Pertanika J. Sci. & Technol. 32 (1): 217 - 234 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Investigation of Blended Seaweed Waste Recycling Using Black Soldier Fly Larvae

Iva Yenis Septiariva[1], I Wayan Koko Suryawan[2]*, Wisnu Prayogo[3], Sapta Suhardono[4] and Ariyanti Sarwono[2]

[1]*Civil Engineering Study Program, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, 57126, Indonesia*
[2]*Department of Environmental Engineering, Faculty of Infrastructure Planning, Universitas Pertamina, Jakarta, 12220, Indonesia*
[3]*Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Medan, Medan, Indonesia*
[4]*Department of Environmental Science, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, 57126, Indonesia*

ABSTRACT

Seaweed waste is often found in the coastal areas of Indonesia. Along with other waste, large quantities of seaweed will disrupt the ecosystem and harm the surrounding environment. Therefore, treating seaweed waste effectively and efficiently is necessary to mitigate such adverse effects. This study processed seaweed waste using Black Soldier Fly (BSF) larvae to accelerate waste degradation, reducing the waste buildup. The characteristics of waste, the feeding treatment, chemical content, and parameters of waste processing were assessed. Based on the results, seaweed waste contains highly organic compounds, potentially used as fertilizer or animal feed. The feeding method demonstrated that the mass of BSF larvae increased according to the intensity of the feeding treatment. The total waste degradation obtained from the BSF larvae was 72.61% with a waste reduction index of 1.87 g/day, and the efficiency of digested feed was 7.61% with feeding treatment every three days. The chemical composition of BSF pre-pupae, pupae, and residues was also evaluated to determine their feasibility as animal feed and biomass. The results suggested that pre-pupae and pupae comprise protein, fat, calcium, and phosphorus. At the same time, the waste residue has a C-organic and N-organic ratio of 13%–14% and is an alternative for future waste-to-energy

ARTICLE INFO

Article history:
Received: 01 February 2023
Accepted: 14 June 2023
Published: 24 November 2023

DOI: https://doi.org/10.47836/pjst.32.1.13

E-mail addresses:
ivayenis@gmail.com (Iva Yenis Septiariva)
i.suryawan@universitaspertamina.ac.id (I Wayan Koko Suryawan)
wisnuprayogo@unimed.ac.id (Wisnu Prayogo)
sapta.suhardono@staff.uns.ac.id (Sapta Suhardono)
ariyanti.sarwono@universitaspertamina.ac.id (Ariyanti Sarwono)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

applications. Overall, BSF offers a great prospect in generating high-value products and simultaneously serves as a strategy for efficient waste management.

Keywords: BSF larvae, coastal area, seaweed waste, waste to energy

INTRODUCTION

Municipal solid waste has long been one of the main environmental issues worldwide, both on land and in the ocean. The higher the population on earth, the more it is produced. The increased amount of waste can profoundly impact the lives of living things on Earth. Waste can be the main trigger for various human health problems, poor life quality of animals and plants, and environmental degradation. Today, different types of waste generated on land, in a river, and an ocean can damage the surrounding environment (Cordova & Nurhati, 2019; Nurhati & Cordova, 2020). Seaweed waste is one type of marine debris commonly found in coastal areas, particularly in Indonesia (Bijang et al., 2018). Seaweed waste typically occurs during east wind season; naturally, tides and sea currents carry the seaweed waste to the coastline. When present in large quantities, seaweed waste can disrupt the ecosystem around the coast and interfere with the activities of humans, animals, and plants. Areas with vast seaweed waste are Tanjung Benoa Beach and Nusa Dua Beach, Bali. At least two to three tons of seaweed waste are observed daily. The accumulated seaweed waste can disturb the lives of other living things (NusaBali.com, 2021); therefore, an effective and efficient treatment of seaweed waste plays a key role in minimizing various environmental threats and avoiding multiple health issues for humans in the coastal environment.

This seaweed can be processed into high-value products. Seaweed, a plant-derived organic waste, can be easily degraded or decomposed along with other organic waste such as vegetables, fruit, and straw. This type of waste can be easily decomposed with microorganisms and animals. Seaweed waste, in general, contains a high amount of complex carbohydrates (Salgado et al., 2021), protein, water, and cellulose (Hidayati et al., 2021). Several studies have been reported to treat seaweed waste to minimize its negative impact on the surrounding environment. Seaweed waste can be converted into feed and organic fertilizer in the form of granules or liquids and into inorganic fertilizers by utilizing pickling waste from the metal coating industry as a mixture (Sulistiyowati & Prayitno, 2021). Certain microbes or Black Soldier Fly (BSF) can assist in the degradation of seaweed and accelerate the decomposition process of seaweed (Liland et al., 2017; Swinscoe et al., 2020).

The main objective of this study is to explore the effectiveness and efficiency of BSF larvae in the degradation and conversion of seaweed waste, thereby providing insights into sustainable waste management practices and potential applications for the resulting products. Piles of seaweed waste could be easily and rapidly reduced while concurrently curtailing environmental risks in coastal areas. Investigating blended seaweed waste recycling using BSF larvae addresses significant challenges and unsolved problems in waste management and resource utilization. Coastal areas in Indonesia often face the accumulation of seaweed waste, which poses environmental and economic burdens. Current waste management practices may not effectively handle the increasing volumes of seaweed waste, necessitating sustainable and efficient methods for waste degradation. Additionally, the underutilization of seaweed waste as a valuable resource for fertilizer, animal feed, and waste-to-energy applications remains a pressing issue.

Investigating blended seaweed waste recycling using BSF larvae is of great importance. Firstly, it offers a sustainable approach to managing seaweed waste by utilizing the degrading capabilities of BSF larvae, thereby reducing waste accumulation and minimizing environmental impact. Secondly, this study contributes to resource recovery by converting seaweed waste into valuable products, including fertilizer, animal feed, and potentially even energy sources. By embracing the principles of the circular economy, the study promotes the efficient use of resources and reduces waste generation. The novelty of this investigation lies in its specific focus on blended seaweed waste recycling using BSF larvae. While previous studies have explored waste management and resource utilization through the application of BSF larvae, this study extends the knowledge base by targeting the specific challenge of seaweed waste. The study introduces a novel and innovative approach to waste management and resource utilization by employing BSF larvae to process and convert seaweed waste into valuable products.

MATERIALS AND METHODS

Feeding

Seaweed waste was dried and homogenized by a blender for the feeding substrate. This seaweed was dried to maintain the salinity of seawater. The research was conducted with two repetitions of treatment. The waste feeding rate into the reactor can be calculated using an average of 40 mg/larva.day, according to Diener (2010). Various feeding treatment times of once a day (F24), every two days (F48), and every three days (F72) were performed in this study.

