Effect of *black soldier fly (Hermetia Illucens)* larvae bioconversion duration in processing household organic waste and market waste in Jakarta on the efficiency of the bioconversion process

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Abstract. The organic waste issue in Jakarta must be immediately addressed because it can harm the environment. Jakarta produces organic waste reaching 45.43% of the total waste generation with organic waste reduction of effectiveness only 4,981 tonnes/year (+1%). One solution to process organic waste is to use black soldier fly (BSF) larvae as decomposers of organic matter. The research examined the effect of bioconversion time/duration for household and market waste in Jakarta on bioconversion efficiency. The research was carried out by opening biopon samples each containing 2 kg of organic waste which were given 11.2 g of BSF 7DOL (*day of life*) larvae, varied with the duration of bioconversion, including 7, 12, 14, 17 and 21 days. The results demonstrated that the optimal time for the bioconversion process for household foodwaste and market waste was 12-14 days. It was based on the value of the bioconversion process efficiency indicator, which achieved the highest score for the *Efficiency of Conversion of Digested-feed* (ECD) value on the 12th day and the *overall reduction* (D) indicator on the 14th day. The low RGR and WRI values on the 17th and 21st days also implied that the bioconversion process was not optimal

1 Introduction

Municipal solid waste management has emerged as a significant challenge due to health and environmental factors related to the large amount of waste produced [1]. Waste is considered as leftovers with low economic value due to the benefits gained from waste management, especially the economic value from organic waste processing, which is deficient [2]. Most organic waste is generated worldwide and is not managed correctly, especially in low- and middle-income countries [3]. Annually, one-third of all food produced (approximately 1.7 billion metric tons) is wasted along the food chain and becomes waste, which causes economic losses of up to $1.2 trillion per year [4]. Almost the entire fraction of organic waste produced is wholly disposed to landfill. It will affect substantial environmental pollution such as groundwater and surface water pollution, as well as GHG emissions [5], public health issues (breeding grounds for disease vectors) [6], economic problems (transportation costs), and social issues.

As a major city in Indonesia, the Special Capital Region (DKI) Jakarta province is still experiencing obstacles in managing its waste. DKI Jakarta's daily waste generation has increased to 7,284.8 tons/day in 2020, where Jakarta produced organic food waste, attaining

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45.43% of the total amount of other types of waste. Most were sourced from household and market waste [7]. Of the total organic waste generation, the effectiveness of reducing new waste by 4,981 tons/year (±1%) was affected by processing facilities and infrastructure, location, mixed-waste conditions, and processing technology.

Waste issues in Jakarta, especially organic waste, must be immediately addressed because they can harm the environment, such as unpleasant odors and the growth of disease vectors. One way to process organic waste is by employing *black soldier fly* (BSF) larvae as decomposers of organic matter [8][9]. BSF has been studied to degrade organic waste by utilizing its larvae, which extract energy and nutrients from vegetable waste, food scraps, animal carcasses, and manure as food ingredients. Therefore, this research aims to provide an overview of Jakarta organic waste processing with the BSF bioconversion process seen from the feasibility of household organic waste and market waste in Jakarta and to find out the optimal duration for bioconversion seen from the *Waste Reduction Index* (WRI), *Efficiency of Conversion of Digested-Feed* (ECD), *Relative Growth Rate* (RGR), *Relative Survival Rate* (RSR) and protein and fat nutrient content in larvae.

2 Literature review

The bioconversion process with Black Soldier Fly (*Hermetia Illucens*) larvae can be defined as a natural process using larvae that will process and absorb nutrients from organic waste into insect larvae biomass and residue from the bioconversion process [10]. BSF larvae have the best decomposition ability compared to other organisms and microorganisms [11]. BSF larvae can reduce waste up to 50-80% (bb) of the total waste given [6]. The BSF larvae can also be an essential component of livestock feed (poultry, farmed fish, and ruminants) due to their relatively high protein content [12].

The bioconversion process with *Black Soldier Fly* (*Hermetia Illucens*) larvae is closely related to the life cycle of *Black Soldier Fly* (*Hermetia Illucens*) larvae. Considering the life cycle of the *Black Soldier Fly* (*Hermetia Illucens*), BSF has five phases: the adult phase, the egg phase, the larval phase, the prepupae phase, and the pupa phase. The process of waste bioconversion occurs in the larval phase, which will eat until the larva reaches its maximum size and turns into a prepupae [2].

