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Original Research Article

Technical Feasibility Analysis of Processing Food Waste into Organic Fertilizer with Black Soldier Fly Composting Method

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Abstract
Food waste is a major issue in Indonesia, accounting for 41.97% of waste generated. This untreated waste can lead to the production of greenhouse gases. However, food waste has the potential to be composted due to its high nutrient content. The purpose of this study was to analyze the technical feasibility of processing food waste using the Black Soldier Fly (BSF) composting method for organic fertilizer production. The study used variations of fish waste and reject milk as composting mixtures, with percentages of 100% food waste, 70% food waste and 30% cow manure, and 30% food waste and 70% fish waste. The dimensions of the BSF composting reactor were 56 cm x 43 cm x 20 cm. The research was conducted for 15 days with the addition of local microorganisms (MoL) to accelerate the degradation process. Various parameters such as pH, moisture content, C-Organic, nitrogen, phosphorus, and potassium were analyzed. The results showed that all variations met the required compost quality standards, it which was technically feasible to be used as organic fertilizer using the BSF composting method. The results of this study can improve the circular economy because compost and bsf larvae products have many benefits if traded.

Keywords: Food Waste; BSF composting; organic fertilizer; technical feasibility analysis; MoL

1. Introduction

Organic waste management is a significant challenge in Indonesia, with serious implications for the environment and public health. Based on data from the National Waste Management Information System (2022), food waste (FW) dominates 41.97% of the total waste generated, equivalent to 6,849,232.45 tonnes per year. This phenomenon indicates the urgency of developing effective and sustainable waste management strategies.

FW that is not optimally managed has the potential to undergo anaerobic fermentation, producing greenhouse gases that contribute to climate change (Puger, 2018). One potential mitigation approach is the conversion of FW into compost, which not only reduces waste volume but also produces agronomically valuable products (Ramadhan, 2020). Compositional analysis of FW showed significant nutrient content: C-Organic 56.00%, nitrogen 1.50%, C/N ratio 37.33%, and moisture content 58.90% (Harahap, 2020), making it an ideal substrate for the composting process. Besides FW, fish industry waste (FIW) and cow manure (CM) also offer potential as compost feedstock. FIW, a by-product of the fishing industry, has a C-Organic composition of 15.49%, nitrogen of 2.46%, C/N ratio of 5.87%, and moisture content of 71.79% (Raafiandy, 2016; Rahmadani, 2022). Meanwhile, CM, which often accumulates without adequate handling, contains 9.4% organic C, 0.14% nitrogen, a C/N ratio of 62.1%, and a moisture content of 76% (Arthawidya, 2017).

Innovations in optimising the composting process involve the incorporation of additives such as waste milk and local microorganisms (MOL). Retired milk, with a protein content of 25.8%, fat 0.9%, and lactose 4.6% per 100 grams, has the potential to improve the nutritional quality of compost (Handayani et al., 2019). MOL from vegetables has been proven effective in increasing the nitrogen content of compost up to 1.37%, significantly higher than the use of Effective Microorganism 4 (EM4) which only reaches 0.86% (Suwatanti & Widiyaningrum, 2017).

The bioconversion approach using Black Soldier Fly (BSF) larvae offers a new perspective in organic waste management. BSF larvae, with protein content reaching 47.56% (Wahyuni et al., 2021), not only accelerate the degradation process of organic waste but also have the potential as an alternative protein source for animal feed. The implementation of BSF in composting systems creates synergy between waste management and feed production, supporting the concept of circular economy (Mulyani et al., 2021).

This research aims to optimise the compost formulation based on FW, FIW, and CM with supplementation of waste milk, vegetable MOL, and BSF larvae application. The hypothesis of this research is that the combination of FW, FIW, and CM with supplementation of aged milk and vegetable MOL, as well as the application of BSF larvae, will produce compost with an optimal C/N ratio (15-20), nitrogen content >2%, and moisture content 40-60%, and produce BSF larvae biomass with protein content >45% which has the potential as high-quality animal feed. In the context of the global environmental crisis and the urgency of food security, this research offers an integrative approach to organic waste management that has the potential to transform the waste management paradigm from an environmental burden to a valuable resource within the framework of a sustainable circular economy.

