Agro Bali : Agricultural Journal
Vol. 9 No. 2: 503-516, July 2026
e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

Enhancing Compost Quality through Black Soldier Fly Larvae Bioconversion of Young Coconut Coir and Low-Carbon Organic Wastes

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Article history: submitted: May 11, 2026; accepted: July 23, 2026; available online: August 13, 2026

Abstract. Young coconut coir is an abundant high-carbon residue in Medan, North Sumatra, Indonesia, but its direct use as an organic amendment is limited by its fibrous structure and high C/N ratio. This study aimed to evaluate whether mixing young coconut coir with several low-carbon residues could improve the quality of frass produced by black soldier fly larvae. The experiment was arranged in a randomized complete block design with seven substrate treatments and three replications. The treatments consisted of young coconut coir alone and its mixtures with cauliflower leaf waste, pineapple skin waste, chicken manure, quail manure, goat manure, and cow manure. After 14 days of larval treatment, the frass was analyzed for moisture content, pH, total organic carbon, total nitrogen, C/N ratio, total phosphorus, and total potassium. The substrate mixtures significantly affected moisture content, pH, total organic carbon, total nitrogen, C/N ratio, and total potassium ($P<0.01$), but did not significantly affect temperature and total phosphorus. The mixture with quail manure produced the most favorable frass, characterized by low moisture content (30.84%), the highest total nitrogen (4.15%), the lowest C/N ratio (12.22), and the highest total potassium (4.59%). It also increased total nitrogen by 116.52% and total potassium by 51.38% compared with the initial substrate. These findings demonstrate that combining young coconut coir with nutrient-rich animal manure, particularly quail manure, is an effective strategy for producing nutrient-enriched BSFL frass suitable for use as an organic amendment.

Keywords: C/N ratio; frass; *Hermetia illucens*; nutrient enrichment; quail manure

1. Introduction

The sale of young coconuts provides income-generating opportunities for local communities in Medan, North Sumatra, Indonesia, because the fruit is widely consumed for its water and flesh. However, this activity also generates a large amount of young coconut coir waste. In Medan, young coconut coir waste has been reported to reach approximately 7 tons/day (Gafur, 2019). Without appropriate treatment, this residue may accumulate around urban markets and roadside vendors, create unpleasant odors, and reduce the aesthetic quality of the surrounding area. Therefore, a practical conversion strategy is needed to transform young coconut coir from a waste problem into a useful organic resource.

Young coconut coir has potential as an organic amendment because it has high water retention capacity, high cation exchange capacity, and contains exchangeable nutrients such as K, Na, Ca, and Mg (Carlile et al., 2019). These properties are beneficial for improving the physical and chemical quality of soil or growing media. However, young coconut coir also contains cellulose, lignin, hemicellulose, polyphenols, and a high C/N ratio (Cerqueira et al., 2017). The direct application of raw coconut coir to soil is therefore not recommended because organic materials with a high C/N ratio may stimulate microbial nitrogen immobilization, temporarily reducing nitrogen availability for plants. Composting or biological conversion is required to stabilize the material before it can be used safely as an organic amendment.

Improving compost quality is scientifically important beyond local waste management because compost supports nutrient recycling, soil fertility improvement, organic matter restoration, and sustainable crop production. A good-quality compost should have suitable moisture content, stable

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e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

pH, adequate nutrient content, and a relatively low C/N ratio to support nutrient mineralization and plant uptake. In Indonesian agricultural systems, the use of animal manure as an organic amendment has been associated with improved crop performance. Purba et al. (2018) reported that cow manure application significantly affected the total number of pods in edamame, indicating the agronomic relevance of nutrient-rich organic materials. However, animal manure must be properly processed or combined with other residues to produce a stable and safe organic amendment.

Bioconversion using black soldier fly larvae (BSFL), *Hermetia illucens* L., is an alternative technology for converting organic waste into valuable products. This process produces larval biomass, which can be used as a protein source, and a residue known as frass. Frass consists of insect feces or excretions, undigested substrate residues, and exoskeleton fragments (Klammsteiner et al., 2020). Recent studies have highlighted the potential of BSFL frass as a sustainable organic fertilizer because it contains nutrients, organic matter, microorganisms, and biostimulant compounds that may improve soil health and plant growth (Abd Manan et al., 2024; Lomonaco et al., 2024). In crop production studies, BSFL frass has been reported to support vegetable growth and nutrient accumulation in lettuce and arugula (Chavez et al., 2024). In addition, a field study showed that BSF frass increased crop biomass and improved soil nitrogen and carbon in sandy soil (Kidd et al., 2025). These findings indicate that frass quality is a key factor in determining the agricultural value of BSFL-based bioconversion.

Although BSFL can digest various organic wastes, their performance is strongly influenced by substrate characteristics. BSFL generally performs better on soft-textured organic wastes with balanced nutrients than on substrates dominated by lignocellulosic materials. High levels of cellulose, hemicellulose, and lignin may limit substrate degradation and larval digestion, thereby reducing the effectiveness of bioconversion. Several studies have attempted to overcome this limitation by combining high-fiber wastes with nutrient-rich or low-C/N organic wastes. Rehman et al. (2017) showed that mixing dairy manure with soybean curd residue improved fiber degradation during BSFL treatment. Similarly, Anjum et al. (2016) suggested that adding nutrient-rich and low-C/N substrates can enhance the degradation of lignocellulosic materials.

Despite these findings, information on the bioconversion of young coconut coir in combination with various low-carbon organic wastes remains limited. Previous studies have examined several agricultural or plantation residues as BSFL substrates. However, the specific use of young coconut coir as a high-carbon substrate, mixed with vegetable and fruit waste, and various animal manures has not been sufficiently evaluated. This research gap is important because the type of co-substrate may strongly influence moisture content, pH, organic carbon decomposition, nitrogen enrichment, C/N reduction, and potassium content of the final frass. Based on previous research, it is necessary to study the effects of mixtures of young coconut coir with different low-carbon organic wastes on the physical and chemical properties of BSFL frass to produce high-quality compost.

