Effect of feeding rate and composition for bioconversion of wastewater treatment plant sludge from the milk and creamer processing industries using black soldier fly larvae

Riang Ursada[1], *Arseto Yekti* Bagastyo[2*], and *Alfan* Purnomo[2]

[1]Master Study Program, Department of Environmental Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Department of Environmental Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. Wastewater treatment plant (WWTP) produces sludge deposits needing further treatment and handling to prevent pollution. Food and beverage industry sludge, rich in organic matter and nutrients, serves as a biomass source. Black Soldier Fly Larvae (BSFL) have degraded various organic materials, transforming nutritious organic waste into high-quality protein biomass. BSFL potentially converts sludge when mixed with other nutrient sources like food waste. This study analyzes the effect of feeding rate and composition on BSFL bioconversion of milk and creamer industrial sludge. The sludge was collected from the creamer processing industry after screw and filter pressing, and the milk processing industry after belt pressing. The substrates contained sludge, mixed fruit-vegetable wastes, and protein wastes (i.e., shrimps and fish wastes), with various ratio of 60:20:20, 60:10:30, 40:30:30, 40:20:40, 40:10:50, 50:25:25, 50:20:30, 50:10:40, and 70:15:15 (in dry weight percentage). Moisture content was kept at 65-85% and pH at 6.5-7. Feeding rates of 10, 20, and 30 mg dry matter/larva/day were assessed. Creamer processing industrial sludge, particularly from filter press is preferable for larval growth than the milk industry. The highest larva weight was obtained from substrates containing mixed fruit-vegetable wastes:fish wastes ratio of 1:1, with the addition of creamer and milk sludge of 50%, i.e., 0.250 gram WM/larva after 17 days of growth. In addition, with the recommended feeding rate is 10-20 mg dry matter/larva/day, the sludges can be bio-converted using BSFL by combining it with food wastes at around 40-60%. This offers alternatives for the treatment and handling of industrial waste sludges.

1 Introduction

Based on the data from the Indonesian Central Statistics Agency, the cumulative growth rate of the food and beverage industry in 2023 reached 4.16. The growth of food production that

* Corresponding author: bagastyo@enviro.its.ac.id

increases along with population growth can have an impact on the environment [1]. Industrial activities generate wastewater that must be treated based on the type of pollutants it contains to ensure that these contaminants are reduced to levels allowed by the established water quality standards for safe discharge [2]. The wastewater treatment system produces sludge. Sludge is a biosolid material generated in large quantities as a byproduct of various industrial processes and sewage treatment plants (STPs) [3]. If not properly managed, sludge can cause environmental harm, including air and soil contamination. Meanwhile, disposal of sludge to landfills can increase the burden on landfills and shorten the life of landfills [4].

Previous research found that industrial food and beverage sludge have nutrition such as percentage levels of fat, protein, crude fiber, carbohydrates up to 10.7, 5.43, 3.754-5.82, 36.8 respectively [4-6]. Several studies related to ultimate analysis of sludge from the food and beverage industry state that the content of the elements C, H, N and O can reach up to 62.90, 7.29, 8.41, and 42.99 in percent [7, 8]. Black soldier fly larvae (BSFL) are capable of transforming sludge into protein-rich feed and organic fertilizer, offering valuable nutrients for fish, pets, poultry, and plants [9-11]. Sludge from the food and beverage industry as a co-substrate has the potential to be a valuable feedstock for cultivating Black Soldier Fly larvae (BSFL), as suggested by previous studies [5, 12]. BSF fed with mixture of ice cream industry sludge with other organic waste had an average weight of 0.01-0.04 gram WM/larva [5].

The nutritional requirements for optimal larval growth necessitate substrates that are rich in protein and carbohydrates [13]. Substrates containing high levels of protein, fat, and carbohydrates are particularly advantageous for larval consumption [14]. The provision of a diet comprising a combination of high protein and complex carbohydrates has been shown to significantly reduce pupal mortality in black soldier flies (BSF) [15]. To enhance the nutritional profile of the substrate, it is essential to incorporate additional sources of protein and carbohydrates as co-substrates. Such co-substrates include food waste from fruits, vegetables, and animal proteins, which represent a significant waste management challenge in Indonesia. Typically, a mixture of fruit and vegetable waste comprises approximately 20% protein, 2% fat, and 69% carbohydrates [16]. Animal-derived food waste serves as a high-quality and abundant protein source, including meat, poultry, fish, and shellfish [17].

There are many factors influencing BSF growth including moisture content, pH, humidity, light intensity, larvae to treatment area density, feeding rate and temperature [18-25]. There is limited comprehensive research on BSF for converting sludge from food and beverage industry wastewater treatment plants (WWTP). This study aims to find the best substrate composition for bioconversion of food and beverage industrial sludge.

2 Research methods

2.1 Sludge and food waste

Sludge was obtained from the milk industry, specifically from the belt press unit, and from the non-dairy creamer industry, from both the filter press and screw press units. This sludge is a by-product of wastewater treatment, resulting from both the production process and domestic wastewater, including black water and grey water from the canteen and laundry facilities. The sludge from non-dairy creamer industry are undigested sludge and digested sludge. The undigested sludge refers to the residual material from wastewater treatment that has passed through a summary pit equipped with a bar screen and grease trap, followed by a sedimentation process in an equalization tank. Undigested sludge undergoes dewatering through a screw press. Digested sludge is produced following the treatment of wastewater through a Moving Bed Biofilm Reactor (MBBR) and a conventional activated sludge system,

which promote the biological breakdown of organic matter. The resulting digested sludge is then dewatered using a filter press. The non-dairy creamer sludge has undergone the Toxicity Characteristic Leaching Procedure (TCLP) test, which confirmed the absence of hazardous elements, indicating that the sludge is non-toxic. Meanwhile milk industry wastewater treatment sludge generated from various processes that can be seen in Figure 1. The sludge is stored at room temperature in a closed container, protected from insects and houseflies, to prevent contamination.