2. Methods

This research has been carried out at the Surabaya State Shipbuilding Polytechnic Compost House and testing the initial and final characteristics at the Baristand Laboratory (Industrial Research and Standardization Center). Waste decomposers in the composting process in this study are 5-day-old BSF larvae or 5-DOL because this larvae These larvae include the larval phase where the larvae can grow by eating waste to become compost (Dortmans et al.,2017). The material variations used in this study were 100% food waste (FW 100%), 70% food waste and 30% cow manure (FW 70% + CM 30%), and 30% food waste and 70% fish waste (FW30% + FIW 70%). The table 1 showed the C/N of CW and FIW were to low and too high. In another hand, C/N of FW was fulfil the SNI 19-7030-2004 standards in the composting process. Therefore, this research use those as compost material to fulfil C/N of compost.

Table 1. Initial characteristics of compost materials

Material Composition	C- Organic (%)	N-Total (%)	C/N ratio	Moisture Content (%)
Food waste (FW)	3.07	0.29	10.58	41.48
Fish Waste (FIW)	10.87	2.77	3.92	75.84
Cow Manure (CM)	44.18	2.25	19.63	8.78

Using reject milk with a dose variation of 0 ml and 200 ml and local microorganisms (MoL) to increased the decomposition process. The microorganisms used were vegetable MoL with a dose variation of 0 ml MoL and 30 ml vegetable MoL. The vegetable MoL can be increased composting process (Suwatanti, E., & Widiyaningrum, P. 2017). The types of variations used in this study can be seen in Table 2.

Table 2. Variation of waste composition

Variation of materials	Variation of Milk Reject Addition	Vegetable MoL Variation	
		0 ml	**30 ml**
FW 100%	0 ml	R1	R2
	200 ml	R3	R4
FW 70% + CM 30%	0 ml	R5	R6
	200 ml	R7	R8
FW 30% + FIW 70%	0 ml	R9	R10
	200 ml	R11	R12

R: reactor

The reactor used as a composting process tool in this study is made of wood with a size of 56 cm x 43 cm x 20 cm as many as 12 reactors according to the specified variation. To get this composter dimention, calculate the density and volume of compost material. So, Capacity of composter to compost 10 Kg of compost material. The composting reactor is equipped with a mesh lid to facilitate air circulation and the composting process is not disturbed by insects that may enter the reactor. In addition to the lid, this reactor is equipped with a hose as a larval migration path and a stacking rack to place the reactor so that the composting reactor is neatly organized (Ramadhany et al., 2023). The design of the composting reactor can be seen in Figure 1.

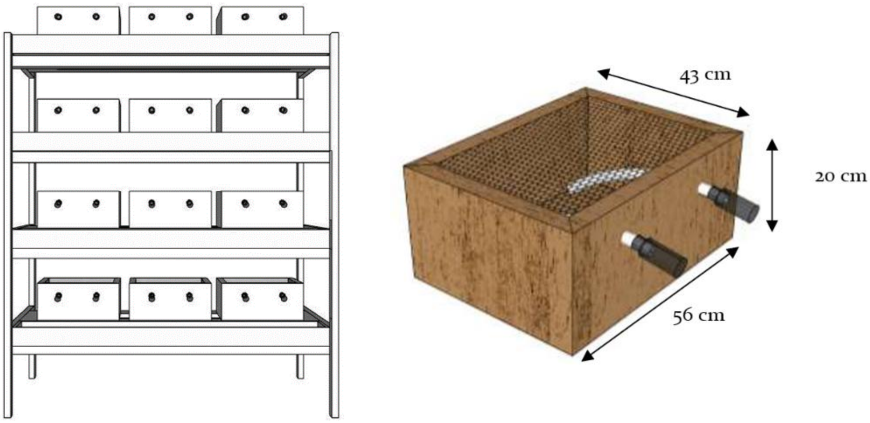

Figure 1. Composting reactor

Tabel 2. Analysis of BSF Composter

Standard of Composter Component	Function	Analysis in the research
Gaza[a]	Air circulation	√
Hose[b]	Larvae migration	√
Pile of compost material ≤ 5m [c]	Aerobic Condition	√

√ : fulfil
a and b : Ramadhany et al.,2023
c : Dortmans et al.,2017

The procedures in this study include preparation of composting reactors, preparation of 5-DOL BSF larvae as decomposers, preparation of materials, making MoL, and testing the initial characteristics of compost materials. The composting process in this study was 15 days by measuring physical and chemical parameters including pH, moisture content, C-Organic, Nitrogen (N), Phosphor (P_2O_5), and Potassium (K_2O). The composting process during 15 days because the larvae phase to decompose compost material (Dortmans et al.,2017). The manufacture of vegetable waste MoL is done by fermentation method and can be done as follows (Suwatanti and Widiyaningrum, 2017) were cutting 500 grams of vegetable waste into small pieces. And then, vegetable waste pieces are put into a bottle containing 1 liter of water in a 1.5 liter bottle. After that, adding 45 grams of salt and Let stand for 2 weeks, every 2 days the bottle is shaken so that no sediment occurs. Finally, the MoL solution was filtered and added 1 ounce of sugar and diluted until the volume reached 5 liters.

