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Black Soldier Fly as a Sustainable Solution for Converting Slaughterhouse Waste into Compost: Influence of Feed Composition and Larvae Quantity

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Abstract: Slaughterhouses play a crucial role in food security but generate substantial organic waste, including rumen content and cattle dung, which contributes to environmental pollution. Bioconversion using Black Soldier Fly (BSF) larvae offers a promising approach for transforming slaughterhouse waste into nutrient-rich kasgot. This study aims to evaluate the efficiency of BSF larval bioconversion in reducing slaughterhouse waste and assessed the quality of the resulting kasgot. The experiment was conducted at the laboratory scale for 15 days, with each reactor containing 400 seven-day-old BSF larvae. Feed composition varied according to rumen-to-cattle dung ratios of 100:0, 80:20, 50:50, and 0:100 (w/w). The feed quantities used were 60, 80, and 100 mg/larvae/day. The results showed that a feed composition of 100% rumen and feed quantity of 100 mg/larvae/day provided optimum results, with a total waste reduction of 78.6%, an Efficiency of Conversion of Digested Food (ECD) of 8.7%, and a total larval growth of 21.71 g. The resulting kasgot met Indonesian standards for solid organic fertiliser, with C-organic, total N, and the C/N ratio ranging from 20.5–38.9%, 1.79–1.92%, and 10.89–20.86, respectively. These findings demonstrate that BSF larvae have strong potential and provide a basis for optimising the composting process as a sustainable waste transformation method.

Keywords: black soldier fly larvae; bioconversion; fertilizer; rumen; slaughterhouse

1. Introduction

Slaughterhouses play an important role in the national economy and food security because they provide meat. However, slaughterhouses also produce organic waste such as rumen content and cattle dung, which can contribute to greenhouse gas emissions in the atmosphere, especially methane (CH_4) [1]. One adult cattle can produce 20–34 kg of cattle dung per day and up to 31 litres of rumen fluid [2]. Solid waste from slaughterhouses that is not properly managed can have various negative impacts, ranging from unpleasant odours caused by ammonia and hydrogen sulphide to soil and groundwater pollution. Pathogenic bacteria such as *Escherichia coli* contained in waste can cause diarrhoea and become a breeding ground for insects and rodents that can transmit diseases. Conventional treatment methods are not suitable for use in highly populated settlements due to their long degradation time and high land requirements [3].

One effective and environmentally friendly method for degrading slaughterhouses waste is bioconversion using black soldier fly (BSF) larvae. BSF larvae can reduce cattle dung by 36.4-50% and suppress the presence of houseflies and pathogenic bacteria [4]. In addition, the bioconversion method produces BSF larvae (prior to pupation) that can be used as an alternative protein source for fish and livestock feed, as well as maggot feed residue (kasgot) that can be used as fertilizer [5].

Studies show that the type and amount of waste affect biomass value, substrate consumption, waste reduction rate, and larval survival rate. The use of a mixture of rumen content and cattle dung as feed media has the potential to increase bioconversion efficiency and residue quality [6]. Most existing studies on BSF larval bioconversion have primarily focused on a single feed media, such as cattle dung or rumen waste, without considering the combined effects of feed composition and feed quantity [7,8]. Consequently, the interaction between substrate composition and feeding rate on waste reduction efficiency and larval growth remains insufficiently understood. This study addresses this gap by systematically evaluating various ratios of rumen waste and cattle dung at different feeding rates. This study aims to analyse the efficiency of BSF larval bioconversion in reducing slaughterhouse waste and to evaluate the quality of the resulting kasgot.

2. Materials and Methods

2.1. Reactor Set Up and Experimental Design

The solid waste used in this study was cattle dung and rumen content sourced from Pegirian Slaughterhouse in Surabaya City, Indonesia. This research was conducted at the BSF House, Campus C, Universitas Airlangga, at a laboratory scale. The reactor used in this study was an open rectangular plastic box measuring 31 cm x 23 cm x 9 cm, fitted with a net lid.

