ISSN 2338-4344
eISSN 2686-200X

OPEN ACCESS

Jurnal Ilmiah Biologi Eksperimen dan Keanekaragaman Hayati (J-BEKH)

Volume 12, Issue 1, June 2025

Article History
Received: April 15, 2025
Accepted: Juni 10, 2025

Bioconversion of Edamame Soybean Waste Using Black Soldier Fly Larvae on Substrate Consumption and Waste Reduction Index

Biokonversi Limbah Kedelai Edamame Menggunakan Larva Black Soldier Fly Terhadap Konsumsi Substrat dan Indeks Reduksi Limbah

Sofiyah Safitri[1], Novy Eurika[1*], Ika Priantari[1]

[1)]Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Jember
*Corresponding author: eurika@unmuhjember.ac.id

Abstrak

Penelitian ini bertujuan untuk mengukur konsumsi substrat dan indeks reduksi limbah kedelai edamame menggunakan larva *Black Soldier Fly* (BSF) sebagai agen biokonversi. Penelitian ini menggunakan Rancangan Acak Lengkap (RAL) dengan tiga perlakuan: limbah kedelai edamame tanpa fermentasi (F0), difermentasi 7 hari (F7), dan difermentasi 14 hari (F14). Biokonversi yang diamati meliputi konsumsi substrat dan indeks reduksi limbah (*Waste Reduction Index*/WRI). Analisis data menggunakan analisis sidik ragam dengan taraf kepercayaan 5%. Hasil penelitian menunjukkan bahwa fermentasi limbah berpengaruh signifikan terhadap konsumsi substrat dan indeks reduksi limbah. Rata-rata konsumsi substrat tertinggi diperoleh pada perlakuan F14 (57,96±7,37), diikuti oleh F7 (41,61±6,73), dan F0 (28,51±4,97). Begitu pula dengan indeks reduksi limbah, di mana perlakuan F14 menunjukkan reduksi tertinggi (2.37±0,61), diikuti oleh F7 (3.46±0,56) dan F0 (4,83±0,41). Hal ini menunjukkan bahwa semakin lama fermentasi dilakukan, semakin tinggi konsumsi substrat dan efektivitas reduksi limbah oleh larva BSF.

Kata kunci: *Black Soldier Fly*, konsumsi substrat, indeks reduksi limbah

Abstract

This study aimed to measure substrate consumption and waste reduction index of edamame soybean using Black Soldier Fly (BSF) larvae as a bioconversion agent. This study used a Completely Randomized Design (CRD) with three treatments: unfermented edamame soybean waste (F0), fermented for 7 days (F7), and fermented for 14 days (F14). The observed bioconversions included substrate consumption and waste reduction index (WRI). Data analysis used analysis of variance with a confidence level of 5%. The results showed that waste fermentation significantly affected substrate consumption and waste reduction index. The highest average substrate consumption was obtained in treatment F14 (57.96±7.37), followed by F7 (41.61±6.73) and F0 (28.51±4.97). Likewise, with the waste reduction index, the F14 treatment showed the highest reduction (2.37±0.61), followed by F7 (3.46±0.56) and F0 (4.83±0.41). This shows that the longer the fermentation, the higher the substrate consumption and the effectiveness of waste reduction by BSF larvae.

Keywords: Black Soldier Fly, Substrate consumption, waste reduction index

How to Cite: Safitri, S., Eurika, N., and Priantari, I. (2025). Bioconversion of Edamame Soybean Waste Using Black Soldier Fly Larvae on Substrate Consumption and Waste Reduction Index. *Jurnal Ilmiah Biologi Eksperimen dan Keanekaragaman Hayati (J-BEKH)*, 12(1), 95-106. https://doi.org/10.23960/jbekh.v9i1.415

INTRODUCTION

Edamame soybeans (*Glycine max*) are one of the important food commodities in Indonesia, so domestic soybean production needs to increase in certain years due to the increasing population. According to a study from the Indonesian Ministry of Agriculture (2020), figures from the Agricultural Quarantine Agency show that Indonesia's total edamame exports in 2018 were 6,690.7 tons, rising to 6,790.7 tons in 2019. Approximately 66,6% of national edamame exports came from Jember, East Java [1]. Edamame production in Jember Regency has increased significantly and is estimated to dominate the primary production in Indonesia. This regency is also a descendant that produces around 70% of the national soybean needs. As much as 80% of exports are in the form of frozen edamame [2]. This significant growth has caused problems in waste accumulation, resulting from edamame waste from pods, stems, and seeds that do not meet export standards [3].