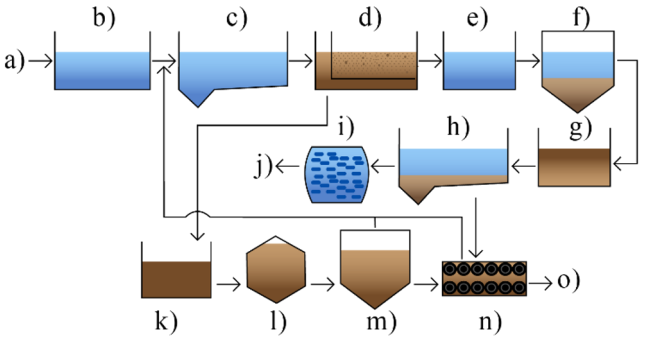

Fig. 1. Flow process of milk industry WWTP where a) influent, b) control pit, c) equalization tank, d) DAF, e) neutralization tank, f) expanded granural sludge beds, g) aeration tank, h) sedimentation tank, i) chemical post treatment, j) liquid effluent, k) scum box, l) CSTR, m) thickener, n) belt press, o) sludge effluent

Analysis of carbohydrates, crude protein, total ash, total fat, and moisture content in the sludge was carried out. Carbohydrate analysis was done with Luff-Scrhoorl reagent where carbohydrates are broken down into monosaccharides that can reduce Cu^{2+} to Cu^{+}. Excess Cu^{2+} was then calculated by iodometric titration. Crude protein was analyzed by the semi-micro Kjeldhal method where nitrogen compounds were converted into ammonium sulfate using concentrated H_2SO_4. Ammonium sulfate was then decomposed with NaOH to ammonia. Ammonia was wrapped with boric acid and calculated by titration of standard acid solution. Total ash content was calculated by decomposing organic matter into air and CO_2 leaving inorganic matter by burning the sample at a temperature of 550°C. Total fat was measured using the Weibull method where the sample was hydrolyzed with hydrochloric acid 25% before the fat was extracted by Soxhlet with a nonpolar solvent. Moisture content is measured by heating the sample in oven at 105°C for 24 hours [26]26.

The fruit waste used in this study includes langsat fruit (*Lansium domesticum*) and red guava (*Psidium guajava Linn*), while the vegetable waste consists of cabbage (Brassica oleracea) and chinese mustard (*Brassica rapa Pekinensis*). The fruit and vegetable mixture were prepared in a 1:1 wet weight ratio. The fish head waste used originates from mackerel tuna (*Euthynnus affinis*), and all fruit, vegetable, and fish waste were sourced from local traditional markets. Whiteleg shrimp waste (*Litopenaeus vannamei*) was obtained from shrimp that died during partial harvesting and those affected by vibriosis. The variations in substrate composition are shown in Tables 1, 2, and 3. Nutritional measurements on substrate from food waste were carried out using secondary data according to Indonesian food composition table [27].

Table 1. Variation of substrate composition for laboratory scale 1

Code	Fruit & veg waste (%)	Protein source waste (%)	Sludge mixture (%)	Sludge DM ratio (FP : SP : BP)
1	20	F 20	60	0.5:0.5:1
2	20	F 20	60	0.5:0.5:2
3	20	F 20	60	1:1:1

Code	Fruit & veg waste (%)	Protein source waste (%)	Sludge mixture (%)	Sludge DM ratio (FP : SP : BP)
4	0	0	100	1:1:0
5	0	0	100	0:0:1
6	10	F 30	60	0.5:0.5:1
7	30	F 30	40	0.5:0.5:1
8	20	F 40	40	0.5:0.5:1
9	10	F 50	40	0.5:0.5:1
10	10	V 50	40	0.5:0.5:1
11	10	P 50	40	0.5:0.5:1
12	10	F+V 50	40	0.5:0.5:1
13	25	F 25	50	0.5:0.5:1
14	20	F 30	50	0.5:0.5:1
15	10	F 40	50	0.5:0.5:1

F: Fish head; V: Vibriosis shrimp; P: Partial harvested shrimp; FP: Filter press; SP: Screw press; BP: Belt press

Table 2. Variation of substrate composition for pilot scale

Code	Fruit & veg waste (%)	Protein source waste (%)	Sludge mixture (%)	Feeding rate (mg DM/larva.day)
510	25	25	50	10
520	25	25	50	20
530	25	25	50	30
610	20	20	60	10
620	20	20	60	20
630	20	20	60	30
710	15	15	70	10
720	15	15	70	20
730	15	15	70	30

DM: Dry Matter

Table 3. Variation of substrate composition for laboratory scale 2

Code	Fruit & Veg Waste (%)	Fish Head (%)	Sludge (%)	Sludge Source
50S	25	25	50	screw press
60S	20	20	60	screw press
70S	15	15	70	screw press
50F	25	25	50	filter press
60F	20	20	60	filter press
70F	15	15	70	filter press
100S	0	0	100	screw press
100F	0	0	100	filter press

The waste mixture was initially processed using a custom mechanical steel blender, which homogenized the material to achieve a porridge-like or slurry consistency [3, 13]. Substrate storage was carried out for no more than 2 days at a temperature of 4^{o}C [28, 29]. The substrate moisture content was maintained in the range of 65-85% [21, 30]. The temperature used is 24-30^{o}C [13]. Temperature and moisture content of the substrat is measured with Digilife soil sand moisture meter DM300L. The pH of the substrate was maintained in the range of 6.0-8.0 [22].

2.2 Black soldier fly

5-days old larvae (DOL) were obtained from BSF cultivation at the reduce reuse and recycle waste management site Wonorejo, Surabaya. BSFL were raised in chicken feed 511 until 5 days old before being transferred to the tested substrate. On a laboratory scale, a plastic jar

reactor with a diameter of 9 cm and a height of 13 cm was used. The feeding rate used was 20 mg dry matter/larva/day and fed every 2 days [31]. On a pilot scale, a plastic reactor with a length of 60 cm, a width of 40 cm, and a height of 18 cm was used. The feeding rates used were 10, 20, and 30 mg dry matter/larva.day. The density of larvae used for the laboratory scales was 5 larvae/cm^2 [32]. Meanwhile density of larvae used for pilot scales was reduce to 4 laravae/cm^2 [13]. Feeding frequency used in pilot scale is once a day. All reactors were covered with aluminum mosquito nets to prevent larvae from escaping.