2.2. Bioconversion Procedure

The bioconversion process was conducted over 15 days using seven-day-old Black Soldier Fly (BSF) larvae. A total of 400 larvae were placed in each reactor. The experimental variables were feed composition and feed quantity. Feed composition was varied using rumen-to-cattle dung ratios of 0:100 (K1), 80:20 (K2), 50:50 (K3), and 100:0 (K4). Feed quantities were set at 60 (J1), 80 (J2), and 100 (J3) mg/larvae/day. Larvae were fed every three days. This study comprised 12 experimental treatments with two replications. Table 1 presents the experimental design.

Table 1. Experimental design

Feed quantity	Feed composition			
	K1	K2	K3	K4
J1	J1K1	J1K2	J1K3	J1K4
J2	J2K1	J2K2	J2K3	J2K4
J3	J3K1	J3K2	J3K3	J3K4

2.3. Analytical Methods

The optimum conditions for bioconversion were evaluated based on the total waste reduction, larval growth, and the Efficiency of Conversion of Digested Food (ECD). The calculation formulas for total waste reduction and ECD are presented in Equations (1) and (2), respectively:

$$Total\ waste\ reduction\ (\%) = \frac{Initial\ feed\ mass\ (g) - final\ feed\ mass\ (g)}{Initial\ feed\ mass\ (g)} \times 100\% \quad (1)$$

$$ECD\ (\%) = \frac{B}{I-F} \times 100\% \quad (2)$$

where B is larval weight gain during the feeding period, obtained from the difference between the final weight and the initial weight of the larvae (g); I is total feed quantity (g); and F is weight of feed residue and bioconversion material (g).

Residue quality parameters evaluated at the beginning and end of the bioconversion process included moisture content, organic carbon, and total nitrogen. These parameters were determined in accordance with the Indonesian National Standard (SNI 7763:2024). All analyses were performed in duplicate to ensure data reliability.

Moisture content was determined using a thermogravimetric method by drying the samples at a controlled temperature until a constant weight was achieved. A 10 g sample was weighed as wet weight (W_1) into a porcelain dish and dried in an oven at 105 °C for 16 h. The sample was then cooled in a desiccator and reweighed as dry weight (W_2). Moisture content was calculated using Equation (3), while the moisture correction factor (f_k) was calculated using Equation (4).

$$Moisture\ content\ (\%) = \frac{(W_1 - W_2)}{W_1} \times 100 \quad (3)$$

$$f_k = \frac{100}{100 - moisture\ content} \quad (4)$$

Organic carbon content was determined using a gravimetric method based on mass loss upon ignition. The oven-dried sample obtained after moisture analysis was placed in a furnace and incinerated at 300 °C for 1.5 h, followed by further heating at 550–600 °C for 2.5 h. After cooling in a desiccator, the sample was weighed as ash weight (W_3). Ash content, organic matter, and organic carbon were calculated using Equations (5)–(7), respectively.

$$Ash\ content\ (\%) = \frac{W_3}{W_1} \times 100 \quad (5)$$

$$Organic\ matter\ (\%) = 100 - (\text{moisture content} + \text{ash content}) \quad (6)$$

$$Organic\ carbon\ (\%) = organic\ matter \times 0.58 \times f_k \quad (7)$$

Total nitrogen content was analysed using the Kjeldahl method. Approximately 0.5 g of homogenized sample ($\leqslant$ 0.5 mm) was placed into a Kjeldahl flask, followed by the addition of 10 mL of salicylic acid solution and allowed to stand for 12 h. Subsequently, 4 g of $Na_2S_2O_3 \cdot 5H_2O$ was added, and the sample was initially heated at low temperature until bubbling ceased. The temperature was then gradually increased to 300 °C and maintained for approximately 2–3 h before cooling. Distillation was performed after adding 10 mL of 40% NaOH, and the distillate was collected in 20 mL of 1% boric acid solution containing three drops of Conway indicator. Distillation was terminated when the distillate volume reached 100 mL. The distillate was titrated with 0.05 N H_2SO_4 until the endpoint was reached, indicated by a colour change from green to pink, and the final titration volume (V_1) was recorded. A blank determination was conducted following the same procedure to obtain (V_2). Total nitrogen was calculated using Equation (8).