The water content of the waste profoundly affects the larval consumption time of the given waste, and 60%–90% wt/wt of water content is considered optimal (Diener, 2010). The higher the water content in the given waste, the more BSF larvae escape from the breeding reactor. On the contrary, the lack of water content might inhibit the digestive process of BSF larvae. Therefore, in this study, water content was adjusted to 70% wt/wt by adding water to the waste.

BSF Larvae

In this study, the reactor was seeded with 200 larvae of one-week-old. When sufficient food reserves are available, BSF larvae have a better tolerance to lower temperatures and grow faster at a temperature of 30°C–36°C. At the same time, young larvae show low survival at less than 20°C and higher than 45°C. Young larvae are typically very susceptible to the influence of external factors, including temperature, low oxygen pressure, mold, moisture content, and toxic materials. Its resistance to these factors will increase after 1 week (5–10 mg in size). After 10 days of age, these larvae will compete with the older ones in the breeding incubator. After hatching, BSF can reduce waste from the larval stage to the prepupa stage to approximately 55% wt/wt of waste (Diener, 2010).

Data on larval wet weight gain is measured using analytical balance to determine the effect of the waste type and feeding frequency on larval growth. During the experiment, 10% of the larvae were weighed in each reactor, and 20 batches were taken. Once weighted, the larvae were immediately returned to the reactor (Diener et al., 2011).

Data Analysis

Feed residues were recorded to determine the overall degradation (OD) and waste reduction index (WRI) as presented by Equations 1 and 2. The larval digestibility of the feed consumed is represented in the digested feed conversion efficiency (ECD), as shown in Equation 3. The metabolism of feed consumed (g) was calculated based on the mass balance.

$$Overall\ degradation\ (OD) = \frac{Total\ feed\ offered\ (g) - Dry\ residue\ remained\ (g)}{Total\ feed\ offered\ (g)} \tag{1}$$

$$Waste\ reduction\ index\ (WRI) = \frac{Total\ feed\ offered\ (g) - Dry\ residue\ remained\ (g)}{Rearing\ duration\ (day)} \tag{2}$$

$$Efficiency\ of\ conversion\ of\ digested\ feed\ (ECD) = \frac{BSF\ Larvae\ biomass\ (g)}{Total\ feed\ offered\ (g) - Dry\ residue\ remained\ (g)} \tag{3}$$

The protein, fat, calcium, phosphorus, and ash content of the BSF prepupa and pupae were measured to explore further the opportunities for cultivating BSF prepupa and pupae as animal feed. The Standar Nasional Indonesia (SNI) methods can be utilized to analyze the parameters of protein, fat, calcium, phosphorus, and ash content in solid fertilizer. These methods are widely recognized and accepted as standard practices in Indonesia. The SNI 01-2891-1992 method can be followed for protein content analysis, which employs the Kjeldahl or Dumas combustion methods. Fat content can be determined using the Soxhlet extraction method according to the procedures outlined in SNI 01-3555-1998. The appropriate technique specified in SNI 01-2894-1992 can be employed to analyze the calcium content, which may involve atomic absorption spectroscopy or other suitable methods described in the standard. Similarly, the phosphorus content can be determined using the methods outlined in SNI 01-2894-1992, which may include colorimetric methods or other applicable techniques. Lastly, the ash content can be analyzed using the gravimetric method described in SNI 01-3554-1998, following the specific steps and procedures mentioned in the standard. Adhering to these SNI methods ensures compliance with the Indonesian standards and facilitates accurate and reliable analysis of the mentioned parameters in solid fertilizer samples.

Analysis of residues resulting from the processing by BSF larvae is adjusted to the Indonesian government's solid fertilizer standards. This study tested solid fertilizer parameters such as pH, C-organic, N-organic, C/N ratio, and water content. The SNI 06-6989-2004 method can be used for pH measurement, which involves using a pH meter or indicator to measure the pH after creating a suspension of the sample in water. The SNI 19-7030-2004 method provides guidelines for determining C-organic (Organic Carbon) and N-organic (Organic Nitrogen) contents. The C-organic content can be measured using the Walkley-Black method or other suitable methods, while the N-organic content can be determined through the Kjeldahl method or other appropriate techniques. The SNI 19-7030-2004 method also outlines the procedure for calculating the C/N ratio based on the determined organic carbon and organic nitrogen contents. Lastly, the water content can be analyzed following the SNI 19-7030-2004 method, which involves drying the sample at a specific temperature and calculating the weight difference before and after drying. Adhering to these standard methods ensures accurate and consistent analysis of the specified parameters in accordance with SNI guidelines.

In addition to the mentioned solid fertilizer parameters, further assessments were conducted to evaluate the quality and composition of the residues. Two additional tests were performed: Thermogravimetric Analysis (TGA) and Gas Chromatography-Mass Spectrometry (GC-MS). TGA analysis was employed to investigate the thermal properties and stability of the residues. This test allows for the determination of weight changes as a function of temperature, providing insights into the decomposition and volatilization behavior of the samples. On the other hand, GC-MS analysis was utilized to examine the chemical composition of the residues and identify the presence of organic compounds. By separating and analyzing the individual components present in the sample, GC-MS provides valuable information about the organic constituents and their relative abundance. These additional tests contribute to a comprehensive understanding of the residues' characteristics and aid in assessing their suitability as solid fertilizers.

RESULTS

In this study, the seaweed waste was characterized prior to being fed to maggot to obtain the nutritional content of maggot feed before being used as a medium for maggot growth.

