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Banana and cassava peel waste bioconversion using black soldier fly (*Hermetia illucens*) larvae

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Abstract
Banana and cassava are typical plant which produces useful fruits and tubers. However, the improper management of peel waste poses danger to the environment and human health. Previous research stated that, black soldier fly larvae (BSFL) is used as bioconversion agents that can convert various types of organic wastes into high-nutrient biomass products and also, residues as organic fertilizer / compost. This study was aimed to analyze the growth and nutritional content of BSFL, the physical properties of compost, produced from banana peel processing and cassava peel waste. The BSFL growing media used in this study were, banana peel waste (L1), cassava peel waste (L2), and a mixture of both banana and cassava peel waste (L3) with a ratio of 1:1. Meanwhile, the results showed that the highest BSFL growth (including: length, width, and weight) was generated in the L1 treatment, followed by the L3 and L2 treatments. Also, proximate analysis indicated that, larvae have a protein and fat content of 25.34-33.71% and 6.11-28.27% respectively. Therefore, the resulting fine residue satisfies the requirements for soil compost.

Keywords: bioconversion, banana peel, cassava peel, black soldier fly larvae (BSFL), *Hermetia illucens*

1. Introduction
Waste is an unimportant debris that is no longer in use but discarded. Therefore, carrying out improper treatment on it, produces a negative effect on health, environment, social and economic life of the community [1]. In Indonesia, the waste generated in 2017 is 64 million tons / year, these wastes consists of 60% organic wastes, 15% plastics, 10%papers, and 15% other wastes (such as metals, glasses, and clothes). The data shows that the existence of organic waste still dominates, compared to other wastes. Organic waste comes from various sources such as households, public places, industry, and agriculture [1]. One source of agricultural waste is banana and cassava peels, because there is high consumption rate of only fruit and tubers. Whereas, banana production in 2017 was 7.2 million tons and a third fraction of it are peel waste [2, 3]. Meanwhile, cassava production in 2017 was 19 million tons and 16% of the total production was peel waste [4, 5]. Based on these data, peel waste produced by bananas and cassava was 2.4 and 3 million tons in 2017 respectively. Whereas, it still contains nutrients that can be used as growing media and source of food for animals such as black soldier fly larvae (BSFL) [6].

BSFL use in solid waste management has been widely employed because of its ability to recycle organic wastes such as food, animal and human waste, fish offal, and more. It is also able to quickly consume large waste, and can be mass produced with minimal costs [7, 8, 9]. BSF is a non-pest insect, and is able to suppress the presence of house flies (*Musca domestica)* [10], making it suitable for low and medium income countries. Another benefit is its use as animal feed such as fish and poultry [9]. Furthermore, the residue produced from this process in form of compost is suitable for soil [11], can reduce odors, pollution and improve environmental sanitation [12]. Presently, there are no data that explains BSFL growth in peel waste media, nutritional content, and the physical properties of the produced compost.

2. Material and Methods
2.1 Research sites
This study was conducted at the Ornamental Fish Culture Research Center (BRBIH) in Depok, and the proximate analysis was performed at the Nutrition Laboratory. Furthermore, the compost quality analysis was carried out at the PAIR Agriculture Laboratory of the National Nuclear Energy Agency (BATAN) in Jakarta.

2.2 Material
The material used was a concrete tub (245 cm × 120 cm × 25cm) for placing feed and BSFL during the bioconversion process, a waste crusher for producing smaller sizes, a pH and temperature measuring device, a digital scale for measuring larvae weight, rulers, stationery, and cameras for documenting activities. Furthermore, the peels were obtained from BRBIH which was collected from food sellers.

Also, the larvae were obtained from the eggs produced by BSF fly colony, which were left to hatch on a fermented palm kernel meal (PKM) substrate. The substrate was placed in 3 plastic containers, followed by placing 25 g of BSF eggs in each and left for seven days. After seven days, the larvae was then used as a bioconversion agent.

2.3 Work stages
Both peels were crushed until the size became smaller. Then, 150 kg waste was placed in the concrete tub. Furthermore, the composition was according to the

treatments given, which were 100% banana peel (L1), 100% cassava (L2), and 50% banana peel mixed with 50% cassava (L3). Seven-day BSFL was then filled into each feed provided in a concrete tub and maintained for 15 days. Also, length, width, larvae weight, pH and temperature measurement of the media were carried out every 2 days by randomly taking 100 maggots at each treatment. The larvae length and width were measured using ImageJ software, while weights were measured using a digital scale.
After 15 days, the larvae and residue was harvested, which was achieved by repeatedly filtering to separate them from the residue. The larvae of each treatment (L1, L2, L3) would be analyzed for their content by proximate testing at the Nutrition Laboratory. Also,the resulting fine residue would be analyzed for C/N ratio and macro nutrients (N and P) at the PAIR Agriculture Laboratory of BATAN.