Compost chemical parameters including C-Organic, Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O) were tested at the Baristand laboratory, while observations of BSF larval characteristics were made every 3 days. It because the best feeding rate was every 3 day. The parameter measurement methods used in this study can be seen in Table 3.

Table 3. Measurement method and frequency

Parameters	Measurement method	Measurement frequency	SNI methods
pH	Soil Analyzer Tester	Everyday	SNI 6989.11-2019
Moisture Content	Gravimetric	Once every 3 days	SNI 19-3964-1994
C-Organic	Gravimetric	At the end of composting	SNI 13-4720-1998
Nitrogen	Kjeldahl	At the end of composting	SNI 13-4721-1998
Phosphor (P_2O_5)	Spectrofotometry	At the end of composting	SNI 6989.31.2021
Potassium (K_2O)	Atomic Absorption Spectrofotometry (AAS)	At the end of composting	SNI 6989.69.2009

3. Result and Discussion

3.1 pH

The increase in compost pH until the end of the composting period is due to the activity of methanogens that convert organic acids into other compounds such as methane, ammonia and carbon dioxide. Mature compost generally has a pH between 6 and 8 (Tan et al., 2023). The optimum degradation process by BSF larvae is at a pH value of 5.0-8.0 (Mahardika, 2016). The decrease in pH at the beginning of composting is characterized by an increase in compost temperature. The pH of the compost will then increase slightly alkaline after a few days. This is caused by the activity of microorganisms in decomposing organic acids into final products (Anam and Regar, 2022). In the variation of adding MoL and reject milk, the pH value tends to be lower. This condition is supported by the statement of Rohim et al. (2015), that the low pH is due to the decay of organic acids and ammonia derived from the degradation process in organic matter. In Figure 2, the pH value tends to drop on day 6 and starts to rise on day 7 until the average pH value of day 15.

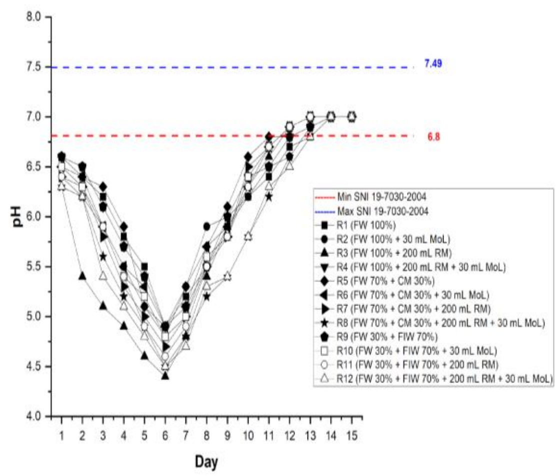

Figure 2. pH during the BSF composting

In Figure 2, it can be seen that during the first day of composting until day 6, it decreased in each reactor. The decrease is due to a certain number of microorganisms in organic waste materials into organic acids (Muhammad & Zaman 2017). The general decrease in pH can be attributed to the possible formation of organic acids after the onset of local and temporary anaerobic conditions that cause hydrolysis of polymeric substrates into amino acids (Rawoteea et al., 2016). After that, the increase in pH started on day 7 until day 15. The increase in pH occurs because the composting process will produce ammonia and nitrogen gas so that the pH value changes to alkaline due to increased bacterial activity (Dewilda & Darfyolanda, 2017). The conclusion is that the pH values of all reactors on day 15 have met the SNI 19-7030-2004 standards in the composting process. According to SNI 19-7030-2004 that the pH of mature compost is usually close to neutral, the minimum compost pH of 6.8 and a maximum of 7.49, meaning that the pH of the compost in the study can already be said to be neutral.