Therefore, this study aimed to evaluate the effect of mixing young coconut coir with different low-carbon organic wastes on the physical and chemical properties of BSFL frass. We hypothesized that combining high-carbon young coconut coir with nutrient-rich, low-carbon organic wastes, particularly animal manure, would produce BSFL frass with lower moisture content and C/N ratio, but higher total nitrogen and total potassium, than young coconut coir alone. The expected contribution of this study is to provide a practical substrate formulation strategy to enhance the quality of BSFL frass as a nutrient-rich organic amendment and increase the value of young coconut coir waste.

e-ISSN 2655-853X
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2. Materials and Methods

The study was conducted at a black soldier fly (BSF) larval farm in Namurambe, Medan, North Sumatra, Indonesia, in a closed room under a corrugated metal shelter measuring 4 x 3 m. During the 14-day bioconversion period, ambient temperature, relative humidity, and indirect light intensity were measured once daily at container height. The mean ambient temperature was 28.5 ± 0.7 °C, with an observed range of 27.2–29.7 °C. The mean relative humidity was 65.4 ± 2.7%, with an observed range of 61–70%, while the mean indirect light intensity was 1,250 ± 136 lux, with an observed range of 1,020–1,490 lux (n = 14). All containers were protected from direct rainfall and excessive sunlight, while adult cages were exposed to natural daylight for approximately 12 h per day to support mating and oviposition.

A population of BSF (*Hermetia illucens*) was attracted from the surrounding ecosystem and maintained in cages measuring 2 x 3 x 2 m, covered with transparent mosquito netting. Organic waste was placed in plastic containers as an oviposition attractant. Ten grams of eggs were collected and hatched on rice bran substrate. After eight days, larvae were separated from the hatching medium using a sieve and used in the experiment. Young coconut coir (YCC) was collected from crushed coir waste discarded by young coconut vendors in Medan and fermented with EM4 for one week. Cauliflower leaf waste (CL), pineapple skin waste (P), chicken manure (CM), quail manure (QM), goat manure (GM), and cow manure (CoM) were collected from local markets and farms. All substrates were stored in closed plastic bags at -5 °C prior to use to minimize microbial decomposition.

The experiment used a randomized complete block design with seven treatments and three replications, resulting in 21 experimental units. The treatments were YCC, YCC+CL, YCC+P, YCC+CM, YCC+QM, YCC+GM, and YCC+CoM. The ratio between YCC and each low-carbon organic waste was 4:6 (v/v). Each experimental unit contained 1 kg substrate mixture and 100 g BSF larvae in a 3.5 L plastic container (25 x 20 x 7 cm). The blocks were defined according to the spatial positions of the containers within the experimental room, namely the front, middle, and rear rows. Each block contained one experimental unit of each of the seven treatments. The treatments were randomly assigned to container positions within each block and remained within their respective rows throughout the 14-day bioconversion period. The three blocks served as three replications, allowing the estimation of experimental error and statistical comparison among treatments. To minimize experimental bias, all units received the same substrate weight and were maintained using larvae of the same age and initial weight, identical container sizes, the same feeding duration, and comparable room conditions.

The bioconversion process was carried out aerobically for 14 days or until prepupae appeared. At harvest, larvae were separated from the frass using a 1 mm sieve. The frass was air-dried and sieved through a 2 mm sieve before analysis. The initial substrate mixture and final frass were analyzed for pH, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), moisture content, and temperature. Frass pH was measured in water at a 1:10 sample-to-solution ratio. TOC was determined using the Walkley-Black method, TN using the Kjeldahl method, and TP and TK after wet digestion with concentrated HNO_3 and $HClO_4$. Potassium was measured using atomic absorption spectrophotometry, while phosphorus was measured using a spectrophotometer. The initial physicochemical properties of each substrate mixture are presented in Table 1.

e-ISSN 2655-853X
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Table 1. Physico-chemical properties of initial substrates before treatment by BSF larvae

Parameter	YCC	YCC +CL	YCC+P	YCC +CM	YCC +QM	YCC +GM	YCC +CoM
Temperature (^{0}C)	32.20	30.30	30.50	31.50	29.50	28.70	30.80
Moisture content (%)	75.16	86.50	88.24	51.11	58.42	77.91	84.75
pH	6.15	5.38	6.10	5.10	5.97	5.18	6.29
TOC (%)	73.34	65.01	60.33	65.57	68.80	70.13	70.24
TN (%)	1.15	1.37	1.25	1.80	1.76	1.45	1.53
C/N	63.77	47.45	48.26	36.43	39.09	48.37	45.91
TP (%)	0.64	1.25	1.15	0.77	0.81	1.90	1.84
TK (%)	3.46	2.16	2.71	1.84	3.03	2.91	2.81

Notes: TOC, TN, C/N, TP, and TK represent total organic carbon, total nitrogen, carbon-nitrogen ratio, total phosphorus, and total potassium, respectively

Data were analyzed using R software version 4.2.2. Before ANOVA, normality and homogeneity of variance were checked using the Shapiro-Wilk test and Levene's test, respectively. Data that met these assumptions were analyzed using ANOVA for RCBD, with treatment and block included in the model. Significant treatment effects were followed by Duncan's Multiple Range Test at the 5% significance level. Results are presented as mean ± standard error from three replications.

Pearson product–moment correlation analysis and simple linear regression were used to evaluate pairwise relationships among selected physicochemical properties of BSFL frass, namely moisture content, total nitrogen (TN), C/N ratio, total potassium (TK), and pH. These parameters were selected because they represent key indicators of frass handling, maturity, nutrient enrichment, and nitrogen transformation. The analyses were performed using pooled observations from all 21 individual experimental units, rather than treatment means. The statistical significance of each two-sided correlation coefficient was tested at $\alpha = 0.05$. Regression equations and coefficients of determination (R^2) were obtained from simple linear regression. All correlation and regression analyses were performed using R software version 4.2.2.

3. Results and Discussion

BSFL bioconversion changed the physicochemical quality of frass depending on the co-substrate mixed with young coconut coir (YCC). The final physicochemical properties of the frass are summarized in Table 2. Overall, YCC+QM showed the most favorable physicochemical profile, as indicated by low moisture content, the highest total nitrogen (TN), the lowest C/N ratio, and the highest total potassium (TK). These results indicate that frass quality was controlled by the balance between the fibrous carbon source from YCC and the nutrient supply from the added co-substrates. Therefore, the response of YCC+QM reflected an effective substrate formulation for converting high-carbon coconut coir into nutrient-enriched BSFL frass.

Temperature of the final frass ranged from 28.5 to 31.4 °C and was not significantly affected by substrate composition ($F = 3.74$; $P > 0.05$). The final temperature range suggests that all frass products had reached a relatively stable stage at harvest. This range is also close to the mature-compost temperature range specified in Indonesian SNI 19-7030-2004 (25.6–31.5 °C) (Badan Standardisasi Nasional, 2004).