The number of larvae needed in each reactor is the result of multiplying the reactor area by the density of the larvae. The addition of larvae to each reactor is not done by counting the larvae one by one but by using a mass approach. Larvae aged 5 days are separated from excess frass. Then the larvae are weighed along with the remaining frass of ±0.1 gram and ±0.2 gram each 3 times. Then the larvae are counted one by one to find the average weight of 5-day-old larvae.

The addition of larvae to each reactor is in accordance with the result of multiplying the number of larvae needed by the average weight of 5-dol larvae. Feeding was carried out until the prepupa larvae appeared ±30% of the population. The reactor is placed in a place protected from direct sunlight [25].

2.3 Determination of experimental parameters

Larval bioconversion was measured by weighing the weight of the larvae and the weight of the frass. On a laboratory scale, 3% of the larval samples were taken from the total number of larvae. Larval samples were taken on the 6th, 12th, and 14th feeding day of substrate. On a pilot scale, 1% of the larval samples were taken from the total number of larvae. Larval samples were taken on the 4th, 8th, and 12th feeding day of substrate. Prepupa samples on a laboratory scale were taken on the 21st feeding day or when they were 26 days old. Larval samples were washed with tap water and then dried with tissue before being weighed. Afterward, all the larvae were returned to their reactor. In addition, calculations were made for waste reduction index (WRI), efficiency of conversion of digested food (ECI), waste reduction, bioconversion rate, and larva growth rate according to the formulas 1 untill 5 [20, 33]. All calculations are done with dry matter data whereby the initial dry weight of 5-DOLs was assumed to be zero.

$$WRI\ (\%\ DM) = \frac{\frac{(substrate\ mass - frass\ mass)}{substrate\ mass}}{days\ of\ trial\ (d)} x100 \quad (1)$$

$$ECI\ (\%\ DM) = \frac{larvae\ gain\ mass\ (g)}{substrate\ mass\ (g) - frass\ mass\ (g)} x100 \quad (2)$$

$$Waste\ reduction\ (\%\ DM) = (1 - \frac{frass\ mass\ (g)}{substrate\ mass\ (g)}) x100 \quad (3)$$

$$Bioconversion\ rate\ (\%\ DM) = (\frac{larvae\ gain\ mass\ (g)}{substrate\ mass\ (g)}) x100 \quad (4)$$

$$Larva\ growth\ rate\ (\frac{mg}{day}) = \frac{(final\ larval\ average - initial\ larval\ average\ weight)}{number\ of\ days\ of\ the\ trial} \quad (5)$$

3 Result and discussion

3.1 Substrate nutrition

The results of the nutrient analysis of the sludge can be seen in Table 4. Laboratory analysis of the milk industry sludge yielded data on pH values, organic carbon content, nitrogen levels, carbon-to-nitrogen (C/N) ratio, and iron concentrations, as presented in Table 5. The sludge from the screw press unit has the highest fat and carbohydrate content. The sludge from the CSTR unit is not used because its moisture content is too high, and its carbohydrate

and crude protein content are low. The sludge with the highest crude protein content is from the filter press and belt press units. However, the belt press also has a high total ash content. Ash represents the inorganic (mineral) residue left after the combustion or thorough acid-assisted oxidation of the organic matter in food [34]. Whereas the natural population of H. illucens are adapted to decompose decaying organic materials. The fat and ash content of larvae is influenced by the substrate. Prepupae reared from substrates containing high ash content will also have high ash content. Whereas prepupae with very low ash content are more suitable for animal feed [35].

Table 4. Industrial sludge nutrients

Measurand (%)	Filter press	Screw press	Belt press	CSTR	Methods
Carbohydrate	4.91	6.37	1.68	1.45	Luff-schoorl
Crude protein	5.02	3.13	5.59	2.09	Semi micro kjeldahl
Total ash	1.81	4.12	6.29	0.58	Gravimetric
Total fat	<0.5	7.63	<0.5	<0.5	Weibull-stoldt
Moisture content	88.1	78.7	86	95.7	Oven drying

Table 5. Milk industrial belt press sludge characteristic

Measurand	Fresh	1 Month	3 Months	Methods
pH	6.9	6.7	6.6	pH meter
C-organic (% DM)	35.72	35.57	34.15	Ashing
N (%DM)	4.27	5.05	4.43	Kjeldahl, titrimetic
C/N ratio	8	7	8	
Fe (ppm DM)	13960	9453	4463	AAS

The nutrient content of food waste can be seen in Table 6. Shrimp has the highest protein content but very low carbohydrates. Shrimp also has the highest ash content. High carbohydrates are found in langsat fruit and red guava. Calculation of nutrients in variations of sludge mixtures with food waste in dry matter is shown in tables 7, 8, and 9.