3.2 Moisture Content

Moisture content is a physical parameter of compost that is controlled daily during composting. Moisture content plays an important role in the degradation process of organic matter and the life of BSF larvae so that they can survive well. The moisture content contained in the compost media must be sufficiently moist with a level of 60 - 90% so that food can be digested by BSF larvae so that success increases (Yuwono & Mentari, 2018). The moisture content during composting tends to decrease until the last day. The decrease in moisture content can be caused by energy generated due to the activity of BSF larvae and microorganisms and experiencing heat so that in compost there is evaporation which causes a decrease in moisture content (Harahap, 2020). Monitoring of water content can be seen in Figure 3.

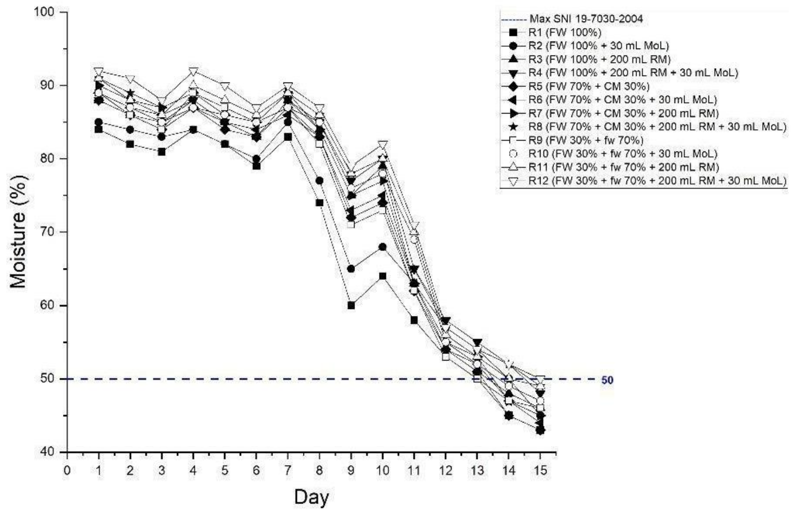

Figure 3. Moisture content of compost

Figure 3 shows that the moisture content in R1, R5, R9 on day 7 to day 15 decreased to <50% because there was no addition of MoL and reject milk so that the decomposition process and moisture content gradually accelerated. This is in contrast to the water content in R4, R8, R12 which is the slowest to decline because there is the addition of 30 ml MoL and 200 ml reject milk with a final percentage slightly below 50%.

3.3 C-Organic

C-organic is one of the important elements that play a role in the composting process. Microorganisms need carbon as a source of energy and growth during the composting process (Saragi, 2015). Energy sources are needed to compose the cellular material of microbial cells by liberating CO_2 and other materials that evaporate (Amnah & Friska, 2019). C-organic tends to decrease after composting. The results of C-organic measurements can be seen in Figure 4.

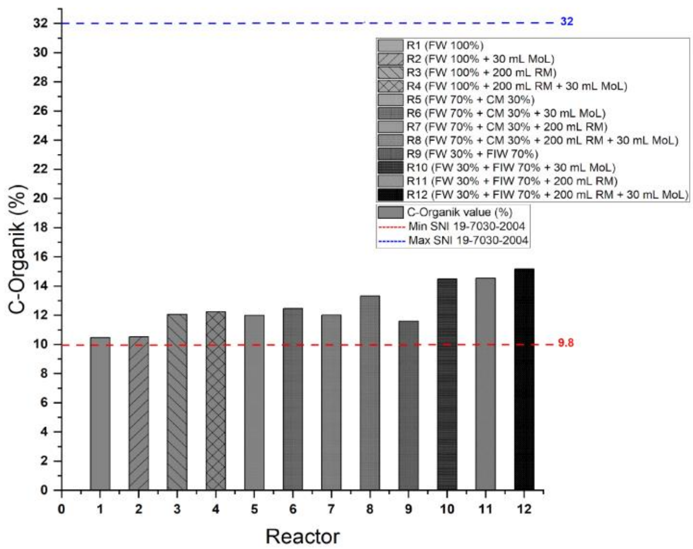

Figure 4. Carbon of compost

The lowest C-organic content was found in Reactor 2 with 100% FW material variation and the addition of 30 mL vegetable mole, which was 10.53%. The low C-organic content in the compost results can be influenced by the initial C-organic content of the materials used. Good compost according to SNI 19-7030-2014 has a minimum carbon content of 9.8% and a maximum of 32%. Based on Figure 4, all reactors have met the compost quality standards (SNI 19-7030-2014). Figure 4 shows that the highest carbon value is found in Reactor 12 with a material variation of 70% FIW and 30% FW and the addition of 200 mL of reject milk and 30 mL of vegetable mole with a C-organic value of 15.165%. The addition of reject milk can affect the high carbon content because reject milk can accelerate the decay process. Decay occurs faster due to the organic content in reject milk which is susceptible to bacteria so that it is easily decomposed (Andrianieny, 2015). Base on study of Priyanti et al., 2023, The more organic matter that decomposes causes high levels of C-organic in compost.

