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The Effect of Additional Composition Substrates on The Rate and Quality of Food Waste Bioconversion by Black Soldier Fly Larvae and Superworm

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Abstract
Food waste that is not managed properly can cause groundwater pollution, greenhouse gas emissions, unpleasant odours, and bacterial breeding grounds, for such examples are tofu pulp and expired bread. This research aims to analyze the effect of additional composition of tofu waste and expired bread substrates on the rate and quality of food waste bioconversion by black soldier fly larvae and superworm. The research method used direct experimentation with variations in substrate composition over 12 days Black Soldier Fly (BSF) and 30 days (Superworms). The highest Waste Reduction Index (WRI) was achieved by BSF in the treatment with 60% tofu pulp and 40% expired bread (M4) at 7,65. For Superworm, substrate consisting of food waste and tofu pulp (K2) produced the highest reduction percentage of 63,4% and the Waste Reduction Index (WRI) value of 2,11%. For the final weight and best Efficiency of Conversion of Digested Feed (ECD) value for BSF larvae were found on variable M5 consisting of food waste, tofu pulp 50%, and expired bread 50%, with a final weight of 0,3 grams per larva and an ECD value of 16,25%. Variable K2 recorded the highest final weight and ECD value for Superworm, with a final weight of 4,15 grams per larva and an ECD value of 2,94%. The characteristics of the bioconversion residue (frass) from both types of larvae meet the C, N, P, K standards in accordance with SNI 19-7030-2004, the results showed that the combination of tofu pulp and expired bread substrates in treatments M4 and K4 produced residues with a more balanced macro nutrient content, making them the most optimal.
Keywords: *bioconversion, black soldier fly, superworm, tofu pulp, expired bread, food waste*

Abstrak
Sampah makanan yang tidak dikelola dengan baik dapat menyebabkan pencemaran air tanah, emisi gas rumah kaca, bau tidak sedap, dan tempat berkembang biak bakteri, seperti contohnya ampas tahu dan roti kadaluarsa. Penelitian ini bertujuan untuk menganalisis pengaruh komposisi tambahan ampas tahu dan roti kadaluarsa sebagai substrat terhadap laju dan kualitas biokonversi limbah makanan oleh larva *Black Soldier Fly* (BSF) dan ulat Jerman. Metode penelitian menggunakan eksperimen langsung dengan variasi komposisi substrat selama 12 hari (BSF) dan 30 hari (Ulat Jerman). Indeks Pengurangan Limbah (WRI) tertinggi dicapai oleh BSF pada perlakuan dengan 60% ampas tahu dan 40% roti kadaluarsa (M4) sebesar 7,65. Untuk ulat Jerman, substrat yang terdiri dari limbah makanan dan ampas tahu (K2) menghasilkan persentase pengurangan tertinggi sebesar 63,4% dan nilai Indeks Pengurangan Limbah (WRI) sebesar 2,11%. Untuk berat akhir dan nilai *Efficiency of Conversion of Digested Feed* (ECD) terbaik pada larva BSF ditemukan pada variabel M5 yang terdiri dari limbah makanan, ampas tahu 50%, dan roti kadaluarsa 50%, dengan berat akhir 0,3 gram per larva dan nilai ECD 16,25%. Variabel K2 mencatat berat akhir dan nilai ECD tertinggi untuk ulat jerman, dengan berat akhir 4,15 gram per larva dan nilai ECD 2,94%.
Kata Kunci: *biokonversi, tentara lalat hitam, ulat jerman, roti kadaluarsa, sampah makanan*

1. Introduction

In Indonesia, one of the primary issues with environmental management is food waste. According to data from the Ministry of Environment and Forestry (KLHK), food waste made up 45.27% of garbage in East Java in 2024. Improper management of food waste can result in bacterial breeding grounds, greenhouse gas emissions, offensive odors, and groundwater pollution. For instance, the food processing industry generates a lot of solid waste from production, such as tofu pulp and outdated bread, which can be harmful to the environment if improperly managed. Both types of garbage can be recycled for things like food ingredients, animal feed, or enhancing soil fertility. Although both wastes have a high nutritious value, the utilization is still not at its best [1].

The bioconversion method using Black Soldier Fly (BSF) larvae and German beetle larvae (Superworm) can be an alternative in waste management. BSF larvae have the ability to break down various types of substrates and convert them into biomass rich in protein (25 to 50%) and fat (15 to 45%), which can be used as animal feed or a source of biodiesel [2]. In addition, the short life cycle of BSF larvae makes BSF larvae cultivation a feasible alternative for everyone. Superworm are another bioconversion agent that can be utilised to clean up daily food waste. The protein content of the larvae reaches 47 – 50%, and superworms are also excellent at degrading organic waste [3].