Table 1
The characteristics of seaweed waste

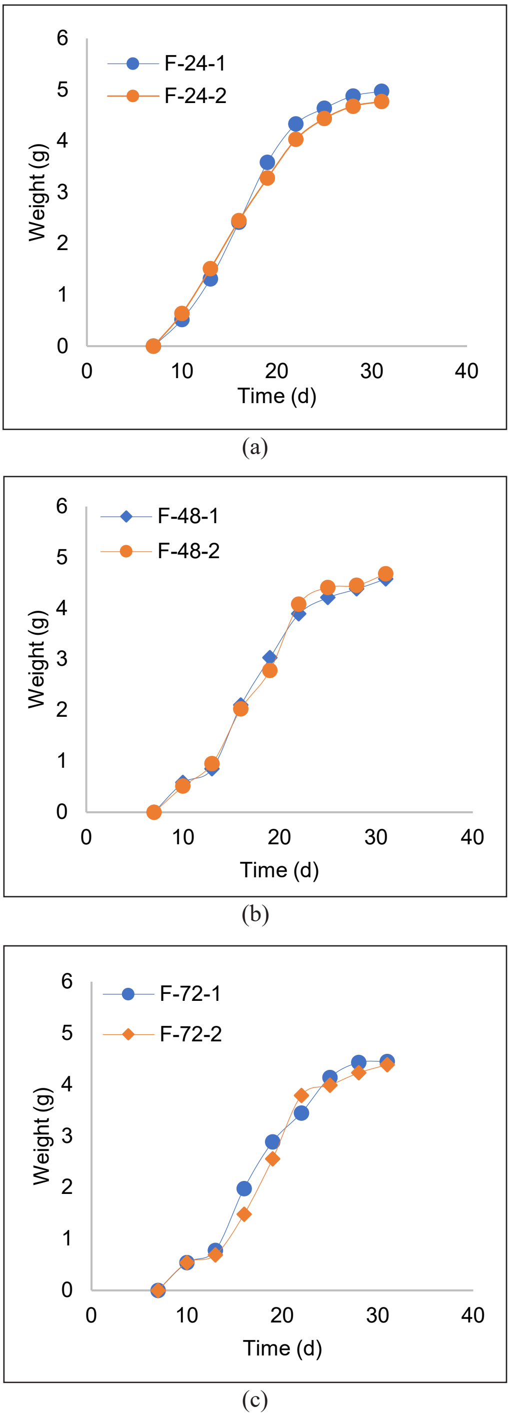
Parameters	Results
Temperature	31°C–33°C
Moisture Content	74.2%±0.8
Ash Content	10.1%±0.4
pH	7.6–7.8
C-organic	39.12%
N-organic	3.85%
C/N	10.16

The characteristics of seaweed waste are summarized in Table 1. Based on these data, seaweed waste has a neutral pH between 7.6–7.8, a water content of 74.2%, and an ash content of 10.1%. Maintaining a near-neutral pH is crucial as a low pH excessively produces nitrogen and might kill eggs from insects (Setyaningsih et al., 2017). pH can affect the amount of nutrients absorbed by BSF larvae by affecting the performance of enzymes in the larvae intestines (Kim et al., 2011). The pH treatments impacted BSF larval weight largely on the first, third, and fifth day instead of the final stage (Meneguz et al., 2018). Data from Table 1 suggest that the breeding site conditions are particularly suitable for breeding BSF larvae as it is in accordance with the optimum temperature for larval growth of 30°C–36°C (Green & Popa, 2012) and an optimum air humidity of 60%–70% (Holmes et al., 2012).

On day 20, when prepupa transforms into a fly, this adult BSF does not require food but merely utilizes fat reserves in the body as an energy source (Diener et al., 2011). In the prepupa phase, BSF lends itself to self-harvesting (Richard, 2017), and based on this, once turning into a prepupa, the wet and moist prepupa is removed from the reactor. For the feeding treatment every two days (Figure 1b), the BSF larvae weight gain was 4.63 g. Meanwhile, feeding every three days (Figure 1c) showed an increase in the average mass of BSF larvae from 0 to 4.42 g. Figure 1 implies that daily feeding treatment had the highest gain weight of BSF larvae, followed by feeding every two and finally every three days. With more intensity of feeding, the BSF larvae will grow rapidly and have nutrients-rich for breeding.

The BSF larvae breeding was carried out using the feeding method at a specified time. In the 7th to the 31st-day range, the feeding time was performed in three ways: every one day, every two days, and every three days. Batch feeding allowed the shortest development time, while daily feeding revealed the heaviest final weight of larvae (Meneguz et al., 2018). Different feeding time aims to identify the optimum conditions for BSF larvae to reduce seaweed waste in large quantities and a short period, as illustrated in Figures 1 and 2. Figure 1 presents the mass changes in BSF larvae after feeding every day, every two days, and every 3 days. All feeding conditions show an increasing trend every day from the 7th to the 31st. In daily feeding treatment (Figure 1a), the mean larval weight reached 3.59 g and 4.87 on the 19th and 31st days, respectively.

To evaluate the water content in the seaweed waste changes in moisture content of seaweed waste against feeding time were measured and presented in Figure 2. This feeding



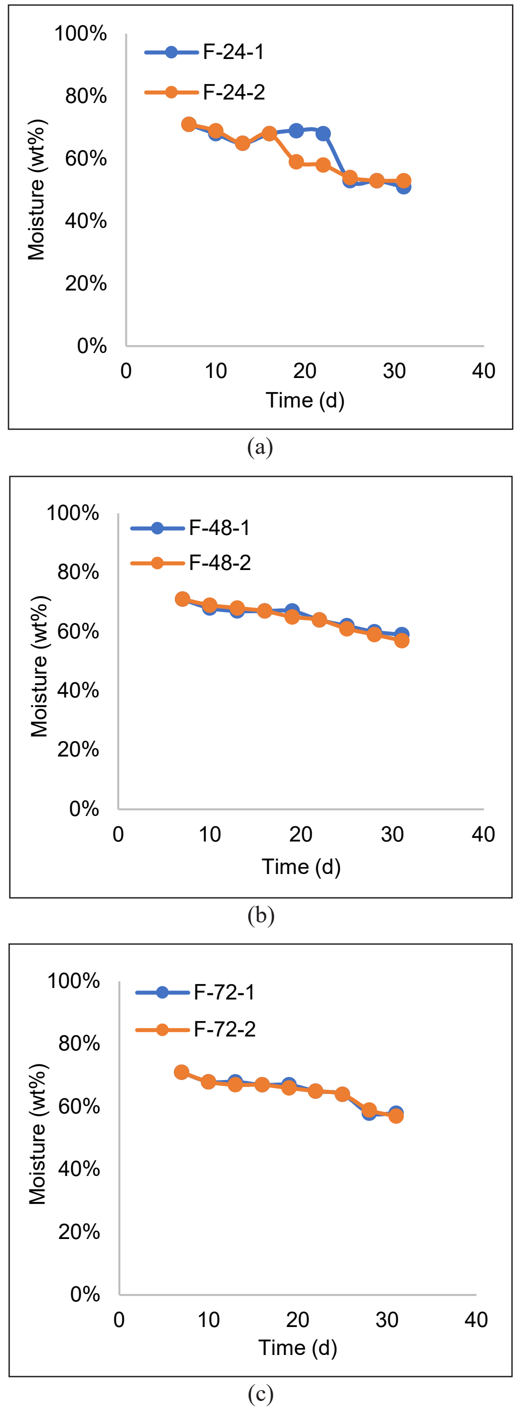


Figure 1. Changes in the mass of BSF larvae from day 7 to day 31: (a) feeding every day; (b) feeding every 2 days; and (c) feeding every 3 days

Figure 2. Changes in the waste moisture of the seaweed waste from day 7 to day 31: (a) feeding every day; (b) feeding every 2 days; and (c) feeding every 3 days

time parameter was performed similarly to in Figure 1. The results reveal that the overall water content of seaweed waste slightly decreased over time. In the first condition of daily feeding treatment (Figure 2a), the water content in the seaweed waste declines from 71% to 52%. It indicates a noticeable reduction in the water content of the seaweed waste throughout the experimental duration. During the feeding process, the larvae consume the organic material and extract nutrients from it. As the larvae consume the seaweed waste, they break it into smaller particles through mechanical action and enzymatic digestion. During this process, the larvae extract moisture from the waste to support their metabolic activities and growth. This moisture extraction from the seaweed waste contributes to reducing its water content. Moreover, BSF larvae have efficient digestive systems that can efficiently process organic matter, including cellulose-rich materials like seaweed. In addition, they have specialized gut enzymes that help break down complex carbohydrates and release water as a byproduct of digestion. It further contributes to the decrease in water content in the seaweed waste.