Moisture content was strongly affected by substrate composition ($F = 156.58$; $P < 0.01$), as presented in Table 2 and Figure 1. The lowest moisture contents were observed in YCC+CM (28.43%) and YCC+QM (30.84%), whereas YCC+CL produced the highest value (64.40%). Compared with their initial substrates, moisture reduction reached 47.21% in YCC+QM and 44.37% in YCC+CM, while the reduction in YCC alone

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

was only about 21%. These results indicate that mixing YCC with animal manure, especially chicken and quail manure, enhanced moisture reduction during larval bioconversion.

These reductions indicate that adding animal manure, especially chicken and quail manure, improved water loss during BSFL bioconversion rather than merely diluting the YCC substrate. The final moisture values of YCC+CM and YCC+QM were close to the lower limit of the 30–72% range summarized for BSFL frass by Basri et al. (2022), whereas the higher moisture values in YCC+CL and YCC+CoM were close to the 62.7% reported by Sarpong et al. (2018). Thus, co-substrate selection strongly influenced whether YCC-based frass became a relatively wet product or a drier and more manageable organic amendment.

Table 2. Physicochemical properties of BSFL frass after 14 days of bioconversion (mean ± standard error; n= 3).

Parameter	YCC	YCC +CL	YCC+P	YCC +CM	YCC +QM	YCC +GM	YCC +CoM	F value
Tempe-rature (^{0}C)	30.4 ±0.9	30.0 ±0.7	29.2 ±0.6	31.4 ±1.1	29.0 ±0.9	28.5 ±1.4	30.6 ±1.7	3.74^{ns}
Moisture content (%)	59.4 ±1.6^{b}	64.4 ±0.3^{a}	53.99 ±3.82^{c}	28.43 ±2.41^{d}	30.84 ±1.35^{d}	51.06 ±0.82^{c}	61.72 ±0.04^{ab}	156.58**
pH	7.90 ±0.15^{f}	8.18 ±0.18^{d}	7.97 ±0.20^{ef}	8.46 ±0.14^{c}	8.76 ±0.06^{b}	8.96 ±0.24^{a}	8.09 ±0.14^{de}	63.03**
TOC (%)	61.77 ±4.81^{a}	44.46 ±4.16^{c}	34.89 ±2.73^{e}	41.79 ±0.64^{cd}	50.38 ±0.34^{b}	40.69 ±0.75^{cd}	39.18 ±1.58^{d}	42.08**
TN (%)	2.49 ±0.19^{cd}	2.88 ±0.17^{bc}	2.04 ±0.13^{d}	3.28 ±0.49^{b}	4.15 ±0.38^{a}	3.15 ±0.11^{b}	2.06 ±0.16^{d}	22.96**
C/N	24.97 ±3.51^{a}	15.44 ± 0.6^{cd}	17.21 ±2.19^{bc}	12.89 ±1.59^{d}	12.22 ±1.15^{d}	12.95 ±0.69^{d}	19.13 ±1.84^{b}	16.21**
TP (%)	1.86 ± 0.33^{ab}	1.30 ± 0.67^{b}	2.49 ± 0.70^{a}	2.06 ± 0.42^{ab}	2.37 ±0.41^{b}	2.14 ±0.32^{ab}	2.54 ± 0.19^{a}	2.56^{ns}
TK (%)	3.87± 0.12^{b}	3.12 ± 0.24^{d}	3.25 ± 0.27^{cd}	3.49 ± 0.42^{bcd}	4.59 ±0.13^{a}	3.89 ± 0.41^{b}	3.66 ± 0.13^{bc}	10.65**

Notes: **P<0.01; ns, P>0.05.

The contrasting moisture response among treatments can be explained by the interaction between the water-retaining structure of YCC and the physical characteristics of the added co-substrates. The relatively high moisture contents in YCC, YCC+CL, YCC+P, YCC+GM, and YCC+CoM suggest that the fibrous and pith fractions of young coconut coir retained water during bioconversion. This agrees with Carlile et al. (2019), who described coir-based materials as having high water absorption and retention capacity. In contrast, the lower moisture contents in YCC+CM and YCC+QM indicate that these manures may have improved substrate porosity, aeration, and larval movement, thereby increasing moisture loss during feeding. This interpretation links the present findings with Cheng et al. (2017), who showed that moisture level affects residue handling and separation in BSFL processing, and with Dortmans et al. (2021), who emphasized the need to control excess moisture during BSFL bioconversion.

Substrate composition significantly affected frass pH (F = 63.03; P < 0.01). All treatments produced alkaline frass, with the

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

lowest pH in YCC (7.90) and the highest in YCC+GM (8.96) (Figure 2). The pH values in this study were higher than the 5.3-7.72 range reported by Sarpong et al. (2018) but close to the alkaline trend reported by Rehman et al. (2017), where the pH of BSFL residue increased from 7.4 to 8.6 when dairy manure was mixed with soybean curd residue. The increase in pH may be associated with nitrogen mineralization and ammonium accumulation during larval degradation of protein-rich substrates.

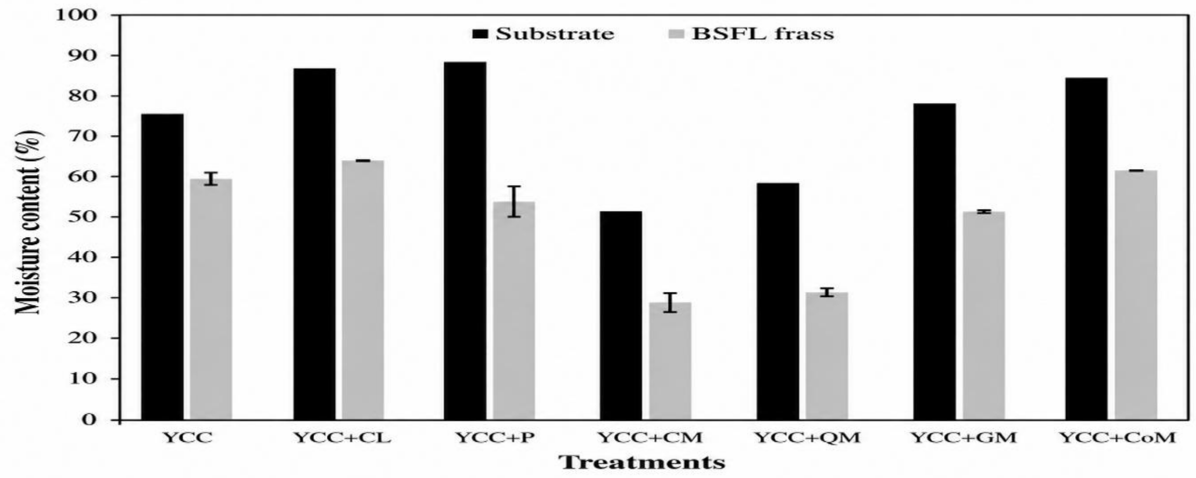

Figure 1. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on the moisture content of the BSFL frass; bars indicate the standard error of the means (n = 3).