2.4 Data Analysis
The analysis of results used ANOVA at 5% level. with a significant effect, further tests were carried out to determine the differences between treatments with the LSD Test. Furthermore, data was analyzed using Microsoft Excel.

3. Result and Discussion
3.1 Black soldier fly larvae growth
The observations showed that banana and cassava peels as a growing media and feed source gave an influence on larvae growth with varying values in each treatment. Descriptively, L1 have more growth compared to L2 and L3. This is consistent with statistical test, which showed the average length, width, and BSFL weight in L1 were significantly different from L2 and L3 ($P < 0.05$) (Table 1).
BSFL growth is influenced by several factors, such as nutrient content, especially protein in the larvae feed, and the higher it is, the greater the growth. Previous studies reported that larvae which consumed chicken feed and tofu dregs have greater growth than those that grew on vegetable waste media or horse dung with low protein content. Furthermore, L2 has the lowest growth because the nutrient is lower than L1 and L3. Previous studies also reported that cassava peel has a low nutrient when used as a growth medium and main BSFL food source. Like animals in general, the growth and biomass reduces when feed is not enough or when nutrient ratio is low.

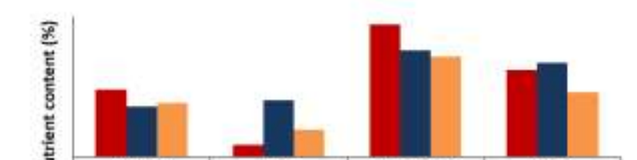
Table 1: The growth of BSFL

Parameter	Unit	Treatment		
		L1	L2	L3
Length	Mm	16.91 ± 3.99^a	14.36 ± 3.18^b	15.06 ± 3.92^b
Width	Mm	4.37 ± 1.12^a	3.67 ± 0.72^b	3.96 ± 1.03^b
Weight	G	0.12 ± 0.06^a	0.09 ± 0.05^b	0.06^b

The second factor is the organic matter diversity in the feed, especially mixing wastes, which provides a more nutritious and balanced feed for larvae growth [13]. Furthermore, L3 has greater growth than L2 because the organic matter diversity in the feed provides more balanced nutrition for growth [9, 10]. Feed consisting a mixture of several organic materials results in greater and faster growth [14]. Also, previous studies showed mixing human and animal feces with food and industrial waste (brewery and banana peels) resulted in greater larvae growth than only feces as a feed source [14, 15].

BSFL grows on kitchen [16] and food waste media [9], its growth is still relatively low because kitchen and food scraps have a variety of organic materials and more balanced nutrients, thus the required nutrient availability better fulfills the needs. Another factor is fiber and lignin presence which makes digestion difficult, and less optimal nutrient use [15, 17]. Furthermore, those that consumes high cellulose and fiber feed (such as banana and cassava peels) produces lower biomass [11, 17]. Previous studies reported that larvae growth on rice straw media have lower biomass than those that grew on other organic media [6]. Also, high cellulose and lignin pre-treatment before being used as a medium and feed source improves digestibility and nutrient absorption. Pre-treatment can also be done by adding microorganism to the substrate to increase cellulose and hemicellulose conversion, degradation, as well as adding chemical compounds such as ammonia (NH_3) which provides a source of non-protein nitrogen for BSFL growth [17].

3.2 Nutrient content of BSF larvae
The results showed the media had an influence on the nutrients contained in the larvae's body. Furthermore, protein and fat content in the three treatments ranged from 25.34–33.71% and 6.11–28.27% respectively. Descriptively, the protein content in L1 and L3 was higher than L2. Meanwhile, for fat, L2 had a higher value than L1 and L3 (Figure 1).