$$\text{Total nitrogen (\%)} = \frac{(V_1 - V_2) \times N \times 14.008}{W} \times 100 \times f_k \quad (8)$$

Environmental parameters, including pH, humidity, and temperature, were measured every three days using a soil tester. The quality parameters of the residue (kasgot, i.e. maggot compost) were compared with the compost quality requirements based on SNI 19-7-30-2004 standards. To determine the optimal overall feed composition and quantity, quantitative analysis was performed using a scoring method adapted from the Multi-Criteria Decision Analysis (MCDA) approach [9].

3. Results and Discussion

3.1. Total Waste Reduction

According to Figure 1, the highest waste reduction achieved in reactor J1K4 (100% rumen with the lowest feed quantity of 60 mg/larvae/day) reaching 78.60%. Meanwhile, the lowest reduction was observed in reactor J3K1 (100% cattle dung with the highest feed quantity of 100 mg/larvae/day) at 65.82%.

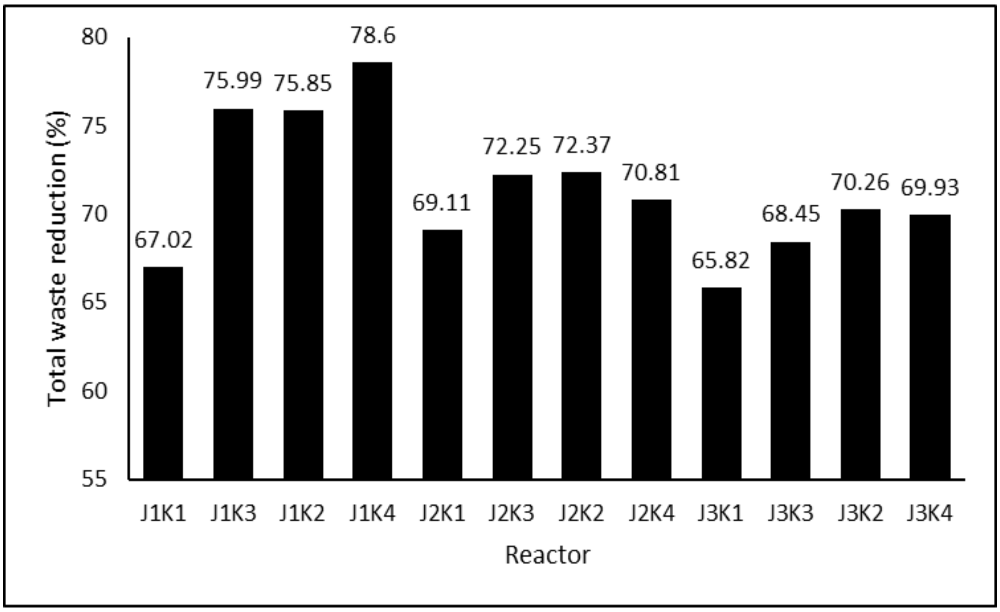

Figure 1. Total waste reduction after 15 days of BSF bioconversion

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A higher proportion of rumen in the feed can increase the total waste reduction.This may be attributed to the combination of rumen and cattle dung producing a more nutrient-rich feed substrate. Rumen contains higher nutrients and microorganisms, making it more easily consumed by larvae [10, 11]. Meanwhile, cattle dung generally contains higher level of crude fibre, lignin, and undigested materials, requiring longer digestion time by larvae [12]. This is also linked to the limited lignin-degrading enzymes in BSF larvae's digestive tracts [13].