Total organic carbon (TOC) differed significantly among treatments ($F = 42.08$; $P < 0.01$). YCC alone produced the highest TOC (61.77%), whereas YCC+P produced the lowest TOC (34.89%) (Figure 3). Compared with the initial substrate, TOC declined by 15.78% in YCC and by 44.22% in YCC+CoM, indicating that mixed substrates promoted greater carbon loss or transformation than YCC alone. The TOC of YCC+P (34.89%), YCC+GM (40.69%), and YCC+CoM (39.18%) was close to the approximately 37% total carbon reported in a critical review of BSFL frass by Lopes et al. (2022) and to the 37.49% carbon reported for BSFL frass by Chavez et al. (2024). In contrast, YCC and YCC+QM retained higher TOC, suggesting that coconut coir contributed to carbon retention in the final frass. This carbon retention may be useful for organic matter addition, but excessive TOC without sufficient nitrogen can maintain a high C/N ratio and reduce compost maturity.

The decrease in TOC across the BSFL-treated substrates indicates that part of the substrate carbon was degraded or transformed during larval bioconversion. In the present study, the greater TOC reduction in mixed substrates, particularly YCC+CoM, compared with YCC alone suggests that low-carbon co-substrates helped improve the decomposition of the fibrous YCC matrix. This response can be linked to the digestive capacity of BSFL. Bonelli et al. (2019) reported the presence of digestive enzymes such as amylase, lipase, and protease in the BSFL gut, which can support the breakdown of carbohydrates, lipids, and proteins. In addition, gut-associated microorganisms, including Bacillus and yeasts, may contribute to lignocellulose degradation and metabolite utilization (De Smet et al., 2018). Therefore, the observed TOC reduction was not merely a general consequence of larval activity. It also reflected the ability of BSFL and their associated microorganisms to transform carbon-rich substrates when suitable co-substrates were added. During bioconversion, part of the carbon is retained in the frass and larval biomass. The remaining fraction may be released mainly as CO_2, as described by Parodi et al. (2020).

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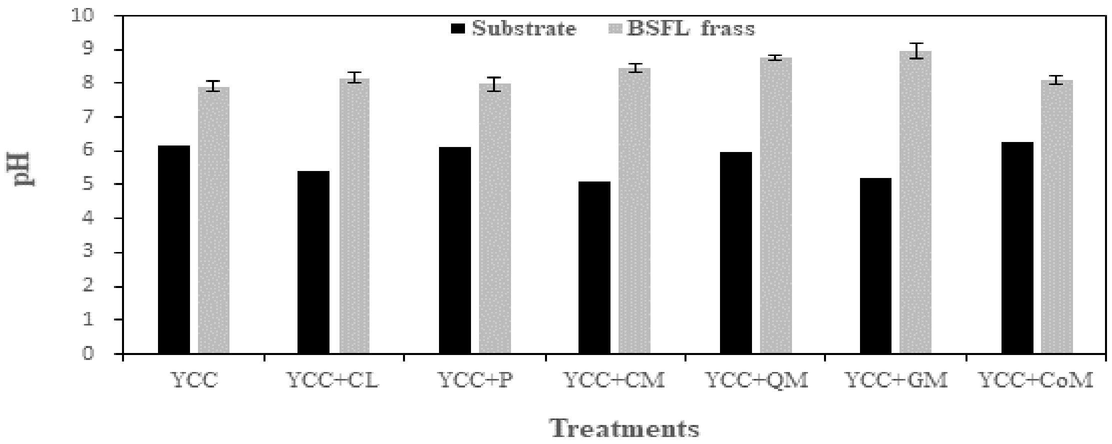

Figure 2. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on pH of the BSFL frass; bars indicate the standard error of the means (n = 3).

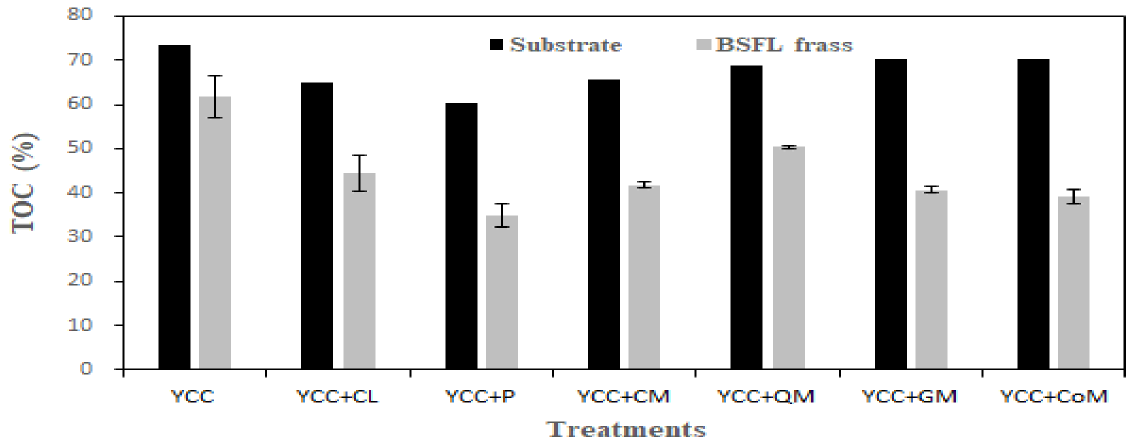

Figure 3. The effect of treatment with a combination of young coconut fiber waste and low-carbon organic materials as BSFL feeds on total organic carbon (TOC) of the BSFL frass; bars indicate the standard error of the means (n = 3).

The highest TN was obtained in YCC+QM (4.15%), followed by YCC+CM (3.28%) and YCC+GM (3.15%), whereas YCC+P produced the lowest TN (2.04%) (Figure 4). Compared with YCC alone (2.49%), YCC+QM increased final TN by 66.7%. Compared with its initial substrate, YCC+QM increased TN by 116.52%, indicating strong nitrogen enrichment during bioconversion. Quantitatively, the TN of YCC+QM (4.15%) was higher than the N range reported by Woo et al. (2024) where co-composted BSFL frass increased N from 2.47% to 3.10% after fish meal addition. It was also considerably higher than the 1.68% total N reported by Tambeayuk et al. (2024) for BSFL frass produced from multiple organic wastes in Cameroon. In addition, YCC+QM was 8.4% higher than the 3.83% N reported for BSFL frass by Chavez et al. (2024).

