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Analysis of Waste Reduction, Methane Gas and Economic Potential of Household Organic Waste Processing in SungaiPenuh City Using Hermetia Illucens/BSF Larvae

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Abstract -. Household waste as the largest source of waste needs to be managed properly and have value through appropriate innovation so that it does not become a source of pollution. This study aims to calculate the potential of Black Soldier Fly (BSF) larvae in reducing household food waste in Sungai Penuh City expressed in Waste Reduction Index (WRI) and methane gas reduction in the form of (GgCO2e) and analyze the economic potential of the waste by processing using BSF larvae through the sale of fresh larvae, kasgot and the sale value of methane gas reduction. The method used in this research is quantitative descriptive. Waste reduction was analyzed using the WRI equation based on data observed during BSF larvae cultivation. Analysis of methane gas reduction using the IPCC waste modelcalculation equation 2006. Meanwhile, the analysis of economic potential is based on the selling price of fresh larvae and kasgot products in the market. Based on the results of the study, BSF larvae were able to reduce household food waste in Sungai Penuh City by 44.73 ± 1.1% with a WRI value of 3.195 ± 0.09% per day and were able to reduce methane gas produced by landfill by 66.68% (1.265 Gg CO2e). The products produced are fresh larvae by 37.37% and kasgot by 27.79% with a potential economic value of Rp. 8,921,131,552, - / year forthe city processing scale and Rp. 444,944, - / year for the household scale. The potential economic value of methane gas reduction utilizing BSF larvae is Rp. 3,683,265 - Rp. 9,202,671, - / year. Based on this, it can be concluded that household food waste in Sungai Penuh City is feasible to be processed by utilizing BSF larvae, in addition to being able to reduce waste, it also has economic potential for the products produced.

Keywords - Waste Reduction Index (WRI), Methane Gas Reduction, Economic Potential of Waste.

I. INTRODUCTION

The Indonesian government has regulated waste management through Law number 18 of 2008 concerning waste management. Waste management is important to reduce its impact on health, environment or beauty and restore natural resources. In addition, waste management basically wants to handle or convert waste into goods that have economic value and are useful and turn them into materials that do not endanger the environment. Waste generation in Indonesia in 2022 reached 35.803 million tons/year with a reduction rate of 14.98% and handling of 47.64%, while managed wastereached 62.62% and unmanaged 37.38%. The source of waste nationally is dominated by household waste (38.40%), if juxtaposed with the amount of waste generated by Sungai Penuh City as a small city is 50.124 tons /day [1]. The composition of waste is dominated by organic food waste of 35.262 tons/day (70.350%).

Household waste is the largest source of waste generated in Indonesia including Sunga Penuh City to date, with thelargest

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composition being food waste. This waste requires landfill sites that continue to grow in size over time and has the potential to pollute water, soil and air quality if not treated. Therefore, a solution is needed to overcome the negativeimpacts of food waste and to increase its positive impacts as much as possible. The presence of food waste also triggersthe formation of methane gas, which is mostly produced during anaerobic decomposition of organic waste in landfills. Methane gas is the main greenhouse gas emitted from the waste sector, amounting to 127,491 GgCO2e (95.06% of the total waste sector greenhouse gas) in 2019 [2]. Through the reduction of organic food waste, it will reduce methane gas formed from waste.

Sungai Penuh City is an area in the highlands of Sumatra located in the westernmost part of Jambi Province. Most of the city's area is land with a high slope and is drained by several rivers and tributaries, making the city prone to landslides and flooding. 59.2 percent (23,178 Ha) of the area of Sungai Penuh City is a protected area of Kerinci SeblatNational Park (TNKS) which is administratively included in the administrative area of Sungai Penuh City [3]. This condition causes the city of Sungai Penuh to have very limited space in developing infrastructure, one of which is the Final Processing Site (TPA). Topographical conditions which are highlands and hills also make it difficult to meet the criteria for providing land for landfills, these conditions require finding solutions and innovations to develop non landfill based waste management and processing efforts. Sungai Penuh City in realizing integrated and sustainable waste management has built village scale Integrated Waste Management Site (TPSR) facilities in 16 villages as many as 16 Integrated Waste Management Site (TPS3R) and area scale as many as 5 TPS3R equipped with organic and inorganic waste processing facilities [4]. Various waste management technologies and innovations can be developed, one of which is waste processing utilizing Hermetia Illucens larvae / BSF larvae, which allows food waste to be decomposed so that no more landfill is needed. BSF larvae are a decomposer species that can be utilized to decompose organic waste such as food waste. The decomposition ability of BSF larvae is better than other organisms including microorganisms, besides that the technology is also easy to apply, has a very good economic impact and most importantly is very environmentallyfriendly [5]. The percentage reduction of household organic waste by BSF reaches 65-75% under optimum conditions [6]. In addition, in the process of BSF larvae harvesting, the larvae will promise profits because they are useful as an alternative source of feed for livestock and a source of compost fertilizer. On average, one ton of organic waste can produce 10-15% fresh maggot by beginners in less than three weeks, utilizing only about 100 - 150 g of BSF eggs [7].