In addition to OD and WRI analysis, the efficiency of feed conversion by BSF larvae efficiency of conversion of digested food (ECD) was also estimated to determine the conversion of digested food to body substance. Based on the calculations in Table 2, the average ECD value is 7.44% for feeding every day, 7.23% for feeding every two days, and 7.61% for feeding every three days. The ECD illustrates the efficiency level of BSF larvae in converting the consumed feed into their biomass (Abduh et al., 2017). The higher the ECD value, the higher the level of efficiency. These results show that feeding every three days increases the conversion efficiency of seaweed waste by BSF larvae. The difference in the percentage efficiency of the various feeding treatments was possibly influenced by several factors, such as the amount of food given to the larvae, environmental factors like temperature, humidity, and pH, as well as internal factors such as disease, presence of parasites, and the sex of the BSF larvae.

In addition to waste processing parameters, in this study, the composition of mass in seaweed processing using BSF larvae was also depicted in Figure 3. From Figure 3, the percentage of dry feed and biomass larvae every three-day feeding treatment had the highest

Table 2
The results of seaweed waste processing parameters with BSF larvae

Parameters	Unit	F-24		F-48		F-72	
		1	2	1	2	1	2
Total dry feed offered	g	248	248	120	120	80	80
Dry residue remained	g	185.58	178.98	51.33	59.81	22.39	21.43
OD	%	25.17	27.83	57.23	50.16	72.01	73.21
WRI	g/day	2.01	2.23	2.22	1.94	1.86	1.89
ECD	%	7.96	6.91	6.67	7.78	7.72	7.50

percentage, followed by feeding treatment every two days and daily feeding treatment. In contrast, daily feeding treatment residue holds the highest percentage.

For further analysis, measurements of chemical content in pre-pupa and pupae from waste processing with BSF larvae were performed, as summarized in Table 3. Based on the measurement results, s and both comprise the BSF's prepupa and pupae and comprise a high portion of protein and fat. Table 3 shows the average protein, fat, and ash contents of 40%, 34%, and 19%, respectively, for both pre-pupa and pupae. As for calcium and phosphorus, the average value is 4% and 1%. The feeding treatment for BSF larvae did not significantly influence the percentage of chemical content present in pre-pupa and BSF pupae. The high protein content of BSF larvae might be affected by dry weight conversion as well as the nutrition of larval food ingredients (Fadhillah & Bagastyo, 2020).

Although BSF larvae are able to decompose seaweed waste efficiently, they still generate residue. This residue can be further utilized as plant nutrients or composting. Therefore, this study assessed the chemical composition of BSF larvae processing residue.

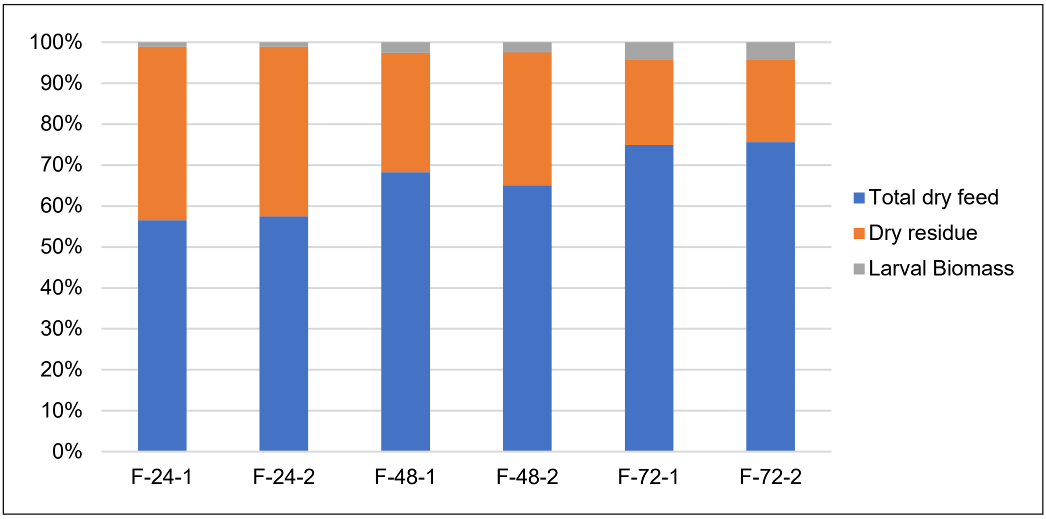


Figure 3. Mass composition in seaweed waste treatment with BSF larvae

Table 3
Chemicals content in pre-pupa and pupae from waste processing with BSF larvae

Chemical content	**Unit**	**Pre-pupa**			**Pupa**		
		F-24	**F-48**	**F-72**	**F-24**	**F-48**	**F-72**
Protein	%	42.2	42.8	40.6	41.3	39.4	39.2
Fat	%	34.3	33.3	34.3	35.4	37.8	36.7
Calcium	%	4.32	3.43	4.84	3.84	4.35	4.78
Phosphor	%	0.98	0.93	0.89	1.05	1.06	1.01
Ash	%	18.2	19.54	19.37	18.41	17.39	18.31

The results in Table 4 suggest that the feeding treatment does not significantly impact the chemical content of the residue. These measurements show that waste residue has an acidic pH ranging from 4.6–4.8, C-organic in the 36%–37% range, N-organic from 2.6%–2.8% with a C/N ratio of 13–14, and water content from 14%–19%. These parameters still fall in the standard range, indicating a safe percentage of the chemical content of the residue. Overall, the residue gives a lower percentage of chemical content than seaweed waste prior to processing (Table 1), implying that decomposing seaweed waste using BSF larvae has been successfully carried out.