YCC alone produced the highest C/N ratio (24.97), while YCC+QM produced the lowest value (12.22) (Figure 5). Compared with YCC alone, YCC+QM reduced the final C/N ratio by 51.1%. Compared with the initial substrate, the C/N ratio of YCC+QM decreased from 39.09 to 12.22, corresponding to a 68.74% reduction. This value was lower than the C/N ratio of 17:1–18:1 reported by David et al. (2024) for BSFL frass produced from a mixture of decanted

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

sago pith and palm kernel expeller, and also lower than most of the 14.94–29.65 range reported by Mulu et al. (2023) for frass produced from water hyacinth and fruit waste.

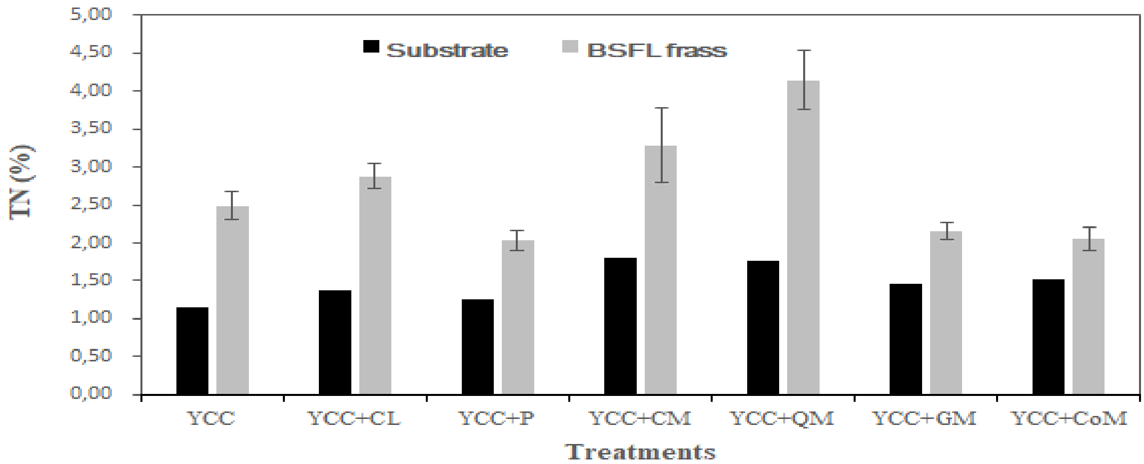

Figure 4. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on Total Nitrogen (TN) of the BSFL frass; bars indicate the standard error of the means (n = 3).

Most frass products obtained from mixtures of YCC and soft-textured organic wastes had C/N ratios below 20, indicating a more mature and agronomically favorable material. A C/N ratio below 20 is generally beneficial because organic nitrogen is less likely to be immobilized and can become more available for plant uptake. However, extremely low C/N values may also indicate rapid mineralization and potential nutrient losses. Previous studies reported very low C/N ratios in BSFL frass produced from food waste or dairy manure (Basri et al., 2022). In the present study, the addition of high-fiber YCC increased the initial C/N ratio of the substrate mixtures and prevented the final frass from reaching excessively low C/N values. A similar strategy was reported by Beesigamukama et al. (2021) who added sawdust to brewery waste to increase the initial C/N ratio from 11 to 15, 20, and 25.

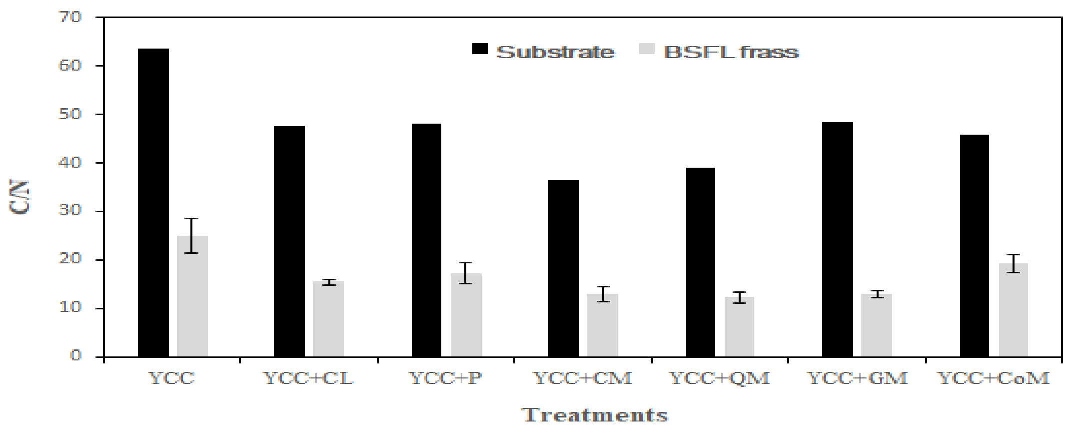

Figure 5. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on the C/N ratio of the BSFL frass; bars indicate the standard error of the means (n = 3).

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

Total phosphorus (TP) varied numerically from 1.30% in YCC+CL to 2.54% in YCC+CoM, but the treatment effect was not significant ($F = 2.56$; $P > 0.05$), as shown in Table 2 and Figure 6. Therefore, these numerical differences should be interpreted cautiously. Nevertheless, the absolute TP values were relatively high compared with several recent reports on BSFL frass. Salomon et al. (2025) reported TP values of 1.3–1.6%, whereas most treatments in the present study, except YCC+CL, produced values above this range. The highest values were recorded in YCC+P (2.49%), YCC+QM (2.37%), and YCC+CoM (2.54%). Woo et al. (2024) also reported substantially lower phosphorus concentrations in co-composted BSFL frass, ranging from 0.024% to 0.042% after bone meal addition.

In contrast, substrate composition significantly affected TK ($F = 10.65$; $P < 0.01$), as shown in Table 2 and Figure 7. The highest TK concentration was recorded in YCC+QM (4.59%). This value was 18.6% higher than that of YCC alone and 51.38% higher than that of the initial YCC+QM substrate. Wu et al. (2022) also reported that combining mineral-rich plant residues with animal-derived substrates increased the K concentration of BSFL frass. Therefore, the high TK observed in this study may reflect both the natural K content of YCC and improved substrate degradation following manure addition.

3.1 Correlation Analysis among Physicochemical Properties of BSFL Frass

Pearson product–moment correlation and simple linear regression analyses were performed using pooled observations from the 21 individual experimental units (Figure 8). The selected parameter pairs represent important physicochemical characteristics associated with frass quality, including moisture reduction, nutrient enrichment, nutrient balance, and nitrogen transformation during BSFL bioconversion.