3.4 N-Total

N-total is a source of energy for soil microorganisms in the process of decomposing organic matter (Hajama, 2014). N-total levels are needed by microorganisms to maintain and form body cells (Widarti et al., 2015). The more nitrogen content, the faster organic matter will decompose (Srihati, 2018). The measurement results of nitrogen content can be seen in Figure 5.

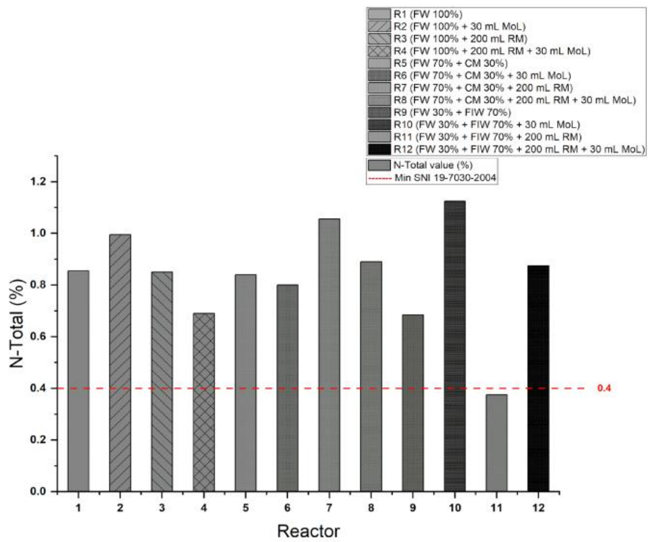

Figure 5. N-Total of compost

Good compost according to SNI 19-7030-2014 has a minimum N-total content of 0.4%. Figure 5 shows that the highest N-total content is in Reactor 10 with a value of 1.125%. High N-total levels will cause the compost to have good quality as a planting medium. The various benefits of nitrogen for plants are to increase plant growth, increase protein levels in plants, and increase the development of microorganisms in the soil (Arisanti, 2021). The lowest N-total content was found in R4 with a value of 0.59%. The low level of N-total in compost can be caused by activators that have stopped working so that the remaining organic matter cannot be broken down by bacteria. Gani et al., 2021 showed that the cessation of the overhaul process can be caused by the low concentration of activators so that it can slow down the growth of bacteria.

3.5 C/N Ratio

The principle of the composting process is to reduce the C/N ratio of organic materials to approach the soil C/N ratio. The C/N ratio value of compost based on SNI 19-7030-2004 is 10-20. In the composting process, compost materials that have a high C/N ratio must be mixed with compost materials that have a low C/N ratio (Ristiawan et al., 2013). During composting, organic carbon is consumed by microorganisms as a source of energy by liberating CO_2 and H_2O for aerobic processes so that the carbon concentration continues to decrease. On the other hand, nitrogen levels increase because the process of breaking down organic matter carried out by microorganisms produces ammonia and nitrogen (Sujiwo et al., 2013).

