A. Cecinato, "Environmental impact of biogas: A short review of current knowledge," *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, vol. 53, no. 10, pp. 899–906, 2018, doi: 10.1080/10934529.2018.1459076.

[14] A. Parodi *et al.*, "Bioconversion efficiencies, greenhouse gas and ammonia emissions during black soldier fly rearing – A mass balance approach," *Journal of Cleaner Production*, vol. 271, p. 122488, 2020, doi: 10.1016/j.jclepro.2020.122488.

[15] J. K. Tomberlin and A. van Huis, "Black soldier fly from pest to 'crown jewel' of the insects as feed industry: An historical perspective," *Journal of Insects as Food and Feed*, vol. 6, no. 1, pp. 1–4, 2020, doi: 10.3920/JIFF2020.0003.

[16] S. Y. Chia *et al.*, "Threshold temperatures and thermal requirements of black soldier fly Hermetia illucens : Implications for mass production," *PLoS ONE*, vol. 13, no. 11, pp. 1–26, 2018, doi: 10.1594/ PANGAEA.895274.

[17] M. Shumo *et al.*, "Influence of temperature on selected life-history traits of black soldier fly (Hermetia illucens) reared on two common urban organic waste streams in Kenya," *Animals*, vol. 9, no. 3, 2019, doi: 10.3390/ani9030079.

[18] S. Raimondi *et al.*, "Effect of rearing temperature on growth and microbiota composition of hermetia illucens," *Microorganisms*, vol. 8, no. 6, pp. 1–13, 2020, doi: 10.3390/microorganisms8060902.

[19] E. A. Ewusie, P. K. Kwapong, G. Ofosu-budu, C. Sandrock, and A. M. Akumah, "The black soldier fly, Hermetia illucens (Diptera: Stratiomyidae): Trapping and culturing of wild colonies in Ghana," *Scientific African*, vol. 5, p. e00134, 2019.

[20] C. Lalander, E. Ermolaev, V. Wiklicky, and B. Vinnerås, "Process efficiency and ventilation requirement in black soldier fly larvae composting of substrates with high water content," *Science of the Total Environment*, vol. 729, p. 138968, 2020, doi: 10.1016/j.scitotenv.2020.138968.

[21] U. Julita, L. L. Fitri, and A. D. Permana, "Bioconversion efficiencies of several food waste by black soldier fly, Hermetia illucens (L.) (diptera: Stratiomyidae) larvae for sustainable waste management," *AIP Conference Proceedings*, vol. 2646, no. 1, p. 20011, Apr. 2023, doi: 10.1063/5.0129600.

[22] S. Mahmood, C. Zurbrügg, A. B. Tabinda, A. Ali, and A. Ashraf, "Sustainable waste management at household level with black soldier fly larvae (Hermetia illucens)," *Sustainablity*, vol. 13, no. 17, p. 9722, 2021, doi: 10.3390/su13179722.

[23] A. Singh, B. H. Srikanth, and K. Kumari, "Determining the black soldier fly larvae performance for plant-based food waste reduction and the effect on Biomass yield," *Waste Management*, vol. 130, pp. 147–154, 2021, doi: 10.1016/j.wasman.2021.05.028.

[24] M. Ichwan, A. Z. Siregar, T. I. Nasution, and E. Yusni, "The use of BSF (black soldier fly) maggot in mini biopond as a solution for organic waste management on a household scale," *IOP Conference Series: Earth and Environmental Science*, vol. 782, no. 3, 2021, doi: 10.1088/1755-1315/782/3/032032.

[25] S. Supangkat, "Analysis of the relationship between the ISO 14001 Environmental management system (EMS) and environmental care behavior," *Journal of Character and Environment*, vol. 1, no. 1, 2023, doi: 10.61511/jocae.v1i1.2023.252.

[26] D. Rosdiana *et al.*, "Chemical and biological contamination of water and air with ARKM: public health risk analysis," *Public Health Risk Assesment Journal*, vol. 1, no. 1, 2023, doi: 10.61511/phraj.v1i1.2023.222.