Feed quantity is another important factor. Insufficient feed may cause nutritional deficiencies, whereas excessive feed may result in overcrowding. Therefore, determining an optimal feed quantity is essential for achieving efficient bioconversion. Waste reduction tends to decrease with increasing feed quantity because larvae have limited digestive capacity, leading to uneaten feed accumulation [14]. Lower feeding quantities allow larvae to consume the available substrate more efficiently, reducing residual waste, whereas excessive feeding may limit larval accessibility to the substrate and ultimately reduces waste reduction efficiency [14].

3.2 Efficiency of Conversion of Digested Food (ECD)

ECD represents the efficiency of larvae in converting ingested feed into biomass during the bioconversion process. Higher ECD value indicates more efficient conversion of feed into larval biomass. Figure 2 shows that the highest ECD value was observed in reactor J3K4 (100% rumen with the highest feed quantity of 100 mg/larvae/day), reaching 8.7%. A relatively wide range of ECD values (4.77–8.7%) was recorded in treatments containing rumen mixtures. In contrast, treatments with 100% cattle dung at various feed quantities exhibited very low ECD values (−0.27–0.76%), with reactor J3K1 (100% cattle dung with the highest feed quantity of 100 mg/larvae/day) showing a negative ECD value.

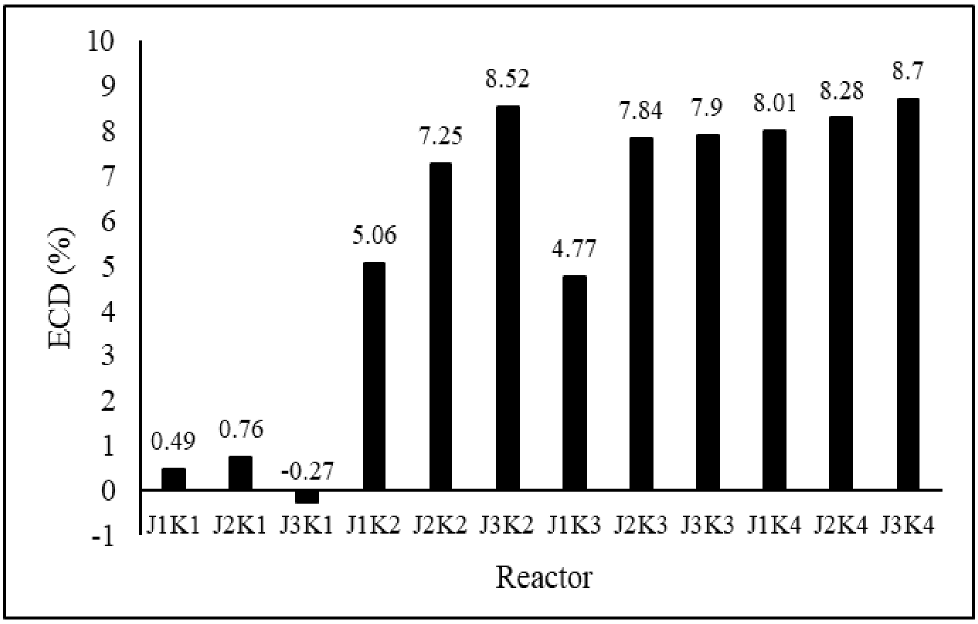

Figure 2. ECD values after 15 days of BSF bioconversion

The inclusion of rumen in the feed improved substrate quality, resulting in high ECD values. This is likely because rumen contains abundant nutrients and partially digested feed, facilitating larval assimilation [15]. Additionally, higher feeding quantities allows BSF larvae to consume larger amounts of food, resulting in optimal larval growth. Conversely, very low or negative ECD values in the 100% cattle dung treatments may be associated with higher larval mortality during the bioconversion process, resulting in a lower final weight compared with initial larval weight. This is likely due to the relatively low nutrient content and the presence of cellulose, hemicellulose, and lignin in cattle dung, which are difficult to degrade and may limit larval metabolism [12].