Moisture content showed a negative but non-significant relationship with total nitrogen ($r = -0.335$; $R^2 = 0.112$; $P = 0.138$) (Figure 8a). Although frass with lower moisture content tended to contain slightly higher TN, the weak relationship indicates that nitrogen enrichment was not determined primarily by water loss during bioconversion. Instead, differences in substrate composition, particularly the addition of nutrient-rich animal manures, appeared to contribute more substantially to the TN concentration of the final frass.

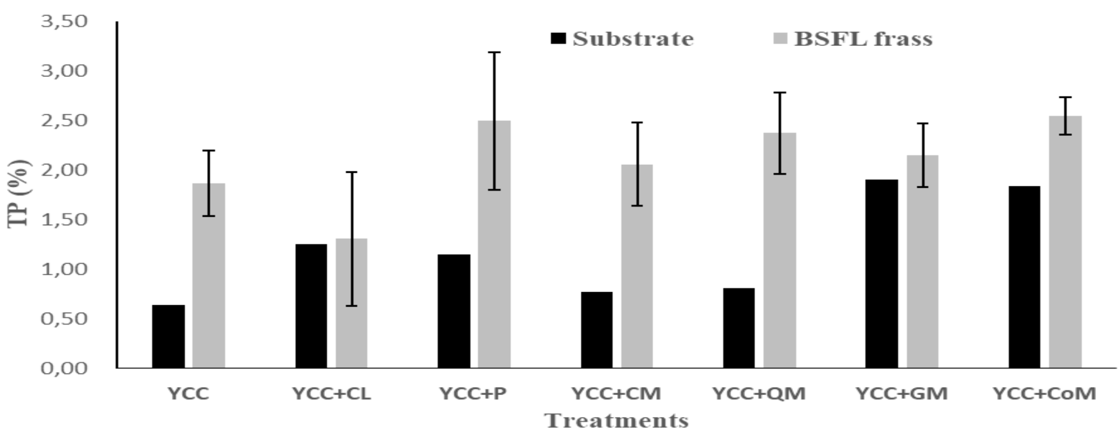

Figure 6. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on total phosphorus (TP) of the BSFL frass; bars indicate the standard error of the means (n = 3).

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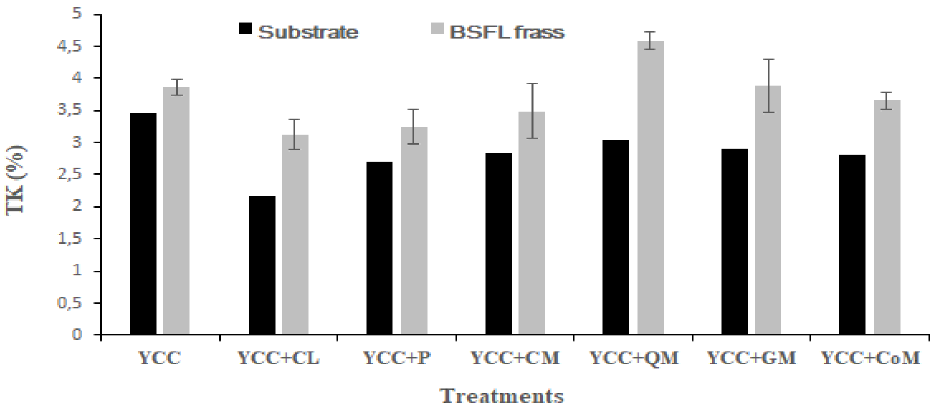

Figure 7. The effect of treatment with a combination of young coconut fiber waste and low- carbon organic materials as BSFL feeds on total potassium (TK) of the BSFL frass; bars indicate the standard error of the means (n = 3)

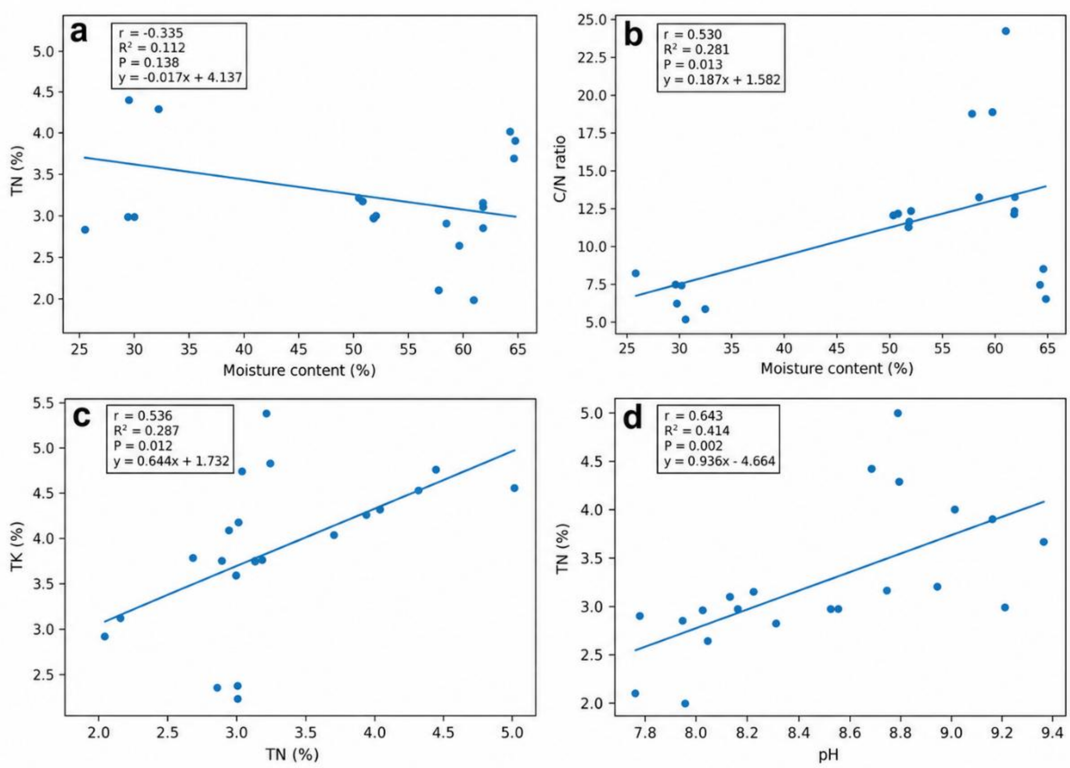

Figure 8. Correlation and simple linear regression relationships among selected physicochemical properties of BSFL frass: (a) moisture content vs TN, (b) moisture content vs C/N ratio, (c) TN vs TK, and (d) pH vs TN (n = 21)

Moisture content was positively correlated with the C/N ratio ($r = 0.530$; $R^2 = 0.281$; $P = 0.013$) (Figure 8b). Frass samples with higher moisture content generally exhibited higher C/N ratios, whereas drier frass tended to have lower C/N ratios. This relationship agrees with the treatment results, in which YCC mixed with quail manure and cow manure produced both relatively low moisture contents and lower C/N ratios. The result suggests that moisture reduction during BSFL bioconversion was accompanied by improved frass maturity.