GC-MS test was conducted to identify residue compounds under the thermal process, as shown in Figure 4. Based on the GC-MS chromatogram, the seaweed residue decomposes into simpler compounds, as many as 50 compound fragments. Some of the compounds produced from the pyrolysis process of seaweed waste residues include

Table 4
Chemical content in seaweed waste residue with BSF larvae

Chemical content	Unit	F-24		F-48		F-72		Standard
		F-24-1	F-24-2	F-48-1	F-48-2	F-72-1	F-72-2	
pH		4.8	4.7	4.89	4.8	4.6	4.8	4-8
C-organic	%	36.2	37.6	36.8	36.5	37.3	36.4	≥12
N-organic	%	2.7	2.8	2.6	2.7	2.6	2.7	-
C/N		13.41	13.43	14.15	13.52	14.35	13.48	10-25
Water Content	%	18.3	19.2	15.2	14.5	14.3	14.8	13-20

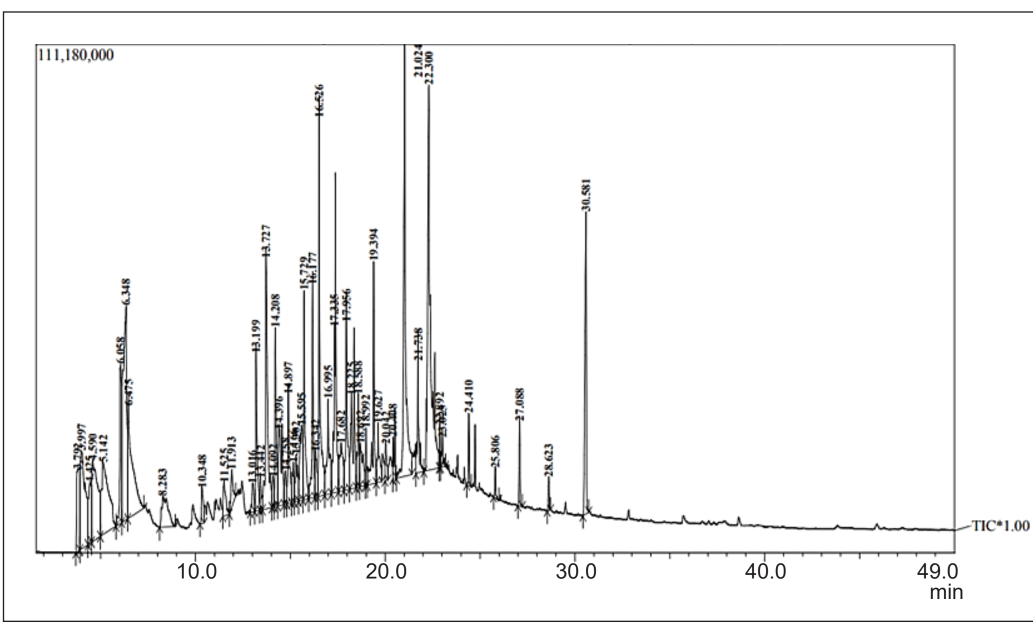


Figure 4. GC-MS chromatogram of seaweed waste residue after processing with BSF larvae

aromatic compounds, alcohol, and ketones such as butyrolactone at 6.30%, hexadecanoic acid at 6.89%, benzene at 4.18%, 2,3-butanedione of 4.14%, phenol of 4.36%, and other compounds (Figure 4). These above compounds can be utilized as biomass precursors if processed with the right method to increase the value of benefits. From GC-MS analysis of seaweed waste residue after processing with BSF larvae, it can be concluded that the residue can be treated using a thermal process to generate biomass fuel.

DISCUSSION

The organic N levels are generally derived from proteins and chlorophyll in the seaweed. Safia et al. (2020) reported 4.16% of protein, 0.36% of fat, and 25.50% of carbohydrate content in seaweed. In addition to the above nutrients, seaweed possesses beneficial bioactive compounds like alkaloids, flavonoids, phenol hydroquinone, and tannins (Safia et al., 2020). The used seaweed waste has a fairly high nutrient content from organic C-organic and N-organic levels. Microorganisms utilize the C and N organic content as an energy source and the formation of body cells (Widyastuti et al., 2021). The above high nutritional content indicates that seaweed waste has great potential as a BSF diet. Due to relatively high water content, seaweed waste needs to be preliminary treated to reduce its water content and steadily maintain larvae consumption. The seaweed waste used in the study had C-organic and N-organic levels of 39.12% and 3.85%, respectively, with a C/N ratio of 10.16. The organic C is derived from carbohydrates such as cellulose, glucose, and lignin. The C/N ratio 15 can reportedly enhance BSF larvae's nutrient consumption, shortening the maturation feed time to five weeks (Beesigamukama et al., 2021). The nutritional composition of the larvae strongly depends on the consumed feeding medium (Sheppard et al., 2002; Tschirner & Simon, 2015).

Daily feeding time showed the highest water content decrement among the three feeding times. The decrease in the water content in the sample indicated that the feeding of BSF larvae through seaweed waste was successfully performed. The amount of feeding for BSF larvae will affect the water condition in waste. The more intense feeding will stimulate the BSF larvae to decompose the seaweed waste, thereby reducing the water content of the seaweed waste.

Previous research stated that low water content of the media is recommended during cultivating BSF. High water content above 70% reportedly hinders the development and growth of the larvae (Diener, 2010; Li et al., 2011). The high water content in the growing media/feed for larvae results in anaerobic conditions (Elvita & Arseto, 2015). The decomposition of organic matter under anaerobic conditions produces ammonia and methane, which can inhibit the feed consumption process by larvae and disturb their growth (Elvita & Arseto, 2015).

Various analyses related to the optimum conditions for feeding BSF larvae, water content in the sample, and parameters associated with seaweed waste processing using

BSF larvae are carried out in this study. Overall, the average seaweed waste degradation (OD) by BSF larvae is 26.50% w/w for feeding every day, 53.69% w/w for feeding every two days, and 72.61% w/w for feeding every three days. The OD value implies that the feeding treatment has the most substantial degradation every three days. It might be due to less food in the same period, stimulating BSF larvae to devour more. The waste reduction index (WRI), a calculation to determine the ability of BSF larvae to consume seaweed waste within a predetermined period (Rofi et al., 2021), is also carried out to indicate the high preference of BSF larvae for the food given. Table 2 shows that after the 31st day, the number of WRIs in the daily feeding treatment (average) was 2.12 g/day, 2.08 g/day for feeding every two days, and 1.87 g/day for a three-day feeding treatment. The daily feeding treatment had the highest number of WRIs because of more available food for BSF.