Supporting this, a study is needed regarding the potential of BSF larvae in reducing household food waste as the largest source of waste in Sungai Penuh City and seeing the economic potential created, which is in line with no landfillbased waste management and processing efforts, and integrated with TPS3R facilities. The concept is also in line with the government's target in 2025 household waste and waste similar to household waste can be managed 100% with a scheme of 30% reduction and 70% waste handling [8].

II. RESEARCH METHODOLOGY

This research was conducted on a representation of households in Sungai Penuh City totaling 31 households, was conducted from April 2023 to October 2023. The method used in this research is quantitative, to obtain data on the level of reduction of household food waste in Sungai Penuh City by BSF larvae during feeding in the form of Waste Reduction Index (WRI) which will then be used to determine methane gas and the economic potential of the final product of waste decomposition by BSF larvae. The data used in this research are primary and secondary data.

This research begins with a preliminary study in the form of feeding BSF larvae for 14 days to see the conditions for the type of feed/waste given, the level of humidity and the duration of time in breaking down household organic waste at the researcher's house. Primary data were obtained from sampling data and observations of waste reduction and preliminary studies. Secondary data is obtained from data and reports sourced from related agencies, journals, regulations and research reports.

The waste sampling technique uses the Indonesian National Standard equation [9] for determining the number of household samples in housing so that 31 households are obtained. Household sampling points are determined by classifying households based on expenditure levels. The number of samples for low income (LI) households is 8 , medium income (MI) is 14, high income (HI) is 9. Data collection related to Waste Reduction Index (WRI) was carried out by cultivating BSF larvae from

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the source of food derived from household waste of sample representatives. The data collected include waste moisture content, waste degradation rate, larval mass data and Waste Reduction Index (WRI). After obtaining the WRI value, the final mass of food waste for a year in Sungai Penuh City was calculated. The knowndry weight of the food waste was calculated through the equation obtained from the drying of the feed and then used to determine the potential methane gas formed. During the decomposition of waste by BSF larvae, fresh larvae and kasgotwere also produced and weighed by dry weight. Based on the data from the cultivation of BSF larvae, the waste degradation rate was analyzed using the following equation.

$$D = (W - R)/W$$

Description:

W = Initial waste amount (g)R =
Residual waste (g)

D = Waste degradation rate

The waste reduction value is calculated based on the Waste Reduction Index (WRI):WRI =
(D/T) x 100

Description:

D = Waste Degradation Rate

t = Time to degrade waste (days)WRI =
Waste Reduction Index

The calculation of methane gas was carried out using the Intergovernmental Panel on Climate Change (IPCC) waste modelcalculation 2006 equation with the equation [10]:

DDOCm Deposited = R.DOC.DOCf. MCF

DDOCm Decomposed = DDOCm Deposited x (1-e-k)

Lo = DDOCm Decomposed. F. (16/12)

CH4 in year T = [Lo x.T – RT] x (1-OX)

Description:

DDOCm = Mass of DOC that can be decomposed (Gg)R = Final Waste Mass/Residue (Gg)

DOC = *Degradable Organic Carbon, degradable organic carbon component*, IPCC (2006))DOCf
= Value of decomposable fraction of DOC (0,15 for food waste, IPCC (2006))

MCF = Methane Correction Factor (0,5 according to landfill conditions (TPA), IPCC (2006))k
= Constant Reaction (= ln(2)/t1/2)

t1/2 = Half-time

Lo = Potential CH_4 gas formed

F = Fraction value of CH_4 formed

(16/12) = Molecular weight ratio of / C

OX = Oxidation Factor

The economic potential of waste treatment using BSF larvae is calculated based on the multiplication of the weightof wet larvae and kasgot from waste reduction against the market selling price and the selling value of methane gas reduction from waste.