Table 6. Food waste nutrients

Measurand (gram/100 gram edible weight)	Langsat	Red guava	Cabbage	Chinese mustard	Mackerel tuna	Shrimp
Carbohydrate	16.1	12.2	8	1.7	8	0.1
Protein	1	0.9	2.5	1	13.7	21
Ash	0.7	0.6	2.2	0.6	2.1	3.7
Fat	0.2	0.3	1.1	0.1	1.5	0.2
Moisture content	82	86	86.2	96.6	74.7	75

Table 7. Total nutrition of the laboratory scale 1 substrate in 14 days feed (DM)

Code	Carbohydrate (gram)	Protein (gram)	Ash (gram)	Fat (gram)
1	29.42	28.18	19.49	9.09
2	27.48	29.58	21.91	7.21
3	31.36	26.79	17.07	10.97
4	30.11	21.64	15.89	21.95

5	10.71	35.62	40.08	3.19
6	26.29	32.02	19.57	9.34
7	33.92	27.96	15.24	7.35
8	30.79	31.80	15.32	7.60
9	27.66	35.64	15.41	7.85
10	14.22	53.76	19.14	5.68
11	14.24	58.04	19.89	5.73
12	21.77	45.47	17.37	6.92
13	32.75	29.93	17.65	8.42
14	31.40	32.21	17.75	8.59
15	28.70	36.79	17.94	8.92

Table 8. Total nutrition of the pilot scale substrate in 12 days feed (DM)

Code	Carbohydrate (gram)	Protein (gram)	Ash (gram)	Fat (gram)
510	380.22	296.10	154.87	98.03
520	760.44	592.19	309.74	196.06
530	1140.66	888.29	464.60	294.09
610	348.64	286.33	168.94	107.94
620	697.27	572.66	337.89	215.88
630	1045.91	858.99	506.83	323.82
710	317.05	276.57	183.02	117.85
720	634.11	553.13	366.04	235.70
730	951.16	829.70	549.06	353.55

Table 9. Total nutrition of the laboratory scale 2 substrate in 14 days feed (DM)

Code	Carbohydrate (gram)	Protein (gram)	Ash (gram)	Fat (gram)
50S	46.80	43.29	15.54	20.57
60S	42.82	37.27	15.91	22.89
70S	38.83	31.25	16.27	25.21
50F	51.35	55.07	13.48	6.32
60F	48.27	51.40	13.43	5.79
70F	45.18	47.74	13.39	5.25
100S	26.86	13.20	17.37	32.17
100F	35.94	36.75	13.25	3.66

3.2 Larval development

The weight of the larvae and the average mass gain of the larvae are illustrated in Figure 2 and Figure 3. On laboratory scale 1, the larvae with the highest weights were in variations 9, 7, 1, and 13 which are 0.212, 0.207, and 0.199 gram WM/larva on 19 days old. These variations had ash content of less than 20 gram DM during the diet period. Variation 9 had a substrate with a higher protein content than

carbohydrates, unlike variations 7, 1, and 13. Proteins are recognized as the most crucial macronutrient in biowaste that affects the performance of the BSFL process. The protein content in the diet increased larval weight and significantly influences larval growth. These proteins provide essential amino acids necessary for larval development [36]. Variations 7, 1, and 13 have a composition ratio between the fruits-vegetable waste and fish waste of 1:1. This ratio is used for pilot scale trials by varying the presentation of sludge 50, 60, and 70.

On laboratory scale 1 variation 5, the larvae did not gain weight and died on the 5th day of feeding. Despite its high protein value, variation 5 has a high inorganic content that cannot be digested by the larvae. Meanwhile, in variation 4, the larvae were still alive but weighed less than the larvae given a mixed substrate of food waste. This proves that in the bioconversion of sludge with BSF, it is necessary to add a co-substrate other than sludge. The nutritional content of the co-substrate in Table 6 shows that fruits and vegetables play a vital part in providing more carbohydrates in the substrate, whereas fish waste is high in carbohydrates and protein. Both of these nutrients are very much required in larval development.

On laboratory scale 2, the larvae had the highest weights in the 50F, 50S, and 60F variations, respectively 0.228, 0.213, and 0.207 gram WM/larva on 19 days old. These three variations are variations with the highest carbohydrate and protein values compared to other variations. Both laboratory scale 1 and 2, on the 12th day of feeding, 30% of the larvae had formed prepupae. This is because the high protein content in the substrate can reduce developmental time [36]. On the 14th day, the average weight of the larvae decreased. This is because most of the larvae have become prepupae and are no longer feeding. BSF larvae shed fat and weight as they transition into prepupae. The model is based on two key metabolic processes: the rate at which they absorb food and the rate of producing body tissues (excluding stored fats), both rates decline over time [37]. In comparing laboratory scales 1 and 2, larval mass increased more effectively on laboratory scale 2.

During laboratory scale, the substrates that remained in the reactor were abundant. The substrat reach 8-10 cm height in reactors. Hence, it is deemed necessary to reduce the amounts of larvae on pilot scale so that the substrate given is reduced too to prevent overloading substrate in the reactor. The amount larvae reduce by changing larva density to 4 larvae/cm^2. On a pilot scale, the highest average larvae were obtained in the variations of 520 and 620 which are 0.250 and 0.235 gram WM/larva on 17 days old. The percentage of sludge in the substrate was better at 50 and 60 than 70.