The higher the feed consumption value, the greater the potential for using larvae to break down feed or waste. A feed consumption value of 26.2%–39.7% was reported by Diener et al. (2009) using chicken feed as bait for BSF larvae. Another feed consumption value of 9.29%–36.82% was reported using cassava waste (Supriyatna et al., 2016). The value gap was likely due to the different quality of the bait, which subsequently affected the nutrient contribution for the development of BSF larvae. Fish waste provides a greater source of protein than cassava waste and chicken feed. While the nutrient composition affected the growth and development of BSF larvae, the bait with high protein and fat content accelerated the increase in larval weight (Sheppard et al., 2002).

Direct and indirect utilization of BSF larvae as animal feed has its advantages. BSF larvae and pre-pupae can be reared in organic waste, used as poultry feed, and simultaneously decompose unused waste. However, further studies on economic utilization are urgently needed, including increasing the ability of maggots to recycle organic waste (Handayani et al., 2021; Pendyurin et al., 2021; Wangko, 2014). BSF larvae have been recommended as an alternative protein source for animal feed, as in corn and soybeans (Kawasaki et al., 2019). The reported protein content of BSF larvae was 12.71% (young jackfruit as a feed substrate) and 11.30% (banana peel as a feed substrate) (Pangestu et al., 2017). In addition, the proximate test of 7 days old pupa stage is crude protein content of 35.40%–42.31%, crude fat of 3.33%–36.41%, crude fiber of 18.68%–37.60 %, and beta-N of 0.03%–10.33% (Mujahid et al., 2017).

Among all the above methods, using black soldier fly (BSF) to degrade organic waste, especially seaweed waste, has recently gained attention and is considered effective. BSF is a species of *Hermetia illucens,* originating from the genus *Hermetia*, and is a family group of *Stratiomyidae* with the order Diptera having a physical shape like a wasp. The BSF larvae of these flies are widely used to accelerate the decomposition of organic waste by breaking down waste through heat generated from the larvae (Raksasat et al., 2020). Using BSF larvae, organic waste reduction can be fastened with the reduction acceleration reaching

50%–60% (Ojha et al., 2020), which is an effective way to decompose organic waste. BSF larvae possess high nutritional value, facilitating their growth and metamorphosis. The body weight of the larvae serves as an indirect indicator of not only the quantity of nitrogen successfully absorbed by the larvae but also the stored energy utilized in the development of organs and tissues during metamorphosis. The significant nutrient content and widespread availability of BSF larvae, coupled with their utilization that does not compete with human resources and the ease of cultivating them using readily available growth media, indicate the promising potential of BSF larvae as a valuable source of animal feed or for aquaculture purposes, particularly in coastal regions.

Using BSF larvae has proven highly effective and efficient in degrading and converting seaweed waste. The study results demonstrate the rapid decomposition of the waste material, with significant waste reduction achieved through the feeding activities of the larvae. It indicates the effectiveness of BSF larvae in breaking down the organic components of seaweed waste. Moreover, the waste degradation process by BSF larvae offers a sustainable waste management practice. It provides an environmentally friendly solution for handling and reducing the accumulation of seaweed waste in coastal areas.

Furthermore, the larvae contribute to developing sustainable waste-to-resource strategies by effectively converting the waste into valuable products, such as protein-rich pre-pupae and pupae. BSF larvae's waste conversion efficiency is evident in the high digested feed efficiency achieved during the study. In addition, the larvae efficiently convert the organic matter in the seaweed waste into biomass, demonstrating their ability to utilize and transform waste materials into valuable resources. Furthermore, conducting an environmental impact assessment is crucial to understanding the sustainability of implementing BSF larvae-based waste management systems. This assessment should include evaluating the carbon footprint, energy efficiency, and potential emissions associated with large-scale implementation and assessing the effects on local ecosystems, soil health, and water quality. Lastly, exploring the economic viability and market potential of utilizing BSF larvae for seaweed waste management is essential. Assessing the cost-effectiveness of large-scale production, examining potential business models, and understanding market demand for the resulting products will provide valuable information for this waste management approach's practical implementation and commercialization (Suryawan et al., 2023).

CONCLUSION

From the study results, the decomposition of seaweed waste can be carried out rapidly using BSF larvae. Different feeding treatments of BSF larvae induce changes in larval mass and water content in seaweed waste—the more intense the feeding, the heavier the larval mass, and the less water content in the seaweed waste. With the optimum feeding time of once every three days, BSF larvae could degrade waste by 72.61% with a waste reduction index of 1.87 g/day and digested feed efficiency of 7.61%. Further, chemical composition was also determined for pre-pupae, pupae, and waste residues to determine their potential as animal feed. Pre-pupa and pupae contain large amounts of protein (40%) and fat (34%), followed by calcium, phosphorus, and dust.

In contrast, all parameters for residue are lower than waste before processing, with the highest C-organic content of 36%–37% and water content of as much as 14%–19%. BSF larvae-treated seaweed waste has advantages such as easy processing, high decomposition speed, and vast applications such as waste-to-biofuel and animal feed. Therefore, BSF's processing of seaweed waste offers a solution to reduce environmental pollution in coastal areas.

Future research recommendations can be proposed to build upon these results and explore additional aspects of sustainable waste management practices and potential applications for the resulting products. Firstly, further research can focus on optimizing the feeding strategies for BSF larvae to enhance waste degradation efficiency. It could involve investigating different feeding frequencies, quantities, and nutrient compositions to determine the optimal conditions for maximizing waste decomposition rates and the quality of the resulting products. In addition, there is a need to explore innovative approaches for valorizing the waste residues left after the BSF larvae processing. Finally, future studies could evaluate the potential applications of these residues as biofertilizers, biofuels, or other value-added products, thereby creating a more comprehensive and sustainable waste management process.

ACKNOWLEDGMENT

We extend our profound gratitude to the coastal communities of Indonesia for granting us access and invaluable insights into the challenge posed by seaweed waste. Their cooperation and firsthand accounts were instrumental in shaping the direction of this research. We also acknowledge the team's dedication responsible for the meticulous collection, treatment, and analysis of seaweed samples. Our sincere thanks go to the experts in the Black Soldier Fly cultivation field, whose guidance ensured the success of the waste degradation process. Furthermore, we appreciate the financial and infrastructural support provided by Universitas Sebelas Maret, Surakarta, Indonesia, and Universitas Pertamina, Jakarta, Indonesia, without which this research would not have been possible.

REFERENCES

Abduh, M. Y., Manurung, R., Faustina, A., Affanda, E., Siregar, I. R. H., & Muhammad, C. (2017). Bioconversion of *Pandanus tectorius* using black soldier fly larvae for the production of edible oil and protein-rich biomass. *Journal Of Entomology and Zoology Studies, 5*(1), 803-809.