	Protein	Fat	Crude fiber	Ash
L1	33.71	6.06	65.92	43.43
L2	25.34	28.27	52.98	47.12
L3	27.02	13.59	50.21	32.41

Fig 1: Nutrient content of BSFL

The nutrient content varies from each treatment, especially protein and fat, which is influenced by the nutrients contained in the consumed waste [12, 18]. Banana and cassava peels are organic wastes with low protein and high cellulose, hemicellulose, and lignin [17, 19]. Although not always directly proportional, feeding on high protein produces more larvae [18]. Previous studies showed larvae that consumed cabbage had low protein and those feeding on avocados had the highest fat content [12]. Furthermore, fiber content in feed also affects the larvae's body. Although not always directly proportional, consuming high fiber and ash waste produces larvae high in ash and fiber. Previous studies reported that grasshopper waste which is high in fiber produces BSFL with higher fiber compared to cricket which is low [20].
Protein and fat accumulation is also influenced by age and body size, and the more the age, the lower the protein content [14, 21]. In the pre-pupa phase, the chitin content increases because it undergoes scleretization process on the exoskeleton [12]. Although the peels contain lots of cellulose and lignin, the larvae produces protein and fat which can be used as animal feed. In addition, cattle feces contain high cellulose and lignin, and low protein and fat. Therefore,

BSFL is able to increase the fat and protein content in waste into biomass [13].

3.3 Media and residues from the bioconversion process

BSFL decomposed the peel wastes for 15 days in all three treatments. The physical parameter results showed temperature in the three media ranged from 30.86 to 32.00ºC. Furthermore, the temperatures at L1 and L3 are higher than L2, and the pH ranged from 5.8 to 6.2, with L2 having a lower value than L1 and L3. The final result is the residues or compost harvesting, and there are two types which are coarse and fine. In addition, the highest fine and coarse residues was produced by L1,and L2 respectively (Table 2).

Table 2: Media and residue measurements

Parameter	Unit	Treatment		
		L1	L2	L3
Temperature	ºC	32.00±1.73	30.86±1.80	31.07±1.64
pH	-	6.2±0.49	5.84±0.32	5.89±0.25
Fine residue	kg	17.45	12.32	14.10
Coarse residue	kg	22.15	30.12	25.25
Total residue	kg	39.6	42.44	39.35

The heat generated during the bioconversion process ranged from 30.86 to 32.00oC and the BSFL activity during waste consumption affects the media temperature change. This is because it expends lots of energy for feeding. However, temperatures significantly help the larvae reduce disease causing microbes. Also, the pH is still within neutral range and the larvae are able to live in low or high pH conditions. An acidic condition helps to overcome growth of several microbes. In fact, they can survive in adverse environmental conditions such as drought, lack of food and oxygen for a certain period.

There are two types of residues, which are fine and coarse. The fine or compost is the result of larvae metabolism, whereas coarse is waste that cannot be completely digested during the bioconversion process. Furthermore, the residue in the three treatments has a blackish brown color, rough texture, distinctive odor, and can be used as fertilizer for land and plant amendments. The coarse residue from L2 is more than L1 and L3, which indicates that cassava waste is quite difficult to be consumed. This is because waste level depends on larvae's ability to consume it.

Based on the analysis, the C/N ratio ranged from 18.79 to 19.56, and descriptively, the ratio in L1 was lower than L2 and L3. Furthermore, total nitrogen (N) content ranged from 0.73 to 0.75%. Descriptively, the N content in L1 was higher than L2 and L3. In addition, phosphorus (P) contents ranged from 0.12 to 0.13%. Descriptively, P content in L3 was higher than L1 and L2 (Table 3). Using the residues as compost has been carried out on lettuce (Lactuta sativa), which causes it to grow well. Also, the results for C / N ratio and nutrient showed the produced residue meets the compost specification standards according to SNI, and can be used as nutrient for soil and plants.

Table 3: The average C / N ratio and residual nutrient content

Treatment	Ratio C/N	Macro nutrient content (%)	
		N	P
L1	18.79 ± 0.11	0.75 ± 0.01	0.12 ± 0.01
L2	19.56 ± 0.21	0.74 ± 0.05	0.12 ± 0.01
L3	19.42 ± 0.00	0.73 ± 0.01	0.13 ± 0.02
SNI	10-20	≥ 0.40	≥ 0.10

Note: * = Indonesian National Standard (SNI: 19-7030-2004)

4. Conclusion

The results showed the three experimental treatments gave different growth effects and BSFL nutrition. The highest growth in length, width, and weight was produced in L1 (16.91 mm; 4.37 mm and 0.12 g), followed by L3 and L2.. Furthermore, the highest protein content was produced by L1> L3> L2, highest fat by L2> L3> L1, and the highest crude fiber content by L1> L2> L3. In addition, the bioconversion process produced residues that can be used as organic fertilizer for plants and soil, and the results of C/N produced in the three treatments varied, 18.79 in L1 and 19.56 in L2. Therefore, All three residues met Indonesian national standards on compost specifications.

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