[27] A. Naldi, "Interaction analysis of youth participation with the household waste management system regarding the existence of local waste treatment facilities," *Interaction, Community Engagement, and Social Environment*, vol. 1, no. 1, 2023, doi: 10.61511/icese.v1i1.2023.186.

[28] P. Nana *et al.*, "Black soldier flies (*Hermetia illucens* Linnaeus) as recyclers of organic waste and possible livestock feed," *International Journal of Biological and Chemical Sciences*, vol. 12, no. 5, p. 2004, 2019, doi: 10.4314/ijbcs.v12i5.4.

[29] G. D. P. da Silva and T. Hesselberg, "A Review of the Use of black soldier fly larvae, hermetia illucens (diptera: stratiomyidae), to compost organic waste in tropical regions," *Neotropical Entomology*, vol. 49, no. 2, pp. 151–162, 2020, doi: 10.1007/s13744-019-00719-z.

[30] I. Hopkins, L. P. Newman, H. Gill, and J. Danaher, "The Influence of food waste rearing substrates on black soldier fly larvae protein composition: a systematic review," *Insects*, vol. 12, no. 7. 2021. doi: 10.3390/insects12070608.

[31] I. Guidini Lopes, V. Wiklicky, E. Ermolaev, and C. Lalander, "Dynamics of black soldier fly larvae composting – Impact of substrate properties and rearing conditions on process efficiency," *Waste Management*, vol. 172, pp. 25–32, 2023, doi: 10.1016/j.wasman.2023.08.045.

[32] B. Dortmans, S. Diener, B. Verstappen, and C. Zurbrügg, *Black Soldier Fly Biowaste Processing*. Switzerland: eawag, 2017.

[33] M. Bonelli *et al.*, "Black soldier fly larvae adapt to different food substrates through morphological and functional responses of the midgut," *International Journal of Molecular Sciences*, vol. 21, no. 14, pp. 1–27, 2020, doi: 10.3390/ijms21144955.

[34] G. Arabzadeh *et al.*, "Diet Composition influences growth performance, bioconversion of black soldier fly larvae: agronomic value and in vitro biofungicidal activity of derived frass," *Agronomy*, vol. 12, no. 8, 2022, doi: 10.3390/agronomy12081765.

[35] I. Kinasih, R. E. Putra, A. D. Permana, F. F. Gusmara, M. Y. Nurhadi, and R. A. Anitasari, "Growth performance of black soldier fly larvae (Hermetia illucens) fed on some plant based organic wastes," *HAYATI Journal of Biosciences*, vol. 25, no. 2, pp. 79–84, 2018, doi: 10.4308/hjb.25.2.79.

BIOGRAPHIES OF AUTHORS

Afifah Zahra is a student of Sekolah Ilmu Lingkungan, Universitas Indonesia. She got her bachelor degree in environmental health from Universitas Indonesia. She can be contacted at email: fifizahra98@gmail.com.

Herdis Herdiansyah is a lecturer who has expertise in Environmental Science, especially in Social Humanities Research and advisory for students and postgraduate students in the Sekolah Ilmu Lingkungan, Universitas Indonesia. He conducts research in the fields of environmental and social sciences, systems thinking, social conflict, and interaction between society and the environment. He can be contacted at email: herdis@ui.ac.id.

Suyud Warno Utomo is a lecturer and advisor for students and postgraduate students in the Sekolah Ilmu Lingkungan, Universitas Indonesia. He conducts research in agricultural biology and its application to the environmental field, environmental impact analysis, and studies of appropriate technology in the environmental field for public health and providing added value to biodiversity. He can be contacted at email: suyudwarno@gmail.com.

Nuraeni is a master student on Faculty of Public Health, Universitas Indonesia. She obtained a bachelor's degree in public health from Hasanuddin University. She can be contacted at email: nuraeni21@ui.ac.id.