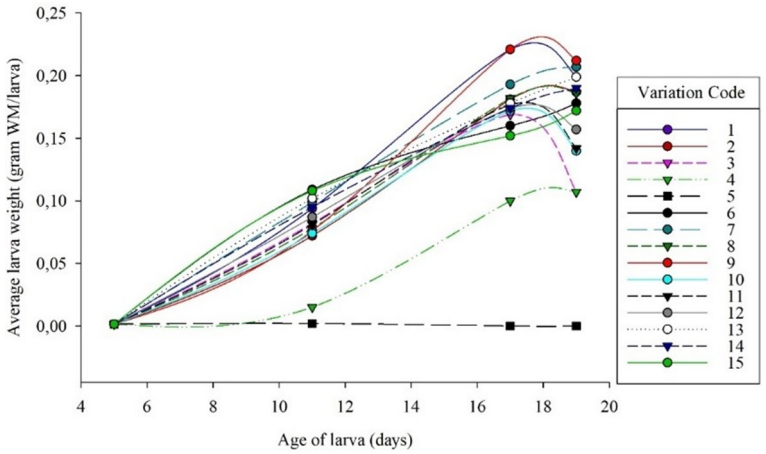

Fig. 2. Average larva weight laboratory scale 1

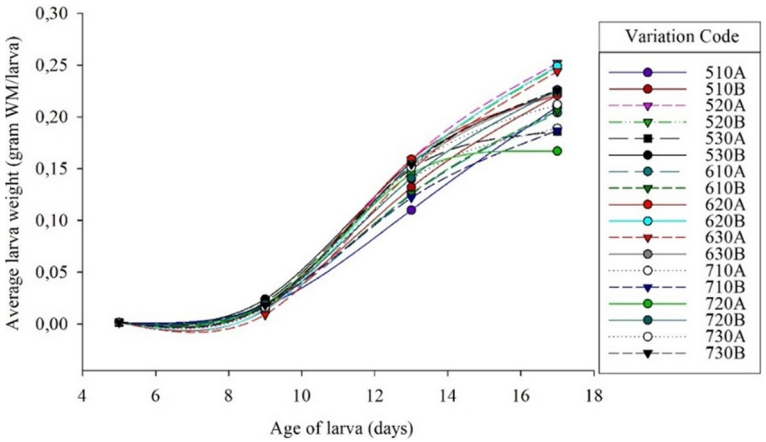

Fig. 3. Average larva weight pilot scale

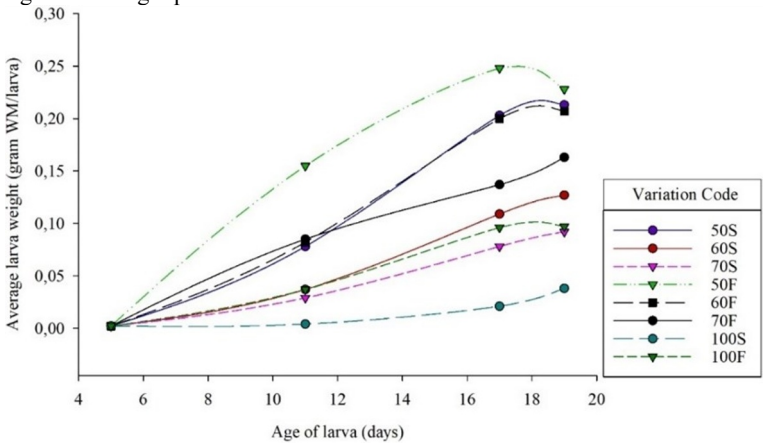

Fig. 4. Average larva weight laboratory scale 2

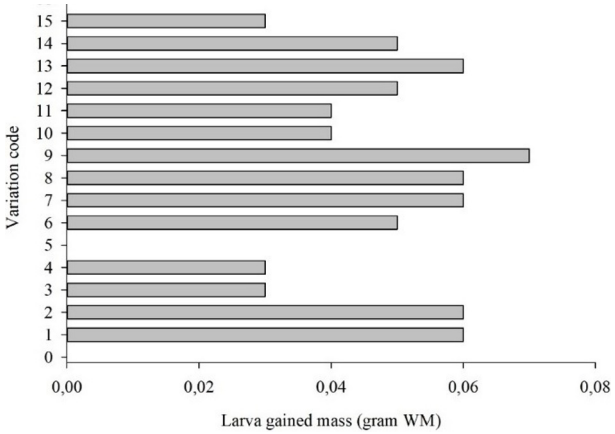

Fig. 5. Average larva gained mass laboratory scale 1

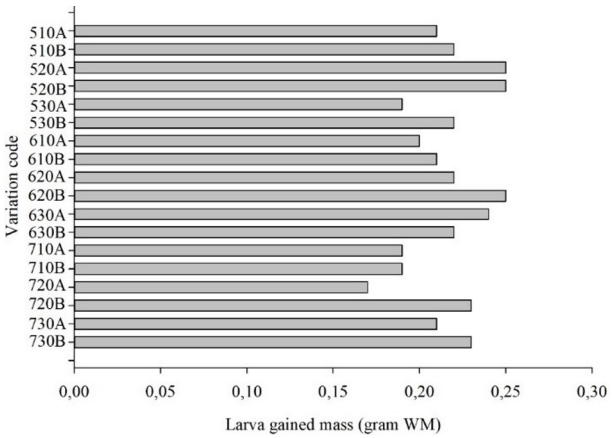

Fig. 6. Average larva gained mass pilot scale

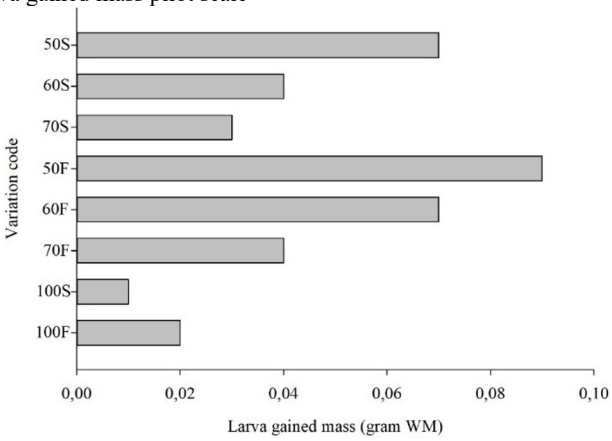

Fig. 7. Average larva gained mass laboratory scale 2

Larva performance can be seen in Tables 10, 11 and 12. The highest WRI and waste reduction on laboratory scale 1 are at 2.99%DM and 41.84%DM, namely in variation 7. The sludge composition of 40 to 60 percent has a waste reduction of between 22-42%. The bioconversion rate ranges from 0.03-0.08%DM. The highest WRI and waste reduction on laboratory scale 2 are at 4.17%DM and 58.43%DM, namely in variation 100F. However, in this variation, the larval growth rate and bioconversion rate are low. So that waste reduction is due to the activity of microorganisms in the sludge, considering that the sludge comes from biological process. The highest bioconversion rate is in the screw press sludge variation of 50% and filter press 60% worth 0.08%DM. On a pilot scale, highest waste reduction and WRI were obtained at a feeding rate of 10 mg DM/larva.day with a bioconversion rate of 0.02%DM even though the average larval mass was higher at a feeding rate of 20 mg DM/larva.day with difference 0.09-0.035 gram WM. Theoretically, the feeding rate influences the WRI; as the feeding rate increases, the WRI decreases.