Local governments have noted that they are almost unable to manage waste using the conventional method of collection, transport, and dumping, which is inefficient in reducing waste volume and very expensive in terms of [4]. The Indonesian Ministry of Environment and Forestry (2019) also stated that 50% of the total waste of 175,000 tons per day, namely organic, especially food and plant waste, is one of the waste streams made from the processing of edamame soybeans [5]. Waste produced from the processing process can be broadly divided into 3: solid waste in the form of skin, fruit skin, and edamame trees. Soybeans are considered to have no economic value and have a relatively large volume of validity, so they can pollute the environment [6].

Edamame soybean waste has extraordinary potential as a mixture of active ingredients based on useful sources because of its significant bioactive content, as with other types of bioactive compounds identified in edamame soybean waste, namely flavonoids [7]. Qualitatively, previous research has shown that edamame waste extract contains 40 ppm of flavonoids, which is relatively high compared to the range of flavonoid content in various soybean varieties, namely 12 to 42 ppm [8]. This potential opens up opportunities to utilize edamame soybean waste more optimally, one of which is through the bioconversion method that can convert this waste into value-added products. One approach that can be applied is bioconversion using Black Soldier Fly (BSF) larvae (*Hermetia illucens)* [9]. This method processes waste into valuable biomass, contributes to waste management, and supports food independence. BSF larvae efficiently convert organic waste, such as edamame soybean waste, into biomass with a protein content ranging from 30-45% and a fat content between 24-30% [10]. In addition, BSF has been proven effective in converting various types of organic waste into nutrient-rich biomass, which has high nutritional value and economic value [11].

The disadvantage of BSF larvae is that they do not have lignin-degrading enzymes in their digestive tract, so they cannot digest feed materials containing high lignin and cellulose. This can be overcome by physical, chemical, and even biological treatment of the substrate used. Biological treatment, namely substrate fermentation, is a simple and effective method. Substrate fermentation increases protein content and reduces antinutrients, thereby increasing the digestibility of BSF [12]. Various studies have shown that applying pretreatment to agro-industrial waste, such as fermentation, can increase substrate digestibility by BSF larvae. Agro-industrial waste generally has a high crude fibre and lignin content, making it difficult to degrade directly by BSF larvae. To overcome this, initial treatment is done through fermentation using biological agents such as Effective Microorganisms-4 (EM4). The fermentation of organic waste with EM4, nitrogen, phosphorus, and potassium levels in the resulting compost increases, indicating an increase in the availability of nutrients for BSF larvae [13].

This pretreatment process reduces the crude fibre content and increases the availability of nutrients through the activity of microorganisms that produce enzymes, such as cellulase and ligninase. Therefore, fermentation as a pretreatment method has proven effective in overcoming the limitations of agro-industrial waste as a growing medium for BSF larvae. With high nutritional content, such as crude protein of around 41-42%, fat of 31-35%, and important mineral content, such as calcium and phosphorus, BSF larvae have a strategic role as an agent for organic waste bioconversion. Its metabolic capabilities allow BSF larvae to consume various organic waste and decompose it efficiently. This is reinforced by research [14], which states that BSF larvae can significantly reduce the volume of organic waste through the bioconversion process [14]. In addition, a study [15] also showed that BSF larvae could reduce up to 80% of organic waste in a relatively short time without causing odor or negative impacts on the environment [15]. This efficiency makes BSF larvae an ecological solution in waste management while supporting a circular economy approach and sustainable waste management system. This study aims to determine the substrate consumption and reduction index of edamame soybean waste using BSF larvae.

METHODS

This research was conducted at the Basic Laboratory of the University of Muhammadiyah Jember, Jember Regency, from February to April 2025. The tools used were large tubs, thin-walled plastic, and stirrers. The materials used were BSF larvae, edamame soybean waste, EM4, and water.