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III. RESULTS AND DISCUSSION

3.1. *Waste Reduction Index* (WRI)

The effectiveness of BSF larvae utilization can be seen from the percentage of reduction, from the provision of 250grams of household waste on days 1, 3, 5 feeding rate 60 mg / larvae.day and week 2 days 7, 9, 11, 13 of 450 grams of feeding rate 108 mg / larvae per day, the average degradation value obtained is 0.447 ± 0.012 or 44.73 ± 0.012%. The reduction value shows that BSF larvae are able to reduce pulverized household food waste by 44.73±0.012% of the total waste mass. Meanwhile, the WRI value obtained was 3.195±0.09%/day, indicating that the BSF larvae were able to reduce the given waste by 3.195±0.09% in one day. The five replicates conducted had similar percentage degradation values, ranging from 38.22 to 52.28% with WRI ranging from 2.73 to 3.73%, as shown in Table 1.

Based on Table 2 from several studies of various types of waste sources, it can be seen that the type of waste givento BSF larvae and the optimum conditions for feeding BSF larvae for a certain period of time (feeding rate) greatly affectthe percentage of degradation and the WRI value. The average feeding rate increased by 2 to 3 times in the second week in accordance with the increasing feed requirements of the larvae. Likewise, for the type of waste originating from households in Sungai Penuh City, based on preliminary studies conducted by researchers on larval feeding, the optimum feeding rate in the first week was 60 mg/larva.day and 108 mg/larva.day. Indeed, the highest percentage of degradation and WRI value was seen in restaurant waste in Nurul's research on 2022, this condition shows that BSF larvae work moreoptimally in reducing restaurant waste if using a feeding rate of 30 mg/larva.day in week 1 and a feeding rate of 80 mg/larva.day in week 2 with a degradation rate of 78.70% and WRI of 5.62%/day. Meanwhile, for waste sources from households in Sungai Penuh City using a feeding rate of 60 mg/larva.day in week 1 and a feeding rate of 108 mg/larva.day in week 2 with a degradation rate of 44.73% and WRI of 3.195%/day. The degradation rate of household waste is smallerthan that of restaurant waste, while the feeding rate given is the optimum amount according to the results of the preliminary study. This proves that the reduction rate and WRI are not only influenced by the feeding rate but also by the composition of the feed type, moisture content and age of the larvae used. In general, food waste and household wasteare rich in carbohydrates, protein and fat. However, household waste that is found in Sungai Penuh City is in the form of processed food waste such as vegetable waste and fruit peels, but only a little in the form of stale food waste, here vegetable and fruit waste, in addition to having a high carbohydrate content, also has high fiber and low protein. The fiber in the waste affects the decomposition of household waste by BSF larvae, which is not optimal. Moisture content also influences, where the moisture content of food waste and its processing in households in Sungai Penuh City is only 51.62% while the moisture content suitable for larval growth and waste decomposition is 70-80% [11].

Table 1. Recapitulation of Waste Reduction by BSF Larvae

Repeat	Mass Initial	Final Mass	Reduced Mass	Degradation Value	Percentage Degradation (%)	WRI (%Day)
1	1282,61	774,30	508,31	0,396	39,63	2,830
2	1282,61	792,29	490,32	0,382	38,22	2,730
3	1282,61	664,36	618,25	0,482	48,20	3,443
4	1282,61	701,30	581,31	0,453	45,32	3,237
5	1282,61	612,05	670,56	0,522	52,28	3,734
Average				0,447	44,73	3,195
Average ± SE				0,447±0,012	44,73±0,012	3,195±0,09[a]

Source: Data from the calculation results, 2023

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Table 2. Comparison of Percentage Degradation andWRI of Several Studies

Source	Type of Waste	*Feeding Rate** (Mg/Larvae.Day)	Percentage Degradation (%)	WRI (%Day)
Research Results	Household residual waste	60 (Week 1) 108 (Week 2)	44,73	3,195
[12]	Household residual waste	30 (Week 1) 80 (Week 2)	78,70	5,62
[13]	Household residual waste	75 (Week 1) 225 (Week 2)	42,90	3,06
[14]	Untreated cafeteria waste	100	-	4,09
[15]	- Cafetaria Waste - Cucumber - Banana	65 52 61	54,00 54,00 52,00	- - -
[16]	Cafeteria waste	19	65,00	-
		18	54,00	-
[17]	Combination of vegetable; fruit; fish 40:35:25	20	55,90	-

Sources : Data from several research results

Description: * optimum conditions for feeding BSF larvae over a period of time.

The final results showed that from 3.93 grams of larvae, the total weight of the larvae grew to 953.025±5.028 grams, meaning there was a 243-fold increase in mass. The final observation of the mass of one larva was 0.464±0.019 grams. While the normal mass of larvae according to Supriyatna and Putra (2017) is 0.1-0.2 grams, when compared with the results of the study, the larvae were four times larger than normal larvae.