Characteristics of feed that are effectively given to BSF larvae include [13]: 1) the food source must be sufficiently moist with water content between 60% and 90% so that the larvae can digest it; 2) materials rich in protein and carbohydrates will produce good growth for the larvae; 3) The size of the food particles because the larvae do not have mouth parts to chew, the nutrients will be easily absorbed if the substrate is in the form of small parts or even in liquid or mush-like form. In practice, employing *Black Soldier Fly* (*Hermetia Illucens*) larvae in the organic waste bioconversion process has some other advantages, specifically low cost, no special equipment required, no need for many workers, and no additional energy sources [14]. Hence, processing organic waste using BSF larvae is alternative solution.

3 Methods

3.1 Research Location and Time

The research was conducted at Laystall (TPS) Rawasari, Cempaka Putih, Central Jakarta, from Oktober to March 2023. Proximate analysis for BSF larvae and the nutritional content of BSF larvae were carried out at the Feed Science and Technology Laboratory, Department of Nutrition and Feed Technology, Institut Pertanian Bogor.

3.2 Tools and Materials

The tools used included bioconversion pots in a rectangular plastic container measuring 32 x 25 x 12 cm with a capacity of 9.6 liters, analytical scales, goods scales, trash chopping machines, shovels, filters, thermometers, and pH and humidity measuring devices.
This research used two sources of organic waste, that were household organic waste and market waste as samples in the bioconversion process. Samples of household organic waste were from TPS Dipo Beringin and the market organic waste from Pondok Bambu Market, East Jakarta. Sampling of organic waste from TPS and Market is carried out for 3 (three) days, 2 days on weekdays and 1 day on weekends. Three times of waste collection was carried out because it was assumed to represent the total waste generated for 7 days. Sampling was done by quartering method. In addition, the materials also included BSF 7DOL (*day of life*) larvae obtained from TPS Rawasari.

3.3 Methods

3.3.1 Experimental design

This research objective was to determine the effect of BSF bioconversion duration for household and market waste in Jakarta on efficiency. The experiment was conducted in a completely randomized design with varied treatments of bioconversion days, including 7 days, 12 days, 14 days, 17 days, and 21 days, with three samples of each variation being replicated.

3.3.2 Organic waste preparation

Household organic waste in this research came from kitchen waste in food scraps, bread, vegetables, and fruit. At the same time, market organic waste comes from market waste in the form of discarded vegetable and fruit scraps. Before being used as *feedstock* in the bioconversion process, a *pre-treatment* process was carried out: waste sorting to separate organic waste from other waste, such as plastic. Then, the organic waste enumeration process was carried out to reduce the size of the organic waste. Furthermore, the enumeration of organic waste was subjected to a *dewatering* process for 48 hours until the organic waste was ready to be employed as *feedstock* in the bioconversion process.

3.3.3 Provision of organic waste

The provision of household organic waste (RT) and market waste (PS) as food for BSF larvae was carried out on the first day of the opening of the bioconversion biopon. Each biopon container was given 2 kg of organic waste. Furthermore, in each biopon container, 1,340 7DOL larvae (*day of life*) or 11.2 grams of 7DOL larvae were given. It referred to [15], which stated that every 1 (one) kg of substrate required as many as 670 larvae.

3.3.4 Weighing of bioconversion results

Furthermore, in samples that have reached the bioconversion determination time (according to the variation of bioconversion days), the process of harvesting the larvae was carried out by pouring the larvae and residue onto a 0.5 cm sieve; Moreover, sieving was carried out to separate the larvae from the residue, then to weigh of final larval weight and remaining residue.

3.3.5 Data analysis

Data analysis and processing were carried out related to the efficiency of the bioconversion process from five variations of bioconversion days for household organic and market waste. Data analysis was collected on the total weight of BSF larvae, 100 larvae, residual weight, and the total of final larvae. The efficiency of the bioconversion process can be seen from:

- *Overall reduction* (D) & *Waste Reduction Index* (WRI)

$$D = \frac{W - R}{W};\ WRI\ = \frac{D}{t}\ x\ 100$$

  Wherein, D = Parameter *overall reduction*; W= Total amount of organic waste (g); R= waste residue (g); t = Bioconversion time (days); WRI = *Waste Reduction Index* (%/day) [16]

- *The efficiency of Conversion of Digested-Feed* (ECD)

$$ECD = \frac{B}{I - F}\ x\ 100$$

  Wherein, B = Larval biomass (g); I = Total food given (g); F= Total residue of waste (g); ECD = *Efficiency of Conversion of Digested-Feed* (%) [17]

- *Relative Growth Rate* (RGR)

$$RGR = \frac{W2}{W1}\ x\ 100$$

  Wherein, W1 = Initial number of larvae (head); W2 = Final number of larvae (head); RSR= *Relative Survival Rate* (%) [17]

- Crude Protein and Crude Fat in Larvae
  The nutritional value composition was determined by proximate analysis. Crude protein is the nitrogen content of the feed multiplied by the average protein factor (6.25), and the crude protein content was determined by the *Kjeldahl* method (N x 6.25); where N is the nitrogen content. Furthermore, crude fat content was determined using the *Soxhlet* extraction method.