Bioconversion research using BSF larvae was conducted using a Completely Randomized Design (CRD) with 1 factor, namely substrate fermentation treatment consisting of 3 levels, including F0 unfermented edamame soybean waste; F7 was fermented for 7 days; and F14 was fermented for 14 days. The treatment used 500 BSF larvae that were 6 days old in each reactor, with three types of treatments consisting of unfermented edamame soybean waste (F0), fermented for 7 days (F7), and fermented for 14 days (F14). The parameters observed included substrate consumption and the waste reduction index (WRI); data analysis was carried out based on data obtained from the study, then tabulated using the Microsoft Excel 2019 application and analysed using the SPSS 25 application with the One-way ANOVA analysis method and continued with the Duncan's Multiple Range Tests (DMRT) at a confidence level of 5%.

Preparation of edamame waste feed media

This study used dried edamame soybean waste as a feed substrate for BSF larvae. The waste was obtained from local farmers in Bondowoso Regency. There were three treatments: waste without fermentation (F0), waste fermented for 7 days (F7), and waste fermented for 14 days (F14). The waste was first cleaned of dirt, dried in the sun, and ground using a grinding machine. Fermentation was carried out with an activated EM4 solution using 30 mL of EM4, 6 grams of brown sugar, and water up to 3000 mL. The shredded waste was washed and squeezed with an EM4 solution using a ratio of 2000 grams of waste: 3000 mL of solution (1:1.5), then fermented anaerobically for 7 and 14 days according to the treatment.

Treatment of Test Larvae

The subjects of this study were six-day-old BSF larvae obtained from the BSF farm in Ambulu, Andongsari, Jember Regency. The larval rearing process was carried out intensively in 2000 ml thin-wall containers, with 500 larvae per container. The feed given was edamame soybean waste in both fermented and non-fermented conditions. The feeding frequency was adjusted to the growth of the larvae, which was once every three days with a dose of 45 mg per reactor. After being reared for 12 days, the larvae that had reached the age of 18 days were then harvested before entering the pre-pupa stage for further observation.

Observation

The parameters observed include substrate consumption and waste reduction index (WRI). Substrate consumption is the process by which BSF larvae take and decompose food or growing media provided to meet their nutritional and energy needs. Substrate consumption measurement is done by calculating the difference in substrate weight before and after being consumed by the test organism, which can be calculated using the formula [16] :

$$\text{Substrate Consumption} = \frac{\text{Initial mass of substrate} - \text{final mass of substrate}}{\text{Initial mass of substrate}} 100\%$$

The waste reduction index (WRI) measures waste reduction by larvae over 3 days. The value of this waste reduction can be calculated using the formula [16] :

$$WRI = \frac{D}{t} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots (1)$$

$$D = \frac{W-R}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Description:

W: Total weight of feed given (g)

t: Experiment duration (days)

R: Total residue during the experiment (g)

D: Overall feed degradation

WRI: Waste Reduction Index

RESULTS AND DISCUSSION

This study was conducted by treating six-day-old BSF larvae using F0, F7, and F14 feed media. Observations were made for 12 days, focusing on substrate consumption and waste reduction index. After observing and measuring substrate consumption, the results are presented in Table 1.

Table 1. Average Substrate Consumption by BSF on Edamame Waste Feed Media

Treatment	N	Average Substrate Consumption (%)
F0	9	28,51±4,97[a]
F7	9	41,61±6,73[b]
F14	9	57,96±7,37[c]

Based on the data in Table 1, it is shown that substrate fermentation treatment had a significant effect on the average substrate consumption. The average substrate consumption in F0 was 28.51 ± 4.97; in F7, it was 41.61 ± 6.73; and in F14, it was 57.96 ± 7.37. F14 showed a higher average percentage of substrate consumption than F7 and F0, whereas F0 showed the lowest percentage compared to F7 and F14. This can be explained by the longer/optimal fermentation time on edamame waste, which caused the average percentage of substrate consumption to increase. The substrate fermentation can increase digestibility and palatability for BSF larvae so that substrate consumption is higher. This finding aligns with research by [17], which states that substrate fermentation with certain microorganisms can increase the consumption and growth of BSF larvae [18]. In addition, [19] reported that the duration of fermentation also affects the efficiency of substrate consumption by larvae, although it does not directly affect their nutritional content [19]. This indicates that the more optimal the fermentation process applied, the greater the larvae's ability to consume the substrate throughout the rearing period consistently.