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

Total nitrogen was positively correlated with total potassium (r = 0.536; R^2 = 0.287; P = 0.012) (Figure 8c). Treatments that promoted nitrogen enrichment also tended to increase potassium concentration, indicating simultaneous improvement of two essential plant nutrients. Nevertheless, TN explained only 28.7% of the variation in TK, suggesting that potassium accumulation was also influenced by the intrinsic potassium content of the co-substrates used during bioconversion.

The strongest relationship among the selected parameter pairs was observed between pH and TN (r = 0.643; R^2 = 0.414; P = 0.002) (Figure 8d). Frass with higher pH generally contained higher TN concentrations. This pattern may reflect changes in nitrogen transformation during the decomposition of nutrient-rich substrates. Higher pH may be associated with greater organic nitrogen mineralization and nitrogen retention in the final frass. Accordingly, treatments with higher pH values also tended to contain higher TN concentrations.

Overall, the correlation analysis complements the treatment comparisons by demonstrating consistent relationships among key physicochemical properties of BSFL frass. These correlations do not establish causal relationships. However, they support the experimental finding that nutrient-rich co-substrates, particularly animal manures, were associated with lower moisture content and C/N ratio, as well as higher TN and TK concentrations.

4. Limitations and Future Directions

This study provides evidence that mixing young coconut coir with low-carbon organic wastes can improve the physicochemical quality of BSFL frass. However, several limitations should be considered. The experiment was conducted under specific rearing conditions using one substrate ratio, one larval density, and a 14-day bioconversion period. Therefore, the results should not be generalized to all BSFL production systems, substrate ratios, or environmental conditions.

Future studies should optimize the proportion of young coconut coir and animal manure to obtain a more stable and nutrient-balanced frass product. Further research is also needed to evaluate the maturity, microbial quality, nutrient release pattern, and safety of BSFL frass before field application. Greenhouse and field experiments on crop growth and soil fertility are recommended to confirm the agronomic effectiveness of the frass produced from young coconut coir-based substrates. These future investigations will help determine the practical application of BSFL frass as a safe and sustainable organic amendment for agricultural production.

5. Conclusion

This study demonstrates that substrate formulation is a key factor controlling the physicochemical quality of BSFL frass produced from young coconut coir. Mixing young coconut coir with low-carbon organic wastes, particularly nutrient-rich animal manure, improved frass quality by reducing moisture content and C/N ratio while increasing nitrogen and potassium contents under the experimental conditions used in this study. The main scientific contribution of this work is the demonstration that high-carbon young coconut coir, which is difficult to use directly as an organic amendment, can be converted into a more balanced and nutrient-enriched frass through BSFL bioconversion when combined with suitable co-substrates. From a practical perspective, this finding provides a substrate formulation strategy for improving the value of young coconut coir waste and producing BSFL frass with better potential as an organic amendment.

However, the applicability of these findings should be limited to the tested substrate ratio, larval density, bioconversion period, and environmental conditions. Further studies are needed to optimize the ratio of young coconut coir and animal manure, evaluate microbial safety and

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

nutrient stability, and test the agronomic performance of the resulting frass on crops and soil under greenhouse and field conditions. These future studies are important to confirm the effectiveness, safety, and practical application of young coconut coir-based BSFL frass for sustainable compost and organic fertilizer production.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with grammar correction, sentence refinement, and structural organization. These tools did not contribute to the generation of scientific ideas, research design, methodology, data analysis, results interpretation, or conclusions. After using this tool, the authors reviewed, verified, and edited the content as needed and accepted full responsibility for the content of the published article.

Authorship Contribution Statement

Dini Mufriah: Conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing—original draft, and writing—review and editing. T. Sabrina: Supervision, conceptual guidance, methodology validation, resources, and writing—review and editing. Lisdayani: Project administration, manuscript submission, journal submission support, and writing—review and editing. All authors have read and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

References

Abd Manan, F., Yeoh, Y.-K., Chai, T.-T., & Wong, F.-C. (2024). Unlocking the potential of black soldier fly frass as a sustainable organic fertilizer: A review of recent studies. *Journal of Environmental Management*, *367*, 121997. https://doi.org/10.1016/j.jenvman.2024.121997

Anjum, M., Khalid, A., Mahmood, T., & Aziz, I. (2016). Anaerobic co-digestion of catering waste with partially pretreated lignocellulosic crop residues. *Journal of Cleaner Production*, *117*, 56–63. https://doi.org/10.1016/j.jclepro.2015.11.061

Badan Standardisasi Nasional. (2004). Spesifikasi kompos dari sampah organik domestik. In *(SNI 19-7030-2004)*. https://www.nawasis.org/portal/download/digilib/953-SNI-2004_7030_19.pdf

Basri, N. E. A., Azman, N. A., Ahmad, I. K., Suja, F., Jalil, N. A. A., & Amrul, N. F. (2022). Potential applications of frass derived from black soldier fly larvae treatment of food waste: A Review. *Foods*, *11*(17), 2664. https://doi.org/10.3390/foods11172664

Beesigamukama, D., Mochoge, B., Korir, N. K., Fiaboe, K. K. M., 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/10.1016/j.wasman.2020.09.043

Bonelli, M., Bruno, D., Caccia, S., Sgambetterra, G., Cappellozza, S., Jucker, C., Tettamanti, G., & Casartelli, M. (2019). Structural and functional characterization of Hermetia illucens larval midgut. *Frontiers in Physiology*, *10*, 204. https://doi.org/10.3389/fphys.2019.00204

Carlile, W. R., Raviv, M., & Prasad, M. (2019). Organic soilless media components. In *Soilless Culture: Theory and Practice* (2nd ed.). Elsevier. https://doi.org/10.1016/B978-0-444-63696-6.00008-6

Cerqueira, J. C., Da Silva Penha, J., Oliveira, R. S., Nani Guarieiro, L. L., Da Silva Melo, P., Viana, J. D., & Souza Machado, B. A. (2017). Production of biodegradable starch nanocomposites using cellulose nanocrystals extracted from coconut fibers. *Polimeros*, *27*(4), 320–329. https://doi.org/10.1590/0104-1428.05316