ECD reflects the ability of larvae to convert digested substrate into biomass. In this study, variations in ECD values across treatments indicate differences in nutrient utilisation efficiency under different feeding quantities and substrate compositions. Although both ECD and total waste reduction are influenced by larval feeding activity, the results indicate no direct linear relationship between them. Total waste reduction reflects an overall substrate mass reduction, which may be influenced by uneaten substrate and moisture loss, while ECD specifically measures nutrients conversion efficiency into biomass. High waste reduction does not always correspond to high ECD values, especially under conditions of excessive or unbalanced feed input. Therefore, ECD provides complementary information to total waste reduction by highlighting nutrient conversion efficiency rather than substrate mass reduction alone.

3.3. Total Larval Growth

Figure 3 shows that BSF larval growth follows a sigmoid growth pattern. Larval growth was relatively low on day 3 (3.93−33.62%), likely due to the high metabolic rate during the early phase. At this stage, the substrate remains relatively complex, so most of the energy from the feed is consumed by the larvae for metabolism. This energy is lost through respiration (as CO_2) and heat production, leaving only a small portion to be converted into larval biomass. This stage corresponds to the lag phase in the sigmoid growth curve, during which larvae primarily focus on metabolic activity [16].

Subsequently, on days 6 and 9, larval weight gain increased significantly, ranging from 4.54–72.17% and 17.58–64.33%, respectively. During this phase, larvae actively accumulate fat as an energy reserve for the pupal stage. This represents the exponential phase of the sigmoid growth curve, where feed is efficiently converted into biomass and energy reserves, resulting in substantial weight gain [17].

Larval weight gain began to decline on day 12 (14.84−40.27%), which may be attributed to some larvae entering the prepupal phase at 14 days of age [18]. As larvae transition into the prepupal phase, feed consumption decreases until it stops, and they begin using energy reserves for metamorphosis [19].

By day 15, at the end of the bioconversion process, overall growth rates had generally slowed; however, several treatment variations still showed increased larval growth, ranging from 14.66–46.13%. This may be attributed to the substrate becoming softer and more digestible over time, allowing active BSF larvae to utilize it more efficiently and achieve additional weight gain [20].