Table 10. Larva performance laboratory scale 1

Code	WRI (%DM)	ECI (%DM)	Waste reduction (%DM)	Bioconversion rate (%DM)	Larva growth rate (mg/day)	Larva gained mass (gram DM)
1	2.26	0.21	31.64	0.07	14.08	0.06
2	1.72	0.26	24.02	0.06	13.25	0.06
3	1.63	0.16	22.87	0.04	7.54	0.03

Code	WRI (%DM)	ECI (%DM)	Waste reduction (%DM)	Bioconversion rate (%DM)	Larva growth rate (mg/day)	Larva gained mass (gram DM)
4	0.83	0.25	11.57	0.03	7.54	0.03
5	0.00	0.00	0.00	0.00	0.00	0.00
6	2.22	0.20	31.04	0.06	12.61	0.05
7	2.99	0.15	41.84	0.06	14.68	0.06
8	2.84	0.16	39.73	0.06	13.18	0.06
9	2.84	0.21	39.80	0.08	15.04	0.07
10	2.90	0.10	40.56	0.04	9.89	0.04
11	2.91	0.12	40.72	0.05	10.04	0.04
12	2.90	0.14	40.62	0.06	11.11	0.05
13	2.38	0.19	33.34	0.06	14.07	0.06
14	2.68	0.16	37.54	0.06	13.46	0.05
15	1.68	0.17	23.45	0.04	12.18	0.03

Table 11. Larva performance laboratory pilot scale

Code	WRI (%DM)	ECI (%DM)	Waste reduction (%DM)	Bioconversion rate (%DM)	Larva growth rate (mg/day)	Larva gained mass (DM gram)
510A	4.60	0.03	55.14	0.02	17.37	0.21
510B	4.72	0.03	56.68	0.02	18.32	0.22
520A	2.49	0.04	29.88	0.01	20.87	0.25
520B	2.27	0.04	27.20	0.01	20.58	0.25
530A	1.23	0.04	14.70	0.01	15.42	0.19
530B	1.02	0.05	12.20	0.01	18.52	0.22
610A	3.67	0.04	44.03	0.02	16.90	0.20
610B	3.67	0.04	44.07	0.02	17.05	0.21
620A	2.26	0.04	27.07	0.01	18.27	0.22
620B	2.26	0.04	27.17	0.01	20.63	0.25
630A	1.33	0.04	16.00	0.01	20.20	0.24
630B	1.10	0.05	13.25	0.01	18.57	0.22
710A	3.70	0.04	44.38	0.02	15.60	0.19
710B	3.84	0.04	46.13	0.02	15.48	0.19
720A	0.80	0.08	9.60	0.01	13.83	0.17
720B	1.16	0.07	13.90	0.01	18.72	0.23
730A	1.34	0.04	16.12	0.01	17.58	0.21
730B	1.05	0.05	12.56	0.01	18.68	0.23

Table 12. Larva performance laboratory scale 2

Code	WRI (%DM)	ECI (%DM)	Waste reduction (%DM)	Bioconversion rate (%DM)	Larva growth rate (mg/day)	Larva gained mass (DM gram)
50S	2.00	0.29	27.94	0.08	15.06	0.07
60S	1.12	0.26	15.64	0.04	8.93	0.04
70S	0.86	0.26	12.05	0.03	6.43	0.03
50F	2.47	0.28	34.54	0.10	16.16	0.09
60F	3.94	0.14	55.14	0.08	14.66	0.07
70F	3.79	0.09	53.13	0.05	11.49	0.04
100S	0.56	0.13	7.88	0.01	2.57	0.01
100F	4.17	0.04	58.43	0.02	6.78	0.02

A high carbohydrate-to-protein ratio also affects the C/N ratio in the substrate. The C/N ratio influences larval development and bioconversion efficiency. Nitrogen content significantly impacts larval weight, while high carbohydrate content can inhibit the development of larvae into prepupae [38, 39]. If the waste used as a substrate has a high C/N ratio, both waste reduction and larval production can be more efficient, although this depends on the type and composition of the waste. A high C/N ratio typically indicates a high carbon-to-nitrogen ratio, which can support larval growth under certain conditions.

4 Summary

From all the experiments it can be concluded that bioconversion of sludge from wastewater treatment plant of milk and creamer industry using BSFL is possible, but it needs additional co-substrate such as food waste. Sludge from creamer industry is better used as substrate than sludge of milk industry because its less inorganic content. A good composition for substrate is 40-60% sludge mixed with co-substrate of fruit-vegetables mixture and fish waste in a ratio of 1:1. The recommended feeding rate is 10-20 mg DM/larva.day.

5 Acknowledgement

The authors express their sincere appreciation for the collaborative Indonesia – NTU Singapore Institute of Research for Sustainability and Innovation (INSPIRASI) program. This research is funded by the Indonesian Endowment Fund for Education (LPDP) on behalf of the Indonesian Ministry of Education, Culture, Research and Technology and managed under the INSPIRASI program (Grant No. 6636/E3/KL.02.02/2023).