Determination of the Waste Reduction Index (WRI) value requires the value of the initial dry mass of waste [18], so it is necessary to calculate the moisture content of the waste given. The average moisture content obtained after testing is 51.62%, if the moisture content obtained is too low, the larval digestion process will be hampered [16]. After obtainingthe moisture content value, the initial dry mass value of the waste can be found. Through research it is found that moisture content can affect the dry mass of feed. The greater the moisture content, the smaller the dry mass of the feed. The trend obtained from dry mass to wet mass is used to estimate the dry mass of Sungai Penuh City waste that will be calculatedfor methane gas.

3.2 Methane Gas Reduction

Based on the results of the study of residential/household waste generation in Sungai Penuh City, it is known that the production/composition of food waste in Sungai Penuh City in 2023 reached 70.35% (35.262 tons/day) of the total waste generation in Sungai Penuh City of 50.124 tons/day for wet mass [1]. The dry mass of food waste in the landfill obtainedbased on the linear trend between the mass of wet initial feed and dry initial feed is 22.008 tons/day (8.003 Gg in one year).

After the dry mass of waste is obtained, the calculation of methane gas formed can be calculated using the 2006 IPCC Guideline method. The IPCC method assumes that methane is emitted by waste directly in the same year after the waste is landfilled. In the calculation of methane gas formed in the Sungai Penuh City Landfill using the DOC value for the type of

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food waste is 0.15 for the Methane Correction factor (MCF) value is 0.5 where the type of landfill is classified as Managed Semi aerobic landfill. From the calculation of DDOCm Deposited obtained by 0.301 Gg, DDOCm Decomposed by 0.151 Gg, so that the potential CH4 gas formed (Lo) is 0.100 Gg.

As for the same initial mass of wet waste through the processing of household food waste by BSF larvae and using the WRI value from the results of the analysis carried out, the dry mass of waste based on linear trends before substitutingthe WRI value is 22.008 tons / day (4.44 Gg in one year), the value of waste reduction using the WRI value is 12.164 tons / day. DDOCm Deposited was obtained at 0.166 Gg, DDOCm Decomposed at 0.050 Gg, so that the potential CH4gas formed (Lo) was 0.033 Gg. Based on the above calculations, the treatment of food waste processing utilizing BSF larvae (under optimal conditions) at the landfill, the methane gas formed is 0.030 Gg CH4 or 0.632 Gg CO2e during 2022. The comparison of waste processing at the RPT landfill with and without processing can be seen in Table 3 below.

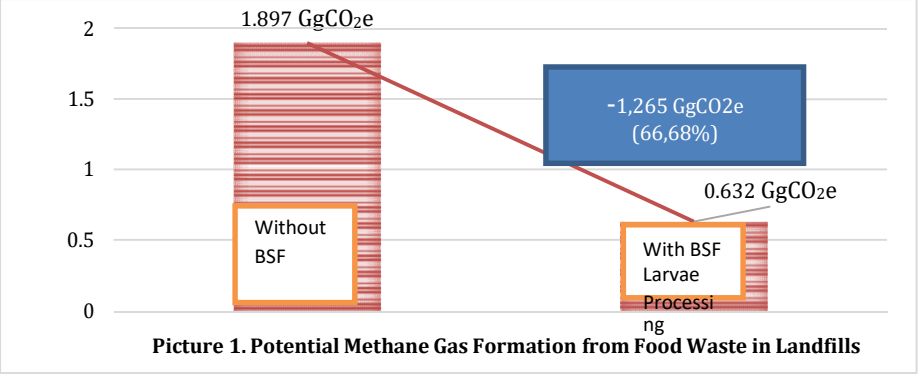
Table 3. Recapitulation of Methane Gas Calculation Without Processing and With Processing of BSF larvae

Aspects	Unit	No Processing	BSF larvae processing
Initial Mass of Waste (Wet)	Ton/day	35,262	35,262
Initial Mass of Waste (Dry)	Ton/day	22,008	22,008
Final Mass of Waste (Dry)	Gg	8,033	4,44
DDOCm Deposited	Gg	0,301	0,166
DDOCm Decomposed	Gg	0,151	0,050
Lo	Gg	0,100	0,033
CH_4 Year 2022	$GgCO_{2e}$	1,897	0,632

Source : Data from the calculation results

Through BSF larvae processing, if optimized, the mass of food waste can be reduced to 12.164 tons/day. The potential methane gas formed in 2022 if waste reduction is carried out by BSF cultivation is 0.632 GgCO2e during 2022,while without processing with BSF larvae it is 1.897 GgCO2e, this figure shows a decrease in the amount of methane gas produced by 66.68% (1.265 GgCO2e) using waste processing with BSF larvae.