3.3.6 Statistic test

A *one-way ANOVA* test was carried out to determine the difference in the values of all variations of the BSF bioconversion time of day for BSF larvae. If the probability value of $P<0.05$; so there was a significant difference, then H_0 was rejected. Furthermore, a *two-way ANOVA* was conducted to determine the difference between household and kitchen waste given as bioconversion *feedstock*. If the *P*-value < 0.05, it is concluded that there was a significant difference, then H_0 was rejected.

4. Results and discussion

4.1 Proximate Analysis of Organic Waste as Feedstock

It is necessary to find out the characteristics of the waste to be processed so that appropriate methods and treatment can be given. Concerning biological processing, this analysis was critical to determine whether the material in the waste could be processed into compost either aerobically or anaerobically. Table 1 demonstrates that household food waste had 69.36% water content, while market waste had 78.62%. It indicates that the waste was feasible to be employed as a bioconversion *feedstock* with a water content that was not too wet as feed for the larvae, and the low ash content implied that the levels of inorganic constituents derived from minerals that were generally difficult for larvae to digest were also trim. Based on the levels of protein and fat, household food waste and market waste were also adequate food ingredients for BSF larvae.

Table 1. Proximate analysis of garbage and comparisons to other researchers

	Household Food Waste	Market Waste	Canteen Food Waste*	Palm Oil Decanter Cake Waste **
Water Content (%)	69.36	78.62	70.81	-
Ash Content (%)	2.18	1.76	2.96	4.16
Crude Protein (%)	17.66	16.61	13.04	15.76
Crude Fat (%)	10.28	8.67	5.62	12.74

Source: Processed by the author (2023); *Kayyis (2017); ** Rachmawati, et.al (2010)

4.2 BSF Larvae Growth (*Hermetia illucens L*)

The growth of BSF larvae in biopon containers occurred at each time variation between 7 – 21 days. During the feeding phase, the larvae grew in length, width, and weight at each time variation. As seen in Table 2, for the type of household food waste source, the total weight of the larvae increased until the 12th bioconversion day, attaining 293±17.95 grams from the initial larval weight of 11 grams. In contrast, the weight of each larva attained the highest weight on the 14th day, with a larval weight of 0.223± 0.004 grams. Meanwhile, for market waste, the total larval weight and each larvae's weight increased up to the 12th bioconversion day, namely 171 ± 6.02 grams and 0.144 ± 0.004 grams, respectively

Household food waste was excellent for supporting BSF's growth because it had diverse types of food waste, from animal and vegetable products, rice and bread. Compared to household food waste and market waste as BSF bioconversion feedstock, household food waste produced a higher total final larval weight and larval weight per head than market waste. Statistically, it indicated that the total weight and weight per larva of household food waste significantly differed from market waste ($P<0.05$), demonstrating that household food waste had a higher value than market waste.

Table 2. Growth of BSF Larvae

Source waste	Bio-conversion Time (days)	Number of Larvae (head) - 7DOL		Live Larval Total Weight (grams)		Larval Weight (g/head)	
		Initial	Final	Initial	Final	Initial	Final
Household	7	1340	1211 ± 23.14	11,2	232 ± 13,38	0,0083	0,192 ± 0,007
	12	1340	1326 ± 5,08	11,2	293 ± 17,95	0,0083	0,221 ± 0,013
	14	1340	1267 ± 84,77	11,2	283 ± 15,95	0,0083	0,223 ± 0,004
	17	1340	1199 ± 33,62	11,2	247 ± 7,56	0,0083	0,207 ± 0,001
	21	1340	1006 ± 50.00	11,2	198 ± 10,54	0,0083	0,198 ± 0,001
Market	7	1340	1127 ± 25,93	11,2	135± 22,68	0,0083	0,119 ± 0,008
	12	1340	1188 ± 9,76	11,2	171 ± 6,02	0,0083	0,144 ± 0,004
	14	1340	1073 ± 67,25	11,2	144 ±15,51	0,0083	0,134 ± 0,006
	17	1340	1059 ± 55,52	11,2	140 ± 18,26	0,0083	0,132 ± 0,005
	21	1340	957 ± 39,24	11,2	127 ± 8,94	0,0083	0,133 ± 0,006
	10	-	-	-	-	0,01	0,12 ± 0,01