References

1. P. Roy, A. K. Mohanty, P. Dick, M. Misra, A review on the challenges and choices for food waste valorization: environmental and economic impacts. ACS Environ. Au. **3**, 58–75 (2023)

https://doi.org/10.1021/acsenvironau.2c00050

2. Y. W. Nugraha, Setiyono, Desain instalasi pengolahan air limbah industri PT Natura Perisa Aroma Lampung. JAI. **11**. (2020) https://doi.org/http://dx.doi.org/10.29122/jai.v11i2.3939
3. A. Mishra, S. Suthar. Bioconversion of fruit waste and sewage sludge mixtures by black soldier fly (Diptera: Stratiomyidae) larvae. Environmental Research. **218** (2023) https://doi.org/10.1016/j.envres.2022.115019
4. N. I. Handayani, Potensi limbah sludge lumpur aktif industri makanan minuman sebagai bahan baku pupuk organik dengan bantuan larva black soldier fly, in Nasional Sains dan Entrepreneurship VII conference, Semarang, Indonesia, August (2021)
5. S. Sulistia, Charlena, H. Ambarsari, Deodorisasi sludge limbah industri makanan untuk pakan maggot BSF (black soldier fly) dengan teknik biosorpsi. J. Teknologi Lingkungan, **22**, 222–230 (2021) https://doi.org/10.29122/jtl.v22i2.4837
6. C. S. Titi, Suprihatin, R. D. Lauda, Stabilisasi sludge dari instalasi pengolahan air limbah (IPAL) menggunakan starter bakteri indigenous pada aerobic sludge digester stabilization of sludge from wastewater treatment plant (WWTP) by using indigenous bacteria starter in aerobic sludge digester. E-Jurnal Agroindustri Indonesia. **3** (2014)
7. A. Admasu, W. Bogale, Y. S. Mekonnen, Experimental and simulation analysis of biogas production from beverage wastewater sludge for electricity generation. Scientific Reports. **12**, 9107 (2022) https://doi.org/10.1038/s41598-022-12811-3
8. K. Skic, Z. Sokołowska, P. Boguta, A. Skic, The effect of application of digestate and agro-food industry sludges on dystric cambisol porosity. PLoS ONE. **15** (2020) https://doi.org/10.1371/journal.pone.0238469
9. S. Arnone, M. De Mei, F. Petrazzuolo, S. Musmeci, L. Tonelli, A. Salvicchi, F. Defilippo, M. Curatolo, P. Bonilauri, Black soldier fly (Hermetia illucens L.) as a high-potential agent for bioconversion of municipal primary sewage sludge. Environmental Science and Pollution Research. **29**, 64886-64901 (2022) https://doi.org/10.1007/s11356-022-20250-w
10. B. Deng, J. Luo, C. Xu, X. Zhang, J. Li, Q. Yuan, H. Cao, Biotransformation of Pb and As from sewage sludge and food waste by black soldier fly larvae: Migration mechanism of bacterial community and metalloregulatory protein scales. Water Research. **254**, 121405 (2024) https://doi.org/10.1016/j.watres.2024.121405
11. R. Raksasat, K. Kiatkittipong, W. Kiatkittipong, C. Y. Wong, M. K. Lam, Y. C. Ho, W. D. Oh, I. W. K. Suryawan, J. W. Lim, Blended sewage sludge–palm kernel expeller to enhance the palatability of black soldier fly larvae for biodiesel production. Processes, **9**, 1–13 (2021) https://doi.org/10.3390/pr9020297
12. M. D. Alifian, M. M. Sholikin, D. Evvyernie, Nahrowi, Potential fatty acid composition of hermetia illucens oil reared on different substrates, in IOP Conference Series: Materials Science and Engineering (2019) https://doi.org/10.1088/1757-899X/546/6/062002

13. B. M. A. Dortmans, J. Egger, S. Diener, C. Zurbrügg, Black Soldier Fly Biowaste Processing-A Step-by-Step Guide, 2nd Edition (Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland, 2021)
14. N. A. Rohmanna, D. M. Maharani, Z. A. N. Majid, Analisis pertumbuhan dan kemampuan reduksi limbah larva tentara hitam (Hermetia illucens) pada solid decanter, ampas kelapa, ampas sagu, dan limbah sisa makanan. Agrointek : Jurnal Teknologi Industri Pertanian, **17**, 666–673 (2023) https://doi.org/10.21107/agrointek.v17i3.15598
15. A. D. Permana, A. Susanto, D. Fahri, R. Giffari, Kinerja pertumbuhan larva lalat tentara hitam hermetia illucens linnaeus (diptera: stratiomyidae) pada substrat kulit ari kedelai dan kulit pisang. Jurnal Agrikultura, **1**, 13–24 (2022) https://doi.org/http://dx.doi.org/10.24198/agrikultura.v33i1.36188
16. N. Zahro, N. Eurika, A. N. Prafitasari, Konsumsi pakan dan indeks pengurangan sampah buah dan sayur menggunakan larva black soldier fly. Bioma : Jurnal Biologi dan Pembelajaran Biologi, **6**, 88–101 (2021) https://doi.org/10.32528/bioma.v6i1.5034
17. B. I. Norra, T. P. Hendrika, A. A. Rohmah, I. Nabinya, identifikasi pemahaman umum ayam (gallus gallus) dan ikan mujair (oreochromis mossambicus) pada mahasiswa UIN Walisongo Semarang. Bio-Lectura, **8**, 29–36 (2021) https://doi.org/10.31849/bl.v8i1.5763
18. S. Y. Chia, C. M. Tanga, F. M. Khamis, S. A. Mohamed, D. Salifu, S. Sevgan, K. K. M. Fiaboe, S. Niassy, J. J. A. van Loon, M. Dicke, S. Ekesi, Threshold temperatures and thermal requirements of black soldier fly hermetia illucens: implications for mass production. PLOS ONE, **13**, e0206097 (2018) https://doi.org/10.1371/journal.pone.0206097
19. S. Y. Chia, C. M. Tanga, I. M. Osuga, S. A. Mohamed, F. M. Khamis, D. Salifu, S. Sevgan, K. K. M. Fiaboe, S. Niassy, J. J. A. van Loon, M. Dicke, S. Ekesi, Effects of waste stream combinations from brewing industry on performance of black soldier fly, hermetia illucens (diptera: stratiomyidae). PeerJ, **2018** (2018) https://doi.org/10.7717/peerj.5885
20. M.Gold, C. M. Cassar, C. Zurbrügg, M. Kreuzer, S. Boulos, S. Diener, A. Mathys, Biowaste treatment with black soldier fly larvae: increasing performance through the formulation of biowastes based on protein and carbohydrates. Waste Management, **102**, 319–329 (2020) https://doi.org/10.1016/j.wasman.2019.10.036
21. T. Liu, S. K. Awasthi, S. Qin, H. Liu, M. K. Awasthi, Y. Zhou, M. Jiao, A. Pandey, S. Varjani, Z. Zhang, Conversion food waste and sawdust into compost employing black soldier fly larvae (diptera: stratiomyidae) under the optimized condition. Chemosphere, **272** (2021) https://doi.org/10.1016/j.chemosphere.2021.129931
22. J. Ma, Y. Lei, K. U. Rehman, Z. Yu, J. Zhang, W. Li, Q. Li, J. K. Tomberlin, L. Zheng, Dynamic effects of initial pH of substrate on biological growth and metamorphosis of black soldier fly (diptera: stratiomyidae). Environmental Entomology, **47**, 159–165 (2018) https://doi.org/10.1093/ee/nvx186