The study's results by [17] explained that fermented waste affects the amount of waste consumption, whereas unfermented waste is 2.17. The variation of feed using EM4 fermentation is 2.80, and the value of the variation of blood-fermented waste is 3.03 [17]. The study's results conducted by [18] also explain the range of substrate consumption in BSF. The study's results obtained values that varied from 40.72% to 72.05%. In the type of fermented waste, 100 mg/larva/day (C1) has the highest value of 72.05%, and the lowest value is 40.72% in carrot and radish waste, 200 mg/larva/day (B3) [18]. Both studies explain that it is directly proportional to the research results, where waste that received fermentation treatment was consumed more by BSF larvae.

The substrate consumption pattern by BSF larvae is explained through a line diagram representing the amount of substrate consumption every three days during the 12-day rearing period. The graph in Figure 1 shows the differences in consumption levels in the three reactors used in the study.

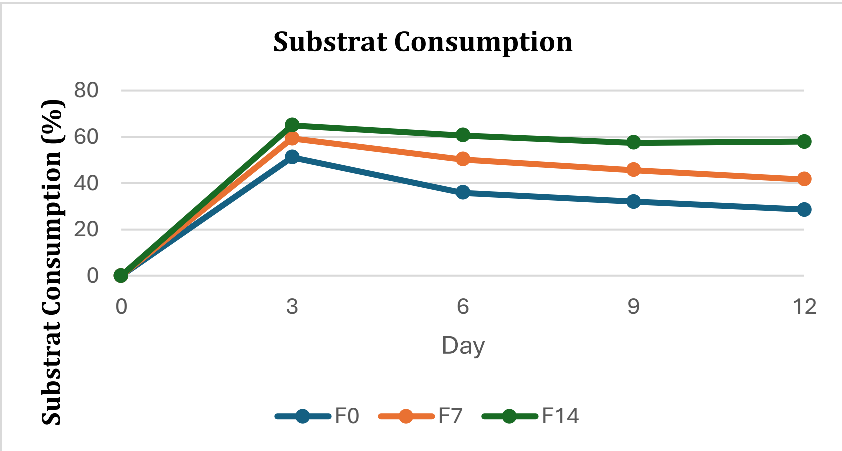

Figure 1. Substrate consumption by BSF on edamame waste feed media during 12 days of observation

Based on Figure 1 regarding the graph of substrate consumption by BSF larvae for 12 days, it can be seen that the substrate fermentation treatment affects the larval consumption pattern. The same pattern is observed in all treatment reactors (F0, F7, and F14), indicating that a decrease in substrate consumption percentage as the larval rearing period increases is closely related to the natural transition of larvae from the active phase to the prepupa phase. This is supported by [16], who reported that waste consumption peaked between days 5 and 11 post-hatching when the larvae were still in the active feeding. The highest substrate consumption in reactors F0, F7, and F14 occurred on the third day of observation (the ninth day of larval hatching), with respective values of 51.1%, 53.9%, and 64.9%. Substrate consumption values continued to decline until the 12th day of observation. These results are consistent with the findings of [20], who explained that as larvae approach the prepupal stages (around days 14 to 18), they cease feeding and prepare for pupation.

In addition to substrate consumption, this study also measures the waste reduction index (WRI). WRI is the ability of larvae to reduce the feed substrate over a specific time. The WRI measurement results in this study are presented in Table 2.

Table 2. Average Results of the Duncan Test Waste Reduction Index

Treatment	N	Average Waste Reduction Index
F0	9	2.37±0,41[a]
F7	9	3.46±0,56[b]
F14	9	4.83±0,61[c]

Table 2 shows the results of the Duncan Advanced Test analysis, which shows significant differences between treatments in the effectiveness of waste reduction by BSF larvae. The table shows an increase along with the treatment given. The F0 treatment has an average waste reduction index of 2.37 ± 0.41; in the F7 treatment, the average value increased to 3.46 ± 0.56. This increase is even more significant in the F14 treatment, with the highest average waste reduction index, 4.48 ± 0.61. The increase in the waste reduction index value in each treatment in this study is in line with the results of previous studies, which also show that fermentation treatment on the substrate can increase the efficiency of waste consumption by BSF larvae.