Medium conditions, environmental conditions, and substrate mixture proportions greatly influence efforts to optimise the bioconversion process [4]. Meanwhile, the studies specifically examining the use of a combination of tofu pulp and expired bread as additional substrates in the bioconversion process are still limited. Tofu pulp is highly nutritious, containing high levels of protein and carbohydrates [5], while expired bread is enriched with carbohydrates and fats [6]. Therefore, the combination of the two can be an ideal substrate for the growth of BSF larvae and Superworm.

Furthermore, in developing an efficient and sustainable food waste treatment system, it is essential to understand the factors that influence the quality of bioconversion. The characteristics of bioconversion products consisting of larval biomass and compost residue (frass) are also necessary to determine their potential use as animal feed and soil fertiliser. This study aims to analyse the rate and quality of food waste bioconversion using tofu pulp and expired bread as substrates with BSF larvae and Superworm, including the effect of substrate composition variations on larval growth, conversion efficiency, and the quality of the resulting residue.

2. Material and Methods

This study's research methodology is a descriptive quantitative approach that includes direct trial on fields and laboratory analysis. This study was conducted at PDU Jambangan, Jambangan District, Surabaya City. This study aims to examine the rate and quality of food waste bioconversion using a combination of tofu pulp and expired bread substrates with BSF larvae and Superworm. This study uses independent variables in the composition of the substrate and bioconversion agents that are used.

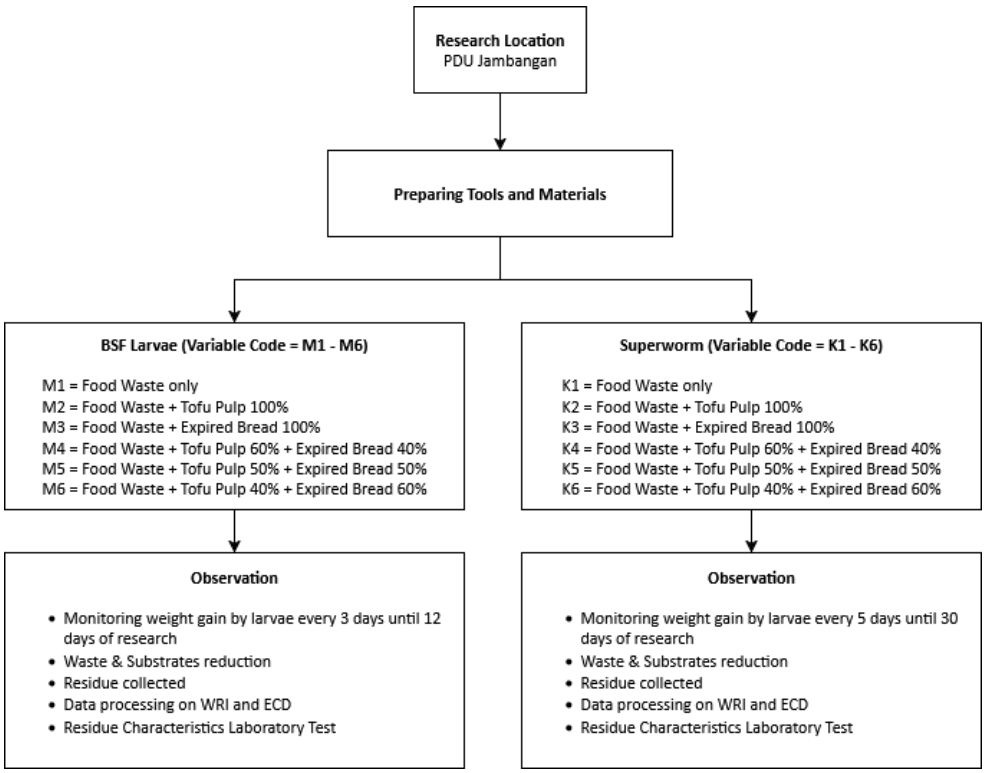

Fig. 1: Study Procedures

The research began with collecting food waste from PDU Jambangan, processed dried tofu pulp, and expired bread and bran as a medium in the biopond. The equipment used included a 40 x 60 x 15 cm HDPE biopond, soil meter, scales, sieve, and shading net.