23. D. Purkayastha, S. Sarkar, Performance evaluation of black soldier fly larvae fed on human faeces, food waste and their mixture. J. of Environmental Management, **326** (2023)
https://doi.org/10.1016/j.jenvman.2022.116727
24. R. Raksasat, K. Kiatkittipong, W. Kiatkittipong, C. Y. Wong, M. K. Lam, Y. C. Ho, W. D. Oh, I. W. K. Suryawan, J. W. Lim, Blended sewage sludge–palm kernel expeller to enhance the palatability of black soldier fly larvae for biodiesel production. Processes, **9**, 1–13 (2021)
https://doi.org/10.3390/pr9020297
25. A. Singh, K. Kumari, An inclusive approach for organic waste treatment and valorisation using black soldier fly larvae: a review. J. of environmental management, **251** (2019)
https://doi.org/10.1016/j.jenvman.2019.109569
26. A. Caligiani, A. Marseglia, G. Leni, S. Baldassarre, L. Maistrello, A. Dossena, S. Sforza. Composition of black soldier fly prepupae and systematic approaches for extraction and fractionation of proteins, lipids and chitin. Food Research International, **105**, 812–820 (2018)
https://doi.org/10.1016/j.foodres.2017.12.012
27. Kementrian Kesehatan Republik Indonesia. Tabel komposisi tabel komposisi pangan indonesia pangan Indonesia. (2020)
28. S. A. Humaid, M. T. Jamal, The effect of storage temperature (4°c, 15°c and 25°c) on the shelf life of whole marine fish (rastrelliger kanagurta). IOSR J. of Environmental Science, Toxicology and Food Technology, **8**, 46–51 (2014)
https://doi.org/10.9790/2402-081114651
29. J. H. Y. Galani, J. S. Patel, N. J. Patel, J. G. Talati, Storage of fruits and vegetables in refrigerator increases their phenolic acids but decreases the total phenolics, anthocyanins and vitamin c with subsequent loss of their antioxidant capacity. Antioxidants, **6**, (2017)
https://doi.org/10.3390/antiox6030059
30. C. Lalander, E. Ermolaev, V. Wiklicky, B. Vinnerås, Process efficiency and ventilation requirement in black soldier fly larvae composting of substrates with high water content. Science of the Total Environment, **729** (2020)
https://doi.org/10.1016/j.scitotenv.2020.138968
31. E. S. Saragi, A. Y. Bagastyo, Reduction of organic solid waste by black soldier fly larvae, in The 5th Environmental Technology and Management Conference, Surabaya, Indonesia (2015)
https://doi.org/https://dx.doi.org/10.1088/1755-1315/506/1/012005
32. A. S. Parra Paz, N. S. Carrejo, C. H. G. Rodríguez, effects of larval density and feeding rates on the bioconversion of vegetable waste using black soldier fly larvae hermetia illucens (l.), (diptera: stratiomyidae). Waste and Biomass Valorization, **6**, 1059–1065 (2015)
https://doi.org/10.1007/s12649-015-9418-8
33. T. Veldkamp, K. van Rozen, H. Elissen, P. van Wikselaar, R. van der Weide, Bioconversion of digestate, pig manure and vegetal residue-based waste operated by black soldier fly larvae, hermetia illucens l. (diptera: Stratiomyidae). Animals, **11** (2021)
https://doi.org/10.3390/ani11113082

34. G. K. Harris, M. R. Marshall, Ash Analysis. (2017). https://doi.org/10.1007/978-3-319-45776-5_16
35. T. Spranghers, M. Ottoboni, C. Klootwijk, A. Ovyn, S. Deboosere, B. D. Meulenaer, J. Michiels, M. Eeckhout, P. D. Clercq, S. D. Smet, Nutritional composition of black soldier fly (hermetia illucens) prepupae reared on different organic waste substrates. J. of the Science of Food and Agriculture, **97**, 2594–2600 (2017) https://doi.org/10.1002/jsfa.8081
36. M. Gold, J. K. Tomberlin, S. Diener, C. Zurbrügg, A. Mathys, Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Management, **82**, 302–318 (2018) https://doi.org/10.1016/j.wasman.2018.10.022
37. N. T. Eriksen, Metabolic performance and feed efficiency of black soldier fly larvae. Frontiers in Bioengineering and Biotechnology, **12** (2024). https://doi.org/10.3389/fbioe.2024.1397108
38. Y. Lu, S. Zhang, S. Sun, M. Wu, Y. Bao, H. Tong, M. Ren, N. Jin, J. Xu, H. Zhou, W. Xu, Effects of different nitrogen sources and ratios to carbon on larval development and bioconversion efficiency in food waste treatment by black soldier fly larvae (Hermetia illucens). Insects, **12** (2021) https://doi.org/10.3390/insects12060507
39. M. Y. Abduh, M.P. Perdana, M. A. Bara, L. W. Anggraeni, R. E. Putra, Effects of aeration rate and feed on growth, productivity and nutrient composition of black soldier fly (Hermetia illucens L.) larvae. J. Asia. Pac. Entomol, **25** (2022) https://doi.org/10.1016/j.aspen.2022.101902