Beesigamukama, D., Mochoge, B., Korir, N. K., K.M. Fiaboe, K., Nakimbugwe, D., Khamis, F. M., Subramanian, S., Wangu, M. M., Dubois, T., Ekesi, S., & Tanga, C. M. (2021). Low-cost technology for recycling agro-industrial waste into nutrient-rich organic fertilizer using black soldier fly. *Waste Management, 119*, 183-194. https://doi.org/https://doi.org/10.1016/j.wasman.2020.09.043

Bijang, C. M., Latupeirissa, J., & Ratuhanrasa, M. (2018). Biosorption of copper metal ions (Cu2+) on brown seaweed (*Padina australis*) Biosorbent. *Indonesian Journal of Chemical Research, 6*(1), 538-549. https://doi.org/10.30598//ijcr.2018.6-cat

Cordova, M. R., & Nurhati, I. S. (2019). Major sources and monthly variations in the release of land-derived marine debris from the Greater Jakarta area, Indonesia. *Scientific Reports, 9*(1), Article 18730. https://doi.org/10.1038/s41598-019-55065-2

Diener, S. (2010). *Valorisation of Organic Solid Waste using the Black Soldier Fly, Hermetia illucens, in Low and Middle-Income Countries* (Doctoral dissertation). Eidgenössische Technische Hochschule Zürich. https://doi.org/10.3929/ethz-a-6559779

Diener, S., Solano, N. M. S., Gutiérrez, F. R., Zurbrügg, C., & Tockner, K. (2011). Biological treatment of municipal organic waste using black soldier fly larvae. *Waste and Biomass Valorization, 2*(4), 357-363. https://doi.org/10.1007/s12649-011-9079-1

Diener, S., Zurbrügg, C., & Tockner, K. (2009). Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. *Waste Management & Research, 27*(6), 603-610. https://doi.org/10.1177/0734242X09103838

Elvita, S. S., & Arseto, Y. B. (2015, November 23-24). *Reduction of organic solid waste by black soldier fly (Hermetia illucens) larvae*. [Paper Presentation]. 5th Environmental Technology and Management Conference "Green Technology towards Sustainable Environment", Bandung, Indonesia.

Fadhillah, N., & Bagastyo, A. Y. (2020). Utilization of *Hermetia illucens* larvae as a bioconversion agent to reduce organic waste. In *IOP Conference Series: Earth and Environmental Science* (Vol. 506, No. 1, p. 012005). IOP Publishing. https://doi.org/10.1088/1755-1315/506/1/012005

Green, T. R., & Popa, R. (2012). Enhanced ammonia content in compost leachate processed by black soldier fly larvae. *Applied Biochemistry and Biotechnology, 166*(6), 1381-1387. https://doi.org/10.1007/s12010-011-9530-6

Handayani, D., Naldi, A., Larasati, R. R. N. P., Khaerunnisa, N., & Budiatmaka, D. D. (2021). Management of increasing economic value of organic waste with Maggot cultivation. In *IOP Conference Series: Earth and Environmental Science* (Vol. 716, No. 1, p. 012026). IOP Publishing. https://doi.org/10.1088/1755-1315/716/1/012026

Hidayati, S., Zulferiyenni, Maulidia, U., Satyajaya, W., & Hadi, S. (2021). Effect of glycerol concentration and carboxy methyl cellulose on biodegradable film characteristics of seaweed waste. *Heliyon, 7*(8), Article e07799. https://doi.org/https://doi.org/10.1016/j.heliyon.2021.e07799

Holmes, L. A., Vanlaerhoven, S. L., & Tomberlin, J. K. (2012). Relative humidity effects on the life history of *Hermetia illucens* (Diptera: Stratiomyidae). *Environmental Entomology, 41*(4), 971-978. https://doi.org/10.1603/EN12054

Kawasaki, K., Hashimoto, Y., Hori, A., Kawasaki, T., Hirayasu, H., Iwase, S., Hashizume, A., Ido, A., Miura, C., Miura, T., Nakamura, S., Seyama, T., Matsumoto, Y., Kasai, K., & Fujitani, Y. (2019). Evaluation of black soldier fly (*Hermetia illucens*) larvae and pre-pupae raised on household organic waste, as potential ingredients for poultry feed. *Animals, 9*(3), Article 98. https://doi.org/10.3390/ani9030098

Kim, W., Bae, S., Park, K., Lee, S., Choi, Y., Han, S., & Koh, Y. (2011). Biochemical characterization of digestive enzymes in the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *Journal of Asia-Pacific Entomology, 14*(1), 11-14. https://doi.org/https://doi.org/10.1016/j.aspen.2010.11.003

Li, Q., Zheng, L., Cai, H., Garza, E., Yu, Z., & Zhou, S. (2011). From organic waste to biodiesel: Black soldier fly, *Hermetia illucens*, makes it feasible. *Fuel, 90*(4), 1545-1548. https://doi.org/https://doi.org/10.1016/j.fuel.2010.11.016

Liland, N. S., Biancarosa, I., Araujo, P., Biemans, D., Bruckner, C. G., Waagbø, R., Torstensen, B. E., & Lock, E.-J. (2017). Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae by feeding seaweed-enriched media. *Plos One, 12*(8), Article e0183188. https://doi.org/10.1371/journal.pone.0183188

Meneguz, M., Gasco, L., & Tomberlin, J. K. (2018). Impact of pH and feeding system on black soldier fly (*Hermetia illucens*, L; Diptera: Stratiomyidae) larval development. *Plos One*, *13*(8), Article e0202591. https://doi.org/10.1371/journal.pone.0202591

Mujahid, M., Amin, A. A., Hariyadi, H., & Fahmi, M. R. (2017). Oil palm empty bunches bioconversion using *Trichoderma* sp. and black soldier fly larvae as poultry feed composition. *Jurnal Ilmu Produksi Dan Teknologi Hasil Peternakan, 5*(1), 5-10. https://doi.org/10.29244/jipthp.5.1.5-10

National Standardization Agency of Indonesia. (1992). *Cara uji makanan dan minuman* [Methods for analysing food and beverages], SNI 01-2891-1992. Badan Standardisasi Nasional, Jakarta.

National Standardization Agency of Indonesia. (1992). *Cara uji bahan pengawet makanan dan bahan tambahan yang dilarang untuk makanan* [Analytical methods for food additives/preservatives], SNI 01-2894-1992. Badan Standardisasi Nasional, Jakarta.

National Standardization Agency of Indonesia. (1998). *Cara uji minyak dan lemak* [Methods for analysing oil and fat], SNI 01-3555-1998. Badan Standardisasi Nasional, Jakarta.