Fig. 2: Collecting shredded food waste

Fig. 3: Biopond container

The first procedure in this study is to put 500 grams of bran in each biopond as a medium and shelter for BSF larvae and Superworm, then add food waste and tofu pulp and expired bread substrate repeatedly, every 3 days for BSF larvae for 12 days and every 5 days for Superworm larvae for 30 days. Then, approximately 1,000 BSF larvae and 200 Superworm are placed in the biopond according to each variable. Observations in the study directly included the increase in biomass in BSF larvae and Superworm, as well as the reduction and residue of the substrate produced.

Biomass increase was measured by weighing the larvae every 3 days for BSF larvae and every 5 days for Superworm. The reduction and residue of the substrate produced was measured by using a mesh sieve to separate the residue (frass) from the substrate that had not been consumed by the BSF larvae and Superworm. The collected data was used to calculate the bioconversion rate, including the WRI value and ECD value. On the final day of the research, laboratory tests were conducted to determine the nutrient values, including organic carbon, organic nitrogen, and P_2O_5.

Fig. 4: Weighing Superworm

Fig. 5: Weighing BSF Larvae

3. Results and Discussion

Biomass Growth

The physical characteristics of BSF larvae and Superworm can be observed as growth occurring in both animals by measuring their weight. Sampling for measurement is carried out by taking 10 larvae and beetle larvae from each treatment to measure their weight.

Table 1. Monitoring of BSF Larvae Weight Gain Over 12 Days

Sample Code	Weight (mg) at the Time of Research (Days)				
	0	**3**	**6**	**9**	**12**
M1	1	31	93	110	125
M2	1	35	122	175	210
M3	1	33	95	155	200
M4	1	42	113	180	236
M5	1	44	118	210	300
M6	1	38	105	168	210

The most effective variable for increasing BSF larva weight was M5, which consistently produced the highest larva weight at each measurement stage and reached 0.3 grams at the end of the study. This indicates that the ideal nutritional profile for biomass synthesis and larva weight accumulation can be achieved by combining protein sources (tofu pulp) and energy sources (expired bread) in a balanced approach [7].

Table 2. Monitoring of Superworm Weight Gain Over 30 Days

Sample Code	Weight (mg) at the Time of Research (Days)						
	0	**5**	**10**	**15**	**20**	**25**	**30**
K1	200	500	1.100	1.600	2.400	2.900	3.100
K2	240	900	1.480	2.200	2.830	3.300	4.150
K3	230	650	1.300	1.700	2.600	3.000	3.330
K4	250	780	1.360	2.070	2.700	3.200	3.500
K5	210	520	1.250	1.850	2.680	3.050	3.450
K6	200	580	1.200	1.780	2.530	2.900	3.300

Meanwhile, in Superworm, variable K2 recorded the highest final weight value of 4,15 grams per caterpillar. These results indicate that tofu pulp as a single protein source has a very positive effect on Superworm biomass accumulation. Variable K1, which was only given food waste without additional protein, showed the most stunted growth. In line with research by Purba [1] that nutritional quality of feed is a major determining factor.

Reduction and Residue

The substrate consumed and the residue produced by the BSF larvae and Superworm were observed. The initial condition of the Jambangan TPS food waste was still mixed with inorganic materials such as paper, plastic, rubber, and also organic materials that were not included in food waste, such as leaf stalks and wood fibres that could not be eaten by BSF larvae and Superworm. The percentage of substrate consumed can be calculated using the following formula [8]:

$$\mathbf{D} = \frac{W - R}{W} \text{ x } 100\%$$

Which D is the waste reduction rate (%); W is the amount of food waste applied or available in the biopond (kg) and R is the waste residue (kg). The results of substrate reduction and residue production are shown in the following table.

Table 3. Reduction and Residue Index

Sample Code	Initial Amount (kg)	Consumed (Reduction) (kg)	Residue (kg)	Percentage Reduction (%)
M1	1,7	1,348	0,352	79,30%
M2	2,1	1,84	0,26	87,64%
M3	2,1	1,753	0,347	83,47%
M4	2,1	1,928	0,172	91,82%
M5	2,1	1,84	0,26	87,64%
M6	2,1	1,788	0,312	85,14%
K1	1,7	1,026	0,674	60,40%
K2	2,1	1,331	0,769	63,40%
K3	2,1	1,189	0,911	56,60%
K4	2,1	1,239	0,861	59,00%
K5	2,1	1,155	0,945	55,00%
K6	2,1	1,119	0,981	53,30%

In BSF larvae, the highest percentage of substrate consumption was achieved by sample M4 at 91,8%, while the lowest percentage was found in M1 at 79,3%. This indicates that the addition of tofu pulp and expired bread improves the substrate reduction efficiency of BSF larvae. However, the percentage of substrate consumed by Superworm was lower overall than that consumed by BSF larvae. The highest value was found in variable K2 at 63,4%, while the lowest value was found in K6 at 53,3%. BSF larvae are known to be highly efficient decomposers with the ability to consume various types of organic waste in a short period of time, while Superworm are likely to be selective in consuming substrates and take longer to reach optimal consumption levels [9].