The results of the research are in line with the results of the research conducted. Their research explained that the value of each bait variation for BSF larvae, including organic waste, was 2.17. The feed variation using EM4 fermentation was 2.80, and the value of the blood fermentation waste variation was 3.03 [17]. The study's results also explained that waste fermented for 7 days experienced , a reduction of 54.71%. Waste fermented for 10 days reduced waste by 62.97%, while waste without fermentation experienced a reduction of 50.67% [19]. In a study by [21] BSF, larvae were cultured on various domestic waste substrates with variations in feed rates of 60, 80, and 100 mg/larva/day. The results showed that the highest substrate consumption occurred in a mixture of rice waste and cassava leaves with a feed rate of 60 mg/larva/day, resulting in a substrate consumption of 65.82% and a WRI of 18.02%. This shows that adequate substrate consumption correlates with increased WRI [21]. From the explanation above, it can be concluded that the average waste reduction achieved by fermentation treatment was better than that of the control treatment. Fermentation treatment is thought to increase the palatability and digestibility of the substrate, thereby increasing larval feeding activity and accelerating the bioconversion process of organic waste.

The average waste reduction index measurement was used to measure BSF's ability to reduce edamame waste that received three treatments. The average reduction of edamame waste during 12 days of observation is shown in Figure 2.

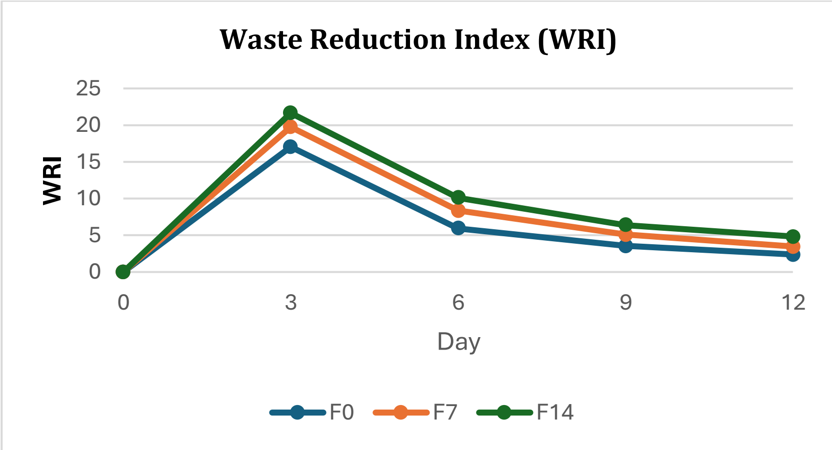

Figure 2. Waste reduction index from edamame by BSF during 12 days of observation

Based on WRI data by BSF larvae during 12 days of observation, in reactor F0, the WRI value on the third day of observation was 17,04, then decreased to 5,97 on the sixth day of observation, then to 5,07 on the ninth day of observation, and further decreased to 2,37 at the end of the observation period (day 12). The same pattern was also observed in the other two treatments (F7 and F14), where the WRI value decreased as the rearing period for the larvae was prolonged. This is directly related to the physiological development phase of BSF larvae. In the early stages of rearing, young larvae exhibit high feeding activity. Then, in the middle phase, the larvae develop into prepupae, and their feeding rate decreases. In the final prepupa phase, the larvae stop feeding and become pupae. According to [16] the WRI, it reaches its optimal value when the larvae are in their active feeding stage. Furthermore, the efficiency of waste reduction begins to decline.

The research result also indicates a direct relationship between substrate consumption and WRI value across all treatments, meaning that the higher the substrate consumption by the larvae, the higher the WRI values attained. This finding aligns with the research results, which indicate that the increase in substrate consumption by BSF larvae positively correlates with the WRI value, reflecting efficiency in the waste reduction process over a specific period [22]. In addition, it reported that the substrate fermentation process significantly increased the effectiveness of reducing biodegradable organic waste through a BSF larvae-based bioconversion system [19]. These two findings indicate that fermentation increases larval consumption and accelerates waste decomposition, thus supporting more efficient organic waste management.

The results of this study are also in line with research [23] that found that BSF larvae fed fermented fruit waste achieved a waste reduction of 46.25% [23]. These findings indicate that substrate modification, such as fermentation, can improve the efficiency of waste reduction by BSF larvae. These results are in line with the increasing trend of the waste reduction index that occurred during 12 days of rearing, where substrate consumption is directly proportional to the level of waste reduction. The increase in substrate consumption by BSF larvae contributes to the increase in the rate of decomposition and utilization of nutrients in organic waste, which further accelerates the bioconversion process. To support this finding, further statistical analysis was conducted to test the differences in waste reduction indexes in various treatments. Duncan's test evaluated the significance of differences in the average WRI during 12 rearing days.