An overview of the CH4 comparison conditions with BSF larvae processing can be depicted in Figure 1 below. However, in decomposing waste using BSF larvae, the feeding rate needs to be considered, so that the waste can be decomposed completely and there is no accumulation of waste at the bottom layer which causes decay so that methane gas is formed. The percentage is not too large but if done consistently, the methane gas reduction will be sustainable. Therefore, BSF larvae can be an alternative to processing organic waste, especially food waste, which can reduce food waste properly.



Picture 1. Potential Methane Gas Formation from Food Waste in Landfills

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3.3 Economic Potential of Household Organic Waste in Sungai Penuh City Utilizing BSF Larvae

Based on the results of the research conducted 2,550 grams of food waste feed can be decomposed by 3,936 grams (2,083) baby larvae until they can be harvested into fresh BSF maggot (1 cultivation cycle) amounting to 953.025 g. While the yield of compost from BSF larvae (kasgot) obtained based on the research is 708.86 grams. Meanwhile, the yield of compost fertilizer from BSF larvae (kasgot) obtained based on the results of the study was 708.86 grams. The results showed that the processing of household organic waste using BSF larvae produced 37.37% fresh larvae and 27.79% compost from the total initial mass of waste. According [6] BSF larvae can digest organic waste with a reduction in organic matter of 65.5% - 78.9% per day and 15,000 BSF larvae can consume approximately 2 kg of food and organicwaste in just 24 hours. [19] Stated that feeding 8.1 kg of household organic waste to BSF larvae derived from 1 grams of eggs can produce as much as 1.5 kg of fresh BSF larvae. [20] Compost produced from the remaining BSF maggot feed can reach 20-30% of the total feed. Fresh maggot can be produced 10-15% of the waste given in less than three weeks, even in good handling, trained workers, the type of feed comes from the waste of restaurants / restaurants / kitchens can produce fresh maggot up to 30% of the amount of feed given [7]. [21] If organic waste is processed into compost, it will shrink to around 40-50%, meaning that as much as 8.1 kg of waste processed by composting will produce compost fertilizer of 3.24 kg - 4.05 kg (50%-60% of total waste). However, economically, processing waste with a composter will only produce compost fertilizer, while processing waste with BSF larvae can produce compost fertilizerand maggot larvae as an alternative source of feed, which is better if the waste is processed using BSF larvae. Meanwhile, on the market the selling price for 1 kg of fresh BSF larvae ranges from Rp.4,000-7,000 IDR while for fine compost fertilizer is Rp. 2,000-5,000 IDR The economic potential that can be obtained from processing household organic wastein Sungai Penuh City if using BSF larvae Rp. 8,921,131,552 IDR/year. Meanwhile, for each household in Sungai Penuh City if utilizing BSF larvae is Rp.444,944 IDR/year.

The potential baseline emission (BE) of GHG from CH4 of waste processing activities in Sungai Penuh City before the application of processing using BSF larvae is 1.897 GgCO2e and the GHG reduction of CH4 after waste processingusing BSF larvae is 0.632 GgCO2e, meaning that the recovery of CH4 gas reaches 66.68% of the total emissions produced, to be precise, a reduction in CH4 of 1.265 GgCO2e. Based on data from the Intercontinental Exchange (ICE)Futures Europe (2021), the trend of CER selling values from 2019 to 2021 shows fluctuating values but tends to increase. The minimum CER selling value is €0.17/tCO2e (IDR 2,876.4/tCO2e) which occurred on November 13, 2019 and the maximum CER selling value is €0.43/t CO2e (IDR 7,275.6/tCO2e) which occurred in 2021 [21]. Based on the assumptions of the maximum and minimum values, the potential CER revenue from processing household organic waste using Hermetia illucens/Black Soldier Fly (BSF) larvae in 2022 ranges from Rp. 3,638,265 IDR to Rp. 9,202,671 IDR

IV. CONCLUSIONS

BSF larvae cultivation was able to reduce household waste in Sungai Penuh City by 44.73 ± 1.1% with a Waste Reduction Index (WRI) value of 3.195 ± 0.09% per day and was able to reduce methane gas produced by landfill in Sungai Penuh City by 66.68% (1.265 Gg CO2e). The products produced from waste processing through the use of BSF larvae are fresh larvae by 37.37% and cassava by 27.79% with a potential economic value of Rp. 8,921,131,552 IDR year for the city processing scale and Rp. 444,944 IDR/year for the household scale. The potential economic value of methane gas reduction in household organic waste processing in Sungai Penuh City utilizing BSF larvae is Rp. 3,683,265IDR - Rp. 9,202,671 IDR /year.

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