Waste Reduction Index (WRI)

The Waste Reduction Index (WRI) is the ratio between the amount of feed consumed by larvae and the residue produced. WRI serves as an indicator of how effective Superworm and BSF larvae are in waste processing [10]. The following formula is used to calculate WRI:

$$\mathbf{WRI} = \frac{D}{t} \times 100\%$$

Which D is the waste reduction rate (%) and t is bioconversion process time (days). The results of WRI values are shown in the following **Table 4**. Superworm are not as effective as BSF larvae in terms of the Waste Reduction Index (WRI). A high WRI value indicates that organic waste reduction is faster and more efficient per unit of time. The WRI value of BSF larvae ranges from 6,61 to 7,65; variable M4 shows the highest value, which is 7,65, and variable M1 shows the lowest value, which is 6,61. Meanwhile, the WRI value for Superworm was between 1,78 and 2,11, with the highest value achieved by variable K2.

Table 4. Waste Reduction Index

Sample Code	Initial Amount of Substrates (kg)	Residue (kg)	WRI
M1	1,7	0,352	6,61
M2	2,1	0,26	7,3
M3	2,1	0,347	6,96
M4	2,1	0,172	7,65
M5	2,1	0,26	7,3
M6	2,1	0,312	7,1
K1	1,7	0,674	2,01
K2	2,1	0,769	2,11
K3	2,1	0,911	1,89
K4	2,1	0,861	1,97
K5	2,1	0,945	1,83
K6	2,1	0,981	1,78

Several factors contributed to the lower WRI value of Superworm. The first was that the metabolism and life cycle of Superworm are naturally slower than those of BSF larvae. The second was that during the 30-day study period, Superworm were still in an active growth stage, during which energy was allocated to body biomass rather than mass consumption. As in the research conducted by Santoso [11], the type of substrate affects the consumption rate of Superworm, which is often lower than that of BSF larvae.

Efficiency of Conversion of Digested Feed (ECD)

The method for assessing how effectively BSF larvae and Superworm absorb nutrients from the feed they consume for growth and development is the Efficiency of Conversion of Digested Feed (ECD). According to Diener [12], ECD is calculated using the following formula:

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

Which B as the increase in larval biomass (mg); I as the initial substrate amount (kg); F as the final residue amount (kg). The results of WRI values are shown in the following table

Table 5. Efficiency of Conversion of Digested Feed (ECD)

Sample Code	Initial Weight of Larvae (mg)	Final Weight of Larvae (mg)	Initial Amount of Substrates (kg)	Residue (kg)	ECD (%)
M1	1	125	1,7	0,352	9,19
M2	1	210	2,1	0,26	11,36
M3	1	200	2,1	0,347	11,35
M4	1	236	2,1	0,172	12,19
M5	1	300	2,1	0,26	16,25
M6	1	210	2,1	0,312	11,69
K1	200	3.100	1,7	0,674	2,81
K2	240	4.150	2,1	0,769	2,94
K3	230	3.330	2,1	0,911	2,61
K4	250	3.500	2,1	0,861	2,62
K5	210	3.450	2,1	0,945	2,80
K6	200	3.300	2,1	0,981	2,77

Variable M5 had the highest ECD value of 16,25% in BSF larvae, which was significantly higher than other variables. The composition of the M5 variable contains a balanced amount of protein from tofu pulp and carbohydrates from bread, allowing BSF larvae to digest well and allocate more resources for growth [13]. While Variable M1 recorded the lowest ECD of 9,19%. This indicates that feed consisting solely of waste food is less digestible or has inadequate nutritional value, resulting in highly inefficient conversion into biomass. Meanwhile, the low and relatively stable ECD value of Superworm confirms that these insects are less efficient bioconverters than BSF larvae. Superworm have a physiology that prioritises biomass accumulation in preparation for the pupation stage [14].