CONCLUSION

Substrate fermentation treatment has been shown to significantly impact increasing substrate consumption, where larvae given substrate with longer fermentation (F14) showed the highest consumption compared to treatments F7 and F0. Substrate consumption by BSF larvae is directly proportional to the waste reduction index (WRI). The higher the substrate consumption, the greater the waste the larvae can reduce. This increase in consumption directly impacts the increased efficiency of waste reduction by larvae, as shown by the higher waste reduction index in treatments with longer fermentation. Fermentation treatment is thought to increase the palatability and digestibility of the substrate, thereby increasing larval feeding activity and accelerating the bioconversion process of organic waste.

REFERENCES

[1] F. S. Wibowo, H. Prayuginingsih, and M. Muliasari, "Analisis Trend Produksi Kedelai Edamame di PT Gading Mas Indonesia Teguh Kabupaten Jember," UMJember Proceeding Series. vol. 2, no. 5, pp. 1–11, 2024.

[2] A. M. Setiawan, "Jember Pengekspor Edamame Terbesar di Indonesia." Accessed: Jan. 13, 2025. [Online]. Available: https://jember.inews.id/read/225334/jember-pengekspor-edamame-terbesar-di-indonesia

[3] S. Wulandari, "Mengatasi Masalah Pembusukan Limbah Kulit Edamame sebagai Bahan Makanan Ternak dan Perbaikan Sanitasi dengan Aplikasi Pengepres Hybriddi ...," *Prosiding*, pp. 78–81, 2018, [Online]. Available: https://publikasi.polije.ac.id/prosiding/article/view/1191%0Ahttps://publikasi.polije.ac.id/prosiding/article

/view/1191/808

[4] R. W. Sekarsari *et al.*, "Pemanfaatan Sampah Organik Untuk Pengolahan Kompos," *J. Pembelajaran Pemberdaya. Masy.*, vol. 1, no. 3, p. 200, 2020, doi: 10.33474/jp2m.v1i3.6510.

[5] D. N. I. Anita and F. Subaidillah, "Optimasi Daur Ulang Sampah Organik dan Anorganik untuk Meningkatkan Jiwa *Enterpreneur* Mahasiswa Teknik Sipil," *J. Abdiraja*, vol. 4, no. 2, pp. 31–38, 2021.

[6] S. A. Isnaini and Y. S. Purnomo, "Pemanfaatan Kulit Ari Kedelai Dan Sampah Organik (Pasar) Sebagai Bahan Dalam Pembuatan Biogas Dengan Starter Em-16," *Pros. ESEC*, pp. 63–68, 2020, [Online]. Available: http://esec.upnvjt.com/index.php/prosiding/article/view/13

[7] N. Nurkholis, S. Nusantoro, D. A. Setiawan, M. Andriani, and T. M. Syahniar, "Stimulus Pertumbuhan Organ Reproduksi Ayam Buras Betina melalui Aplikasi Pemberian Phytoestrogen dari Kelompok Isoflavonoid Hasil Ekstrak Limbah Edamame," *J. Agripet*, vol. 24, no. 1, pp. 75–82, 2024, doi: 10.17969/agripet.v24i1.27727.

[8] S. Gómez-Zorita, M. González-Arceo, A. Fernández-Quintela, I. Eseberri, J. Trepiana, and M. P. Portillo, "Scientific evidence supporting the beneficial effects of isoflavones on human health," *Nutrients*, vol. 12, no. 12, pp. 1–25, 2020, doi: 10.3390/nu12123853.

[9] I. K. Wiryajati, I. G. A. S. Utari Putri, and M. Setiawati, "Pemanfaatan Limbah Organik Sebagai Media Budidaya Maggot Di Desa Lendang Nangka," *J. Bakti Nusa*, vol. 5, no. 1, pp. 1–9, 2024, doi: 10.29303/baktinusa.v5i1.113.

[10] N. Zahro, N. Eurika, and A. N. Prafitasari, "Konsumsi Pakan Dan Indeks Pengurangan Sampah Buah Dan Sayur Menggunakan Larva Black Soldier Fly," *Bioma J. Biol. dan Pembelajaran Biol.*, vol. 6, no. 1, pp. 88–101, 2021, doi: 10.32528/bioma.v6i1.5034.