Source waste	Bio-conversion Time (days)	Number of Larvae (head) - 7DOL		Live Larval Total Weight (grams)		Larval Weight (g/head)	
		Initial	Final	Initial	Final	Initial	Final
Palm Oil Cake *[19]	14	-	-	-	-	0,01	0,16 ± 0,01
	18	-	-	-	-	0,01	0,18 ± 0,01

4.3 Efficiency of bioconversion processes

4.3.1 Overall Reduction (D) & Waste Reduction Index (WRI)

Generally, the calculation results of *Overall Reduction* (%) on a *dry basis* (BK) obtained that the most significant waste reduction was on the 14th day, namely household food waste and market waste were 80.13% and 86.38%, respectively (see figure 1 (a) and (b)). It indicates that the larvae were still highly active in eating from the first day of bioconversion to the 14th day. After the 14th day, the level of consumption of the bioconversion *feedstock* by the larvae began to decrease. However, when considering the value of the *Waste Reduction Index* (WRI), i.e., the index of waste reduction per day, the highest WRI values for household food waste and market waste were on the 7th day, i.e., 10.52%/day and 9.71%/day (see figure 1 (c)). The WRI value on the following day variations significantly decreased until it reached a nearly constant value from the 14th to the 21st. Compared to previous research stated that the ability of BSF larvae would increase from the age of 7th days [18] or continue to increase from the 5th to 17th day, and after that, its started to reduce the feedstock constantly [19]. A high WRI value indicated that larvae's higher ability to reduce organic waste. The decrease in the waste reduction rate could be caused by the dwindling substrate availability and the substrate's drier conditions. Comparing the WRI values between the two types of waste, the WRI value of RT food waste was still higher than that of market waste. It was also because the larvae preferred household food waste that contained a wider variety of nutrient sets.

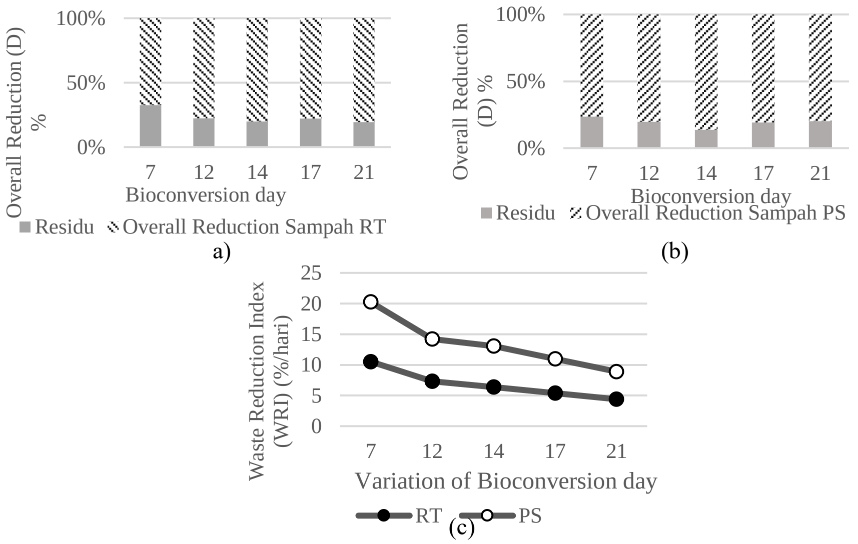

Fig. 1. (a) *Overall Reduction* (D) % of household waste; (b) *Overall Reduction* (D) % market waste; (c) *Waste Reduction Index* (WRI) (%/day)

4.3.2 Efficiency of Conversion of Digested-Feed (ECD) & Relative Growth Rate (RGR)

The ECD provided an overview of the efficiency of converting waste into larva biomass; thus, the higher the ECD value, the greater the efficiency of the bioconversion process. The results showed that the highest conversion efficiency of waste into biomass occurred on the 12th day for household food and market waste, with values of 16.72% and 10.29%. figure 2 demonstrates that the ECD value increased from the 7th to the 12th day, then decreased until the 21st. It implied that from the first to the 12th day of bioconversion, the larvae consumed waste actively and converted it into their body biomass. It was in line with the value of the WRI gap between the 7th day and the 12th day as the largest at $\pm$ 3%, It indicated that the bioconversion processes up to the 12th day were significant for reducing waste mass. The ECD value was also directly proportional to the WRI value during bioconversion.