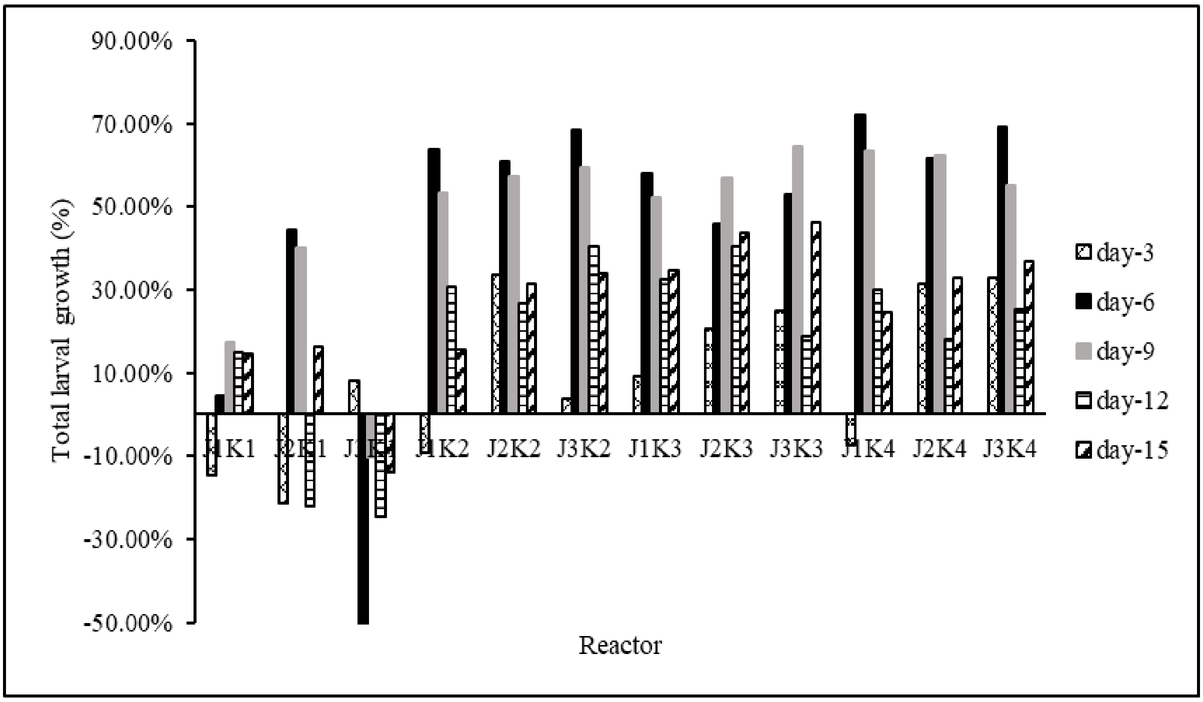

Figure 3. Larvae weight growth during the organic waste bioconversion process

The highest final larval weight was recorded in reactor J3K4 (100% rumen and a feed quantity of 100 mg/larvae/day), reaching 21.7 g. In contrast, the lowest final larval weight was observed in reactor J3K1 (100% cattle dung and a feed quantity of 100 mg/larva/day), at only 0.42 g. This difference can be attributed to the variations in nutrient composition among the feed substrates, which directly affected larval growth. Rumen contains higher levels of carbohydrates, fat, and protein, and lower fibre content compared with cattle dung. BSF larvae consuming carbohydrate-rich substrates tend to accumulate higher body fat, which is reflected in increased larval weight, Accordingly, treatments dominated by rumen content resulted in greater larval weights. In contrast, high fibre content in cattle dung limits digestibility, thereby slowing larval metabolism and growth [13].

The larval growth pattern observed in this study followed a sigmoid curve, consistent with previous studies reporting sigmoidal growth of BSF larvae across substrates of varying quality [16]. Arabzadeh et al. [17] further demonstrated that larval growth performance and final larval weight are strongly influenced by feed composition, resulting in non-linear growth patterns and variability among treatments. Similarly, the variation in final larval weight observed in this study can be attributed to differences in both feed quantity and nutrient availability. Overall, the observed growth pattern and final larval weights are in agreement with findings reported in the literature.

3.4 Quality of Kasgot

The residue generated from the bioconversion of organic waste by BSF larvae is referred to as kasgot (maggot compost) [21]. As shown in Table 2, the quality of most kasgot met the standards for mature compost based on SNI 19-7-30-2004. The organic carbon, total nitrogen, C/N ratio, and moisture content of kasgot ranged from 20.51–38.99%, 1.79–1.92%, 10.89–20.86, and 14.41–44.25%, respectively (Table 2). Compared with initial conditions

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Table 2. Kasgot quality after the bioconversion process

Reactor	Organic carbon (%)		Total nitrogen (%)		C/N ratio		Moisture content (%)	
	Kasgot	Compost quality requirements[21]	Kasgot	Compost quality requirements[21]	Kasgot	Compost quality requirements[21]	Kasgot	Compost quality requirements[21]
J1K1	38.99	9.8-32	1.87	≥0.4	20.86	10 - 20	15.53	≤50
J2K1	35.50		1.89		18.84		24.66	
J3K1	28.75		1.79		16.06		38.05	
J1K2	32.83		1.82		18.14		18.55	
J2K2	24.41		1.83		13.34		34.42	
J3K2	23.92		1.88		12.70		42.07	
J1K3	33.18		1.83		18.17		17.51	
J2K3	23.10		1.92		12.07		28.64	
J3K3	20.51		1.89		10.89		38.59	
J1K4	26.54		1.84		14.41		14.41	
J2K4	22.41		1.80		12.49		36.44	
J3K4	23.14		1.88		12.34		44.25	

[21]Indonesian National Standards Agency, 2004

prior to bioconversion, organic carbon and total nitrogen levels increased across all reactors. In addition, the C/N ratio and moisture content remained within ranges considered suitable for compost maturity. These results indicate that BSF larval bioconversion was not only reduces organic waste volume but also produces a value-added compost product.