Residue Characteristics

The bioconversion products are derived from excretion and substrate residues fed to BSF larvae and Superworm [15]. The analysis conducted on the bioconversion/frass results included the composition of nutrients, such as organic carbon, organic nitrogen, and phosphorus (P_2O_5). The frass was harvested on the last day of the study and immediately tested to avoid further decomposition by decomposer microorganisms contained in the medium.

Table 6. Residue Characteristics

Code Sample	Organic Carbon	Organic Nitrogen	Phosphor (P_2O_5)
M1	14,34%	1,78%	1,38%
M2	15,03%	2,25%	1,50%
M3	15,36%	1,74%	1,45%
M4	17,48%	2,04%	2,58%
M5	17,59%	2,12%	1,45%
M6	18,41%	2,06%	1,78%
K1	24,13%	3,23%	1,74%
K2	25,04%	3,67%	2,01%
K3	23,21%	3,31%	1,85%
K4	24,53%	3,61%	2,07%
K5	24,07%	3,44%	1,92%
K6	23,68%	3,52%	1,86%

Fig. 6: Residue samples produced and subsequently tested

In Superworm frass, organic carbon ranges from 23,21 to 25,04%, while in BSF frass it ranges from 14,34 to 18,41%. The highest carbon value in BSF larvae was found in variable M6 at 18,41% and variable K2 in Superworm at 25,04%. The organic carbon content of both types of frass meets the requirements of SNI 19-7030-2004, which requires a minimum of 9,8%. This condition is interpreted to mean that BSF larvae are better at decomposing organic matter, resulting in lower levels of residual carbon. BSF larvae use high levels of digestive enzymes such as lipase, protease, and amylase, and work together with microbes to break down complex organic matter into simpler substances more quickly [16].

The organic nitrogen content on BSF frass ranges from 1,74 to 2,25%, while Superworm frass is higher, at 3,23 to 3,67%. Both far exceed the SNI minimum limit of 0,4%. The highest organic nitrogen value in BSF larvae was achieved by variable M2 at 2,25%, and in Superworm it was achieved by variable

K2 at 3,67%. Both used tofu pulp as a protein source. Tofu pulp is a material with a high protein content that is easily broken down into ammonia and nitrate compounds by microbes and proteolytic enzymes [17]. However, there is also a risk that excess nitrogen will not be absorbed by the substrate, resulting in high organic nitrogen values in the residue. The high organic nitrogen content in Superworm frass is also due to the slow substrate reduction process. Although Superworm were given more time to consume the substrate than BSF larvae, the rate of consumption and conversion of substrate into biomass was slower, resulting in a higher organic nitrogen content in Superworm frass than in BSF larvae frass [7].

The phosphorus content in BSF ranges from 1,38% (M1) to 2,58% (M4), while in Superworm it ranges from 1,74% (K1) to 2,07% (K4). The chemical form of phosphate in the substrate, its availability, and the consumption rate of the larvae affect phosphate. Phosphorus mobilisation in the substrate can be increased by treating it with mixed substrates, such as tofu pulp and expired bread, because the activity of the larvae's enzymes and microbes work together. Variables with low substrate consumption rates produce the lowest P_2O_5 values, such as variable M1, with substrate consumption of only 79,3%, so that phosphorus is not mobilised and remains in the residue. In addition, suboptimal digestion processes can cause minerals to be poorly converted [18].

4. Conclusion

Based on the results of the study, it can be concluded that the addition and combination of tofu pulp and expired bread substrates affect the rate and quality of food waste bioconversion by BSF larvae and Superworm. The best bioconversion rate in BSF larvae was found in variable M4, producing the highest feed reduction percentage of 91,82% and the highest Waste Reduction Index (WRI) value of 7,65%. Meanwhile, for Superworm, variable K2 produced the highest reduction percentage of 63,4% and a Waste Reduction Index (WRI) value of 2,11%. However, the waste reduction index for Superworm was lower than that for BSF larvae. Meanwhile, for the final weight and best ECD value for BSF larvae were found in variable M5, with a final weight of 0,3 grams per larva and an ECD value of 16,25%. Variable K2 recorded the highest final weight and ECD value for Superworm, with a final weight of 4,15 grams per larva and an ECD value of 2,94%. The characteristics of the bioconversion residue (frass) from both types of larvae meet the C, N, P, K standards in accordance with SNI 19-7030-2004, the results showed that the combination of tofu pulp and expired bread substrates in treatments M4 and K4 produced residues with a more balanced macro nutrient content, making them the most optimal.

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