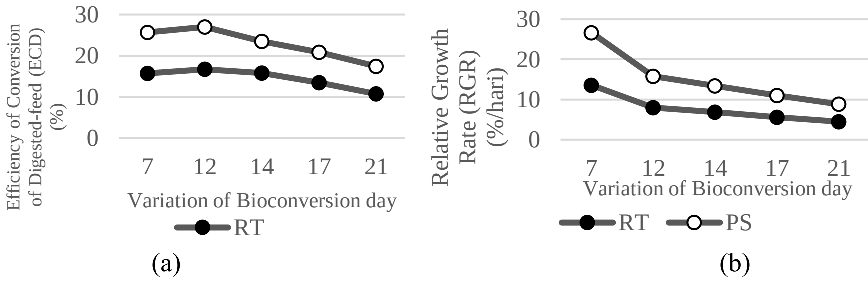

Fig. 2. (a) Efficiency of Conversion Digested-feed (ECD) %; (b) Relative Growth Rate (RGR) %

Furthermore, considering RGR as a value that indicated the growth rate of larvae from the initial bioconversion process to the final bioconversion process, which was expressed in units '%/day'; hence, the resulting value was a percentage of the rate of growth of larvae per day. The higher the RGR value, the greater the growth rate. The results indicated that the highest RGR value was on the 7th day, i.e., 13.60% and 13.10% for household food waste and market waste, respectively. This value on the next bioconversion day decreased until the 21st day. It showed that the first seven days of bioconversion were the days with the highest larval growth rate because, on those days, the larvae's age and body weight were still small, so the larvae would be highly active in consuming food.

4.3.3 Crude Protein and Fat Content

Larvae can degrade organic waste, as indicated by the nutritional content of BSF larvae [11]. The nutritional quality of the food given to BSF larvae is crucial and affects body mass and/or larval size. The highest fat content reached 16.64% on the 14th day for household waste and 15.76% on the 12th day for market waste (see figure 3). In general, for household waste, the fat content was not significantly different between the variations of bioconversion days, which ranged from 11-16%, while for market waste, it differed significantly between 4-16%. Meanwhile, for protein content, the results were relatively even at variations in time, i.e. approximately 15-22% and 14-20% for household and market waste, respectively. After comparing both, household waste has higher levels of fat and protein because the food sources for the larvae were quite varied such as rice, oil, vegetables, and animal protein than market waste, which was relatively homogeneous such as vegetables and fruit.

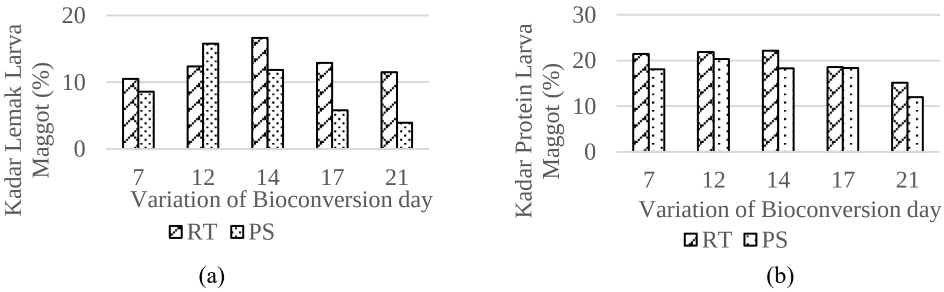

Fig. 3. (a) Efficiency of Conversion Digested-feed (ECD) %; (b) Relative Growth Rate (RGR) %

4.4 Statistic test

The *One-Way ANOVA* test obtained a *P*-value of 0.004<0.05 for household waste and a *P*-value of 0.046<0.05 for market waste, which explained that there was a significant difference between the variation in bioconversion days and the yield of BSF larvae and the efficiency value of the waste conversion process into larva biomass (ECD). For a comparison between household waste and market waste employing the *Two-Way ANOVA* test, a *P*-value of 0.008 <0.05 was obtained, which explained that there was a significant difference between BSF final larvae and ECD values for household food waste and market waste, where the ECD value for household waste was higher than market waste.

5. Conclusion

Based on the research results, the optimal time for the bioconversion process in food and market waste was 12-14 days. It was based on the efficiency of the bioconversion process indicator, which achieved the highest score for the *Efficiency of Conversion of Digested-feed* (ECD) value on the 12th day and the *Overall Reduction* (D) indicator on the 14th day. In contrast, the WRI and RGR values were most significant on the 7th day, which implied that in the first seven days, the value of the waste reduction index and the larval growth rate was most significant. However, when seen on the graph, this value significantly moved significantly until it became stable after the 14th day, i.e., a little change occurred. The low RGR value on the 17th and 21st days also meant that larval growth was not optimal.

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