[11] A. F. Rodli and A. M. Hanim, "Strategi Pengembangan Budidaya Maggot Bsf Sebagai Ketahanan Perekonomian Dimasa Pandemi," *IQTISHADequity J. Manaj.*, vol. 4, no. 1, p. 11, 2022, doi: 10.51804/iej.v4i1.1584.

[12] D. A. Peguero, M. Gold, D. Vandeweyer, C. Zurbrügg, and A. Mathys, "A Review of Pretreatment Methods to Improve Agri-Food Waste Bioconversion by Black Soldier Fly Larvae," *Front. Sustain. Food Syst.*, vol. 5, no. January, pp. 1–9, 2022, doi: 10.3389/fsufs.2021.745894.

[13] D. Pratama, R. Apriyadi, R. Lingga, and M. Rahmawati, "Kualitas Kimia Kompos Hasil Biokonversi Berbagai Jenis Limbah Organik Menggunakan

Larva Black Soldier Fly dan EM-4," *AGROSAINSTEK J. Ilmu dan Teknol. Pertan.*, vol. 6, no. 2, pp. 38–47, 2022, doi: 10.33019/agrosainstek.v6i2.434.

[14] Febrian, A. Razak, E. Yuniarti, and L. Handayuni, "Potensi Larva Black Soldier Fly Sebagai Pengurai Limbah Organik Melalui Budidaya Maggot untuk Pakan Unggas dan Ikan," *J. Ekol. Masy. dan Sains*, vol. 5, no. 1, pp. 130–137, 2024, doi: 10.55448/b8m24h50.

[15] A. Zahra, H. Herdiansyah, and S. W. Utomo, "Model Pengelolaan Sampah Organik dengan Biokonversi Larva Black Soldier Fly Berbasis Pemberdayaan Masyarakat.," *J. Ilmu Lingkung.*, vol. 21, no. 1, pp. 94–105, 2023, doi: 10.14710/jil.21.1.94-105.

[16] K. T. Stefan Diener, and Christian Zurbrügg, "Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates," *Sage J.*, vol. 27, no. 6, 2009, doi: https://doi.org/10.1177/0734242X 09103838.

[17] I. Ramadhan, A. Arifin, and J. Jumiati, "Efisiensi Penggunaan Larva Black Soldier Fly (*Hermetia illucens*) Untuk Mendekomposisi Sampah Organik Dengan Variasi Bahan Fermentasi," *J. Ilmu Lingkung.*, vol. 20, no. 4, pp. 717–725, 2022, doi: 10.14710/jil.20.4.717-725.

[18] H. Haryandi and S. N. Izzy, "Pengaruh Rasio Umpan, Variasi Jenis Sampah Organik, Dan Kualitas Kompos Hasil Biokonversi Menggunakan Larva Black Soldier Fly (*Hermetia illIucens*)," *J. Agrotek Ummat*, vol. 7, no. 2, p. 59, 2020, doi: 10.31764/jau.v7i2.2699.

[19] J. Beno, A. Silen, and M. Yanti, "A review of adult black soldier fly biology, *Hermetia illucens* (Diptera: Stratiomyidae)," *Braz Dent J.*, vol. 33, no. 1, pp. 1–12, 2022.

[20] M. Gold, J. K. Tomberlin, S. Diener, C. Zurbrügg, and A. Mathys, "Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review," *Waste Manag.*, vol. 82, no. October, pp. 302–318, 2018, doi: 10.1016/j.wasman.2018.10.022.

[21] M. Sidiq Muhayyat, A. Tawfiequrrahman Yuliansyah, and Agus Prasetya, "Pengaruh Jenis Limbah dan Rasio Umpan pada Biokonversi Limbah Domestik Menggunakan Larva Black Soldier Fly (*Hermetia illucens*)," *J. Rekayasa Proses*, vol. 10, no. 1, pp. 23–29, 2016.

[22] N. A. Rohmanna, D. M. Maharani, and Z. A. N. M. Majid, "Analisis pertumbuhan dan kemampuan reduksi limbah larva tentara hitam (*Hermetia illucens*) pada solid decanter, ampas kelapa, ampas sagu, dan limbah sisa makanan," *Agrointek J. Teknol. Ind. Pertan.*, vol. 17, no. 3, pp.

666–673, 2023, doi: 10.21107/agrointek.v17i3.15598.

[23] D. Y. Rofi, "Teknologi Reduksi Sampah Organik Buah Dan Sayur Dengan Modifikasi Pakan Larva Black Soldier Fly," 2020.