The increase in organic carbon content in kasgot is likely due to the enzymatic activity of BSF larvae during the decomposition of organic waste. BSF larvae secrete enzymes such as amylase and maltase from the salivary glands in their mouths. Alpha amylase breaks down carbohydrate into simpler nutrients, which are subsequently absorbed by the larval midgut. Part of the absorbed carbohydrates is utilized for larval growth, while the remaining fractions contribute to kasgot formation [22]. The increase in total nitrogen content in kasgot is associated with residual nutrients absorbed by the larvae, resulting in elevated nutrient levels in the residue [23]. The C/N ratio, which is falls within the range of mature compost quality standards, indicates that kasgot possesses a balanced nutrient composition [24]. The moisture content of kasgot decreases during the bioconversion processes because the decomposition of organic waste by BSF larvae and associated microorganisms generates heat, which promotes water evaporation from the substrate [25].

3.5 Scoring Analysis

The optimum feed composition and quantity were determined using a scoring approach for each parameter. Scores were assigned by allocating the highest score (12) to the treatment with the highest parameter value and the lowest score (1) to the treatment with the lowest parameter value. The scoring range was based on the number of experimental variations in this study (12 treatments).

According to Table 3, reactor J3K4 (100% rumen with a feed quantity of 100 mg/larvae/day) was identified as the most optimum treatment, achieving the highest score of 33. The J3K4 treatment obtained the highest scores (12) for both larval growth and ECD parameters, which are key indicators of successful larval biomass production for potential use as an alternative feed. Although total waste reduction was not the highest, it was still considered good with a score of 5. Furthermore, the kasgot from reactor J3K4 met Indonesian standards for mature compost quality. This finding is consistent with previous studies [26], which indicate that optimal condition should balance biomass conversion efficiency and kasgot quality, even if maximum waste reduction is not achieved.

Table 3. Total scoring results for optimum variation

Reactors	Total waste reduction	ECD	Total larval growth	Organic carbon	Total nitrogen	C/N ratio	Moisture content	Total score
J1K1	2	2	2	0	1	0	1	8
J2K1	4	3	3	0	1	1	1	13
J3K1	1	1	1	1	1	1	1	7
J1K2	10	5	4	0	1	1	1	22
J2K2	9	6	11	1	1	1	1	30
J3K2	6	11	8	1	1	1	1	29
J1K3	11	4	6	0	1	1	1	24
J2K3	8	7	10	1	1	1	1	29
J3K3	3	8	9	1	1	1	1	24
J1K4	12	9	5	1	1	1	1	30
J2K4	7	10	7	1	1	1	1	28
J3K4	5	12	12	1	1	1	1	33

4. Conclusions

The J3K4 reactor, with a feed composition of 100% rumen and a feeding rate of 100 mg/larvae/day, demonstrated optimum bioconversion performance based on the highest total scoring value. This reactor achieved a total waste reduction of 69.93%, an ECD value of 8.7%, and total larval biomass growth of 21.71 g. In addition, the kasgot produced met compost quality standards based on SNI 19-7-30-2004. Specifically, organic carbon, total nitrogen, C/N ratio, and moisture content ranged from 20.51–38.99%, 1.79–1.92%, 10.89–20.86, and 14.41–44.25%, respectively. These findings indicate that bioconversion of organic waste using BSF offers a promising alternative for environmentally friendly and efficient waste transformation while producing nutrient-rich compost.

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Conflicts of Interest

The authors declare no conflict of interest.

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