Chavez, M. Y., Uchanski, M., & Tomberlin, J. K. (2024). Impacts of black soldier fly, *Hermetia illucens*, larval frass on lettuce and arugula production. *Frontiers in*

Sustainable Food Systems, *8*, 1399932. https://doi.org/10.3389/fsufs.2024.1399932

Cheng, J. Y. K., Chiu, S. L. H., & Lo, I. M. C. (2017). Effects of moisture content of food waste on residue separation, larval growth and larval survival in black soldier fly bioconversion. *Waste Management*, *67*, 315–323. https://doi.org/10.1016/j.wasman.2017.05.046

David, C. S., Omar, L., Ahmed, O. H., Huzaifah, M., Roslim, M., & Krishnan, K. (2024). Waste reduction rate, selected agronomic properties, and effect on bekenu series soil pH buffering capacity of black soldier fly larvae frass. *Technology in Agronomy*, *4*, e020. https://doi.org/10.48130/tia-0024-0016

De Smet, J., Wynants, E., Cos, P., & Van Campenhout, L. (2018). Microbial community dynamics during rearing of black soldier fly larvae (*Hermetia illucens*) and impact on exploitation potential. *Applied and Environmental Microbiology*, *84*(9), e02722-17. https://doi.org/10.1128/AEM.02722-17

Dortmans, B., Diener, S., Verstappen, B., & Zurbrügg, C. (2021). *Black soldier fly biowaste processing: A step-by-step guide* (2nd ed.). Eawag: Swiss Federal Institute of Aquatic Science and Technology. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/swm/Practical_knowhow_on_BSF/BSF_Biowaste_Processing_2nd_Edition_LR.pdf

Gafur, M. (2019, April 10). Limbah kelapa muda. *ANTARA*. https://sumbar.antaranews.com/berita/259125/limbah-kelapa-muda

Kidd, D. R., Enkhbat, G., Wisdom, J. M. B., Kragt, M. E., Jenkins, S. N., & Ryan, M. H. (2025). Black soldier fly frass greatly improves growth of four crops in a fertilised sandy soil. *Journal of Cleaner Production*, *520*, 146046. https://doi.org/10.1016/j.jclepro.2025.146046

Klammsteiner, T., Turan, V., Juárez, M. F. D., Oberegger, S., & Insam, H. (2020). Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization. *Agronomy*, *10*(10), 1578. https://doi.org/10.3390/agronomy10101578

Lomonaco, G., Franco, A., De Smet, J., Scieuzo, C., Salvia, R., & Falabella, P. (2024). Larval frass of *Hermetia illucens* as organic fertilizer: Composition and beneficial effects on different crops. *Insects*, *15*(4), 293. https://doi.org/10.3390/insects15040293

Lopes, I. G., Yong, J. W. H., & Lalander, C. (2022). Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives. *Waste Management*, *142*, 65–76. https://doi.org/10.1016/j.wasman.2022.02.007

Mulu, D., Yimer, F., Opande, G., & Bekele, T. (2023). Waste reduction, biomass conversion and growth performance of black soldier fly larvae using organic waste. *Asian Journal of Scientific Research*, *16*(1), 1–8. https://doi.org/10.3923/ajsr.2023.1.8

Parodi, A., De Boer, I. J. M., Gerrits, W. J. J., Van Loon, J. J. A., Heetkamp, M. J. W., Van Schelt, J., Bolhuis, J. E., & Van Zanten, H. H. E. (2020). Bioconversion efficiencies, greenhouse gas and ammonia emissions during black soldier fly rearing – A mass balance approach. *Journal of Cleaner Production*, *271*, 122488. https://doi.org/10.1016/j.jclepro.2020.122488

Purba, J. H., Parmila, I. P., & Sari, K. K. (2018). Pengaruh pupuk kandang sapi dan jarak tanam terhadap pertumbuhan dan hasil kedelai (*Glycine max* L. Merrill) varietas edamame. *Agro Bali: Agricultural Journal*, *1*(2), 69–81. https://doi.org/10.37637/ab.v1i2.396

Rehman, K. ur, Rehman, A., Cai, M., Zheng, L., Xiao, X., Somroo, A. A., Wang, H., Li, W., Yu, Z., & Zhang, J. (2017). Conversion of mixtures of dairy manure and soybean curd residue by black soldier fly larvae (*Hermetia illucens* L.). *Journal of Cleaner Production*, *154*, 366–373. https://doi.org/10.1016/j.jclepro.2017.04.019

Salomon, M. J., Cavagnaro, T. R., & Burton, R. A. (2025). Potential of black soldier fly larvae frass (BSFL) as a novel fertilizer: Impacts on tomato growth, nutrient uptake, and mycorrhizal formation. *Plant and Soil*, *513*(1), 417–434. https://doi.org/10.1007/s11104-024-07187-4

e-ISSN 2655-853X
https://doi.org/10.37637/ab.v9i2.2787

Sarpong, D., Oduro Kwarteng, S., Fosu Gyasi, S., Buamah, R., Donkor, E., Yaw Botchway, E., & Acquah, S. (2018). Biodegradation of heterogeneous mixture of organic fraction of municipal solid waste by black soldier fly larvae (*Hermetia illucens*) under the tropical climate conditions. *IJISET-International Journal of Innovative Science, Engineering & Technology*, *5*(3), 244–254. www.ijiset.com

Tambeayuk, M. A., Taiwo, O. J., & Kamga, M. A. (2024). Evaluation of the fertilizer potential of black soldier fly larval frass obtained by the processing of multiple organic wastes in agriculture in Cameroon: Effects on plant growth parameters and maize kernel nutrient composition. *Research Journal of Agricultural Economics and Development*, *3*(2), 43–63. https://doi.org/10.52589/RJAED-V0OFXZMX

Woo, K. T., Shamsuddin, R., Hakimi, M., Manogaran, M. D., Looi, L. W., Tan, Z. Sen, & Abubakar, A. M. (2024). Co-composting of black soldier fly frass (BSFF) with various organics additives for nutrient enhancement. *Bioresource Technology Reports*, *27*, 101944. https://doi.org/10.1016/j.biteb.2024.101944

Wu, N., Wang, X., Mao, Z., Liang, J., Liu, X., & Xu, X. (2022). Bioconversion of chicken meat and bone meal by black soldier fly larvae: Effects of straw addition on the quality and microbial profile of larval frass. *Journal of Environmental Management*, *307*, 114579. https://doi.org/10.1016/j.jenvman.2022.114579