National Standardization Agency of Indonesia. (1998). *Cara uji air minum dalam kemasan* [Analytical methods for bottled drinking water], SNI 01-3554-1998. Badan Standardisasi Nasional, Jakarta.

National Standardization Agency of Indonesia. (1998). *Spesifikasi kompos dari sampah organik domestik* [Compost specifications from domestic organic waste], SNI 19-7030-2004. Badan Standardisasi Nasional, Jakarta.

Nurhati, I. S., & Cordova, M. R. (2020). Marine plastic debris in Indonesia: Baseline estimates (2010-2019) and monitoring strategy (2021-2025). *Marine Research in Indonesia, 45*(2), 1-6. https://doi.org/10.14203/mri.v45i2.581

NusaBali.com. (2021). *Sampah Rumput Laut Menumpuk di Pesisir Timur* [Seaweed Trash Piles Up on the East Coast]. https://www.nusabali.com/berita/96000/sampah-rumput-laut-menumpuk-di-pesisir-timur

Ojha, S., Bußler, S., & Schlüter, O. K. (2020). Food waste valorisation and circular economy concepts in insect production and processing. *Waste Management, 118*, 600-609. https://doi.org/10.1016/j.wasman.2020.09.010

Pangestu, W., Prasetya, A., & Cahyono, R. B. (2017). Pengolahan limbah kulit pisang dan nangka muda menggunakan larva black soldier fly (*Hermetia illucens*) [Banana peel waste processing and young jackfruit using black soldier fly larvae (*Hermetia illucens*).]. *Simposum Nasional Rapi XVI*, *2*, 97-101.

Pendyurin, E. A., Rybina, S. Y., & Smolenskaya, L. M. (2021). Research of black soldier fly (Hermetia illucens) maggots zoocompost's influence on soil fertility. In *International Conference Industrial and Civil Construction* (pp. 42-49). Springer International Publishing. https://doi.org/10.1007/978-3-030-68984-1_7

Raksasat, R., Lim, J. W., Kiatkittipong, W., Kiatkittipong, K., Ho, Y. C., Lam, M. K., Font-Palma, C., Zaid, H. F. M., & Cheng, C. K. (2020). A review of organic waste enrichment for inducing palatability of black soldier fly larvae: Wastes to valuable resources. *Environmental Pollution, 267*, Article 115488. https://doi.org/https://doi.org/10.1016/j.envpol.2020.115488

Richard, N. (2017). Process manual for the establishment of a black soldier fly (Hermetia illucens) production system*. Haettu, 20*(43), 1-8.

Rofi, D. Y., Auvaria, S. W., Nengse, S., Oktorina, S., & Yusrianti, Y. (2021). Modification of black soldier fly (*Hermetia illucens*) larvae Feed as an effort to accelerate the reduction of fruit and vegetable waste. *Jurnal Teknologi Lingkungan, 22*(1), 130-137. https://doi.org/10.29122/jtl.v22i1.4297

Safia, W., Budiyanti, & Musrif. (2020). Kandungan nutrisi dan senyawa bioaktif rumput laut (*Euchema cottonii*) yang dibudidayakan dengan teknik rakit gantung pada kedalaman berbeda [The nutritional content and bioactive compounds of grass sea (*Euchema cottonii*) which is cultivated using the hanging raft technique different depth]. *Jurnal Pengolahan Hasil Perikanan Indonesia, 23*(2), 261-271.

Salgado, C. L., Muñoz, R., Blanco, A., & Lienqueo, M. E. (2021). Valorization and upgrading of the nutritional value of seaweed and seaweed waste using the marine fungi *Paradendryphiella salina* to produce mycoprotein. *Algal Research, 53*, Article 102135. https://doi.org/https://doi.org/10.1016/j.algal.2020.102135

Setyaningsih, E., Astuti, D. S., & Astuti, R. (2017). Kompos daun solusi kreatif pengendali limbah [Leaf compost is a creative solution waste control]. *Bioeksperimen: Jurnal Penelitian Biologi, 3*(2), 45-51. https://doi.org/10.23917/bioeksperimen.v3i2.5181

Sheppard, D. C., Tomberlin, J. K., Joyce, J. A., Kiser, B. C., & Sumner, S. M. (2002). Rearing methods for the black soldier fly (Diptera: Stratiomyidae). *Journal of Medical Entomology, 39*(4), 695-698. https://doi.org/10.1603/0022-2585-39.4.695

Sulistiyowati, H. I., & Prayitno, P. (2021). Pengolahan air limbah industri pengolahan rumput laut menggunakan nano adsorben tersuspensi [Processing industrial wastewater treatment seaweed using suspended nano adsorbents]. *DISTILAT: Jurnal Teknologi Separasi, 7*(9), 514-521. https://doi.org/10.33795/distilat.v7i2.272

Supriyatna, A., Manurung, R., Esyanti, R. R., & Putra, R. E. (2016). Growth of black soldier larvae fed on cassava peel wastes, An agriculture waste. *Journal of Entomology and Zoology Studies, 4*(6), 161-165.

Suryawan, I. W. K., Septiariva, I. Y., Sari, M. M., Ramadan, B. S., Suhardono, S., Sianipar, I. M. J., Tehupeiory, A., Prayogo, W., & Lim, J. W. (2023). Acceptance of waste to energy (WtE) technology by local residents of Jakarta City, Indonesia to achieve sustainable clean and environmentally friendly energy. *Journal of Sustainable Development of Energy, Water and Environment Systems, 11*(2), 1-17.

Swinscoe, I., Oliver, D. M., Ørnsrud, R., & Quilliam, R. S. (2020). The microbial safety of seaweed as a feed component for black soldier fly (*Hermetia illucens*) larvae. *Food Microbiology, 91*, Article 103535. https://doi.org/https://doi.org/10.1016/j.fm.2020.103535

Tschirner, M., & Simon, A. (2015). Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed. *Journal of Insects as Food and Feed, 1*(4), 249-259. https://doi.org/10.3920/JIFF2014.0008

Wangko, S. (2014). *Hermetia illucens* aspek forensik, kesehatan, dan ekonomi [*Hermetia illucens* forensic, health and economic aspects.]. *Jurnal Biomedik: JBM, 6*(1), 23-29. https://doi.org/10.35790/jbm.6.1.2014.4159

Widyastuti, R. A. D., Rahmat, A., Warganegara, H. A., Ramadhani, W. S., Prasetyo, B., & Riantini, M. (2021). Chemical content of waste composting by black soldier fly (*Hermetia illucens*). In *IOP Conference Series: Earth and Environmental Science* (Vol. 739, No. 1, p. 012003). IOP Publishing. https://doi.org/10.1088/1755-1315/739/1/012003