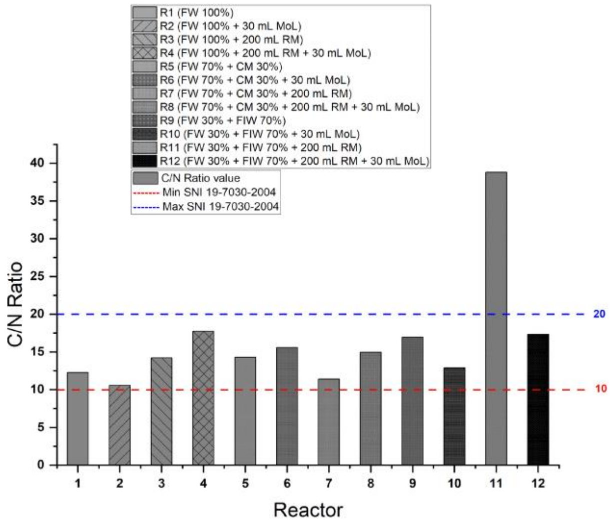

Figure 6. C/N Ratio of Compost

Based on Figure 6, the C/N ratio values for all reactors are in accordance with compost quality standards. The highest C/N ratio value was found in Reactor 4 with 100% FW treatment, 200 mL reject milk, and 30 mL vegetable mole with a value of 17.75. The high C/N ratio is due to the high C-organic content which is not balanced by the low nitrogen content (Gani et al., 2021). The lowest C/N ratio value was found in Reactor 2 with 100% FW treatment and 30 mL of vegetable mole with a value of 10.58. The low C/N ratio value is caused by the amount of carbon that decreases because it is used by microbes as an energy source to decompose organic matter. Ardiyansyah et al., 2023 described that during the composting process, CO2 evaporates so that carbon levels decrease and nitrogen increases, causing the C/N ratio value to decrease.

3.6 Phosphor (P_2O_5)

One of the parameters in composting is the measurement of phosphorus (P2O5) content. The value of phosphorus (P2O5) in the laboratory test results states that the value of phosphorus (P2O5) in each treatment has met the requirements of mature compost based on SNI 19-7030-2014. The following graph of laboratory test results can be seen in Figure 7.

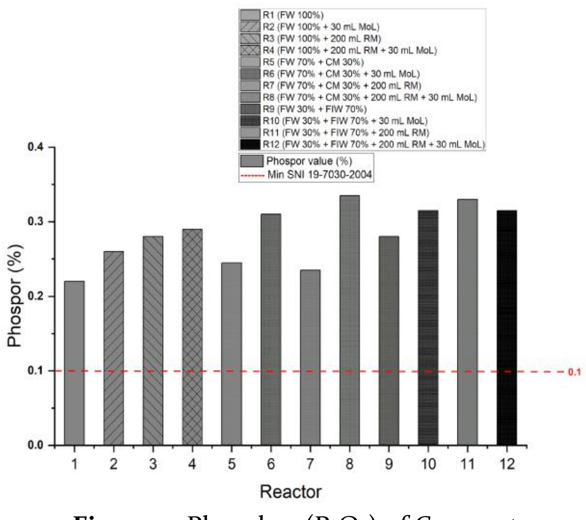

Figure 7. Phosphor (P_2O_5) of Compost

High levels of phosphorus (P_2O_5) can affect plant growth. The element phosphorus (P_2O_5) has a role in soil fertility where nutrient intake from organic matter is very helpful to increase soil nutrient levels in achieving optimal fertility intensity (Aprilia, 2021). Phosphorus (P_2O_5) levels in fish waste compost, cow manure, reject milk and the addition of vegetable MoL biostarter have a higher value than the SNI 19-7030 2004 compost quality standard, which is >0.10%. This is because the weathering process that occurs in compost material causes high levels of phosphorus (P_2O_5) (Kaswinarni and Nugraha, 2020). At the compost maturation stage, the microbes will die and the levels of phosphorus (P_2O_5) in the microbes will be mixed with the compost material, thus directly increasing the levels of phosphorus (P_2O_5) in the compost. From the results of this study, it is also known that compost (R8) produces the highest levels of phosphorus (P_2O_5). Based on (Supadma and Arthagama, 2008), this is because CM generally contains food scraps and bone meal that will cause the level of phosphorus (P_2O_5) in compost to increase.

High levels of phosphorus (P_2O_5) can also be associated with nitrogen levels contained in compost. As the results of research conducted by Kaswinarni (2016) with the same treatment, the total N content in compost with the addition of chicken manure starter is quite high (1.31%). With the higher total N content, the number of microbes will also increase, so that with the number of microbes, the overhauled phosphorus (P_2O_5) also increases, and this is one of the causes of high phosphorus (P_2O_5) levels in compost (Marlina et al, 2010 ; Rahmadhani, 2022). Based on Figure 7, the highest phosphorus (P_2O_5) value is found in R12 with compost materials in the form of fish waste and food waste and also the addition of MoL Vegetable and reject milk. The addition of reject milk can increase the value of phosphorus (P_2O_5) as evidenced by R4, R8, and R12 with percentage values of 0.29%, 0.335%, and 0.375%. The addition of 30 ml MoL and 200 ml reject milk affects the increase in phosphorus (P_2O_5).

3.7 Potassium (K_2O)

Potassium element is one of the macro nutrients in compost that shows the quality of compost. The value of potassium test results can be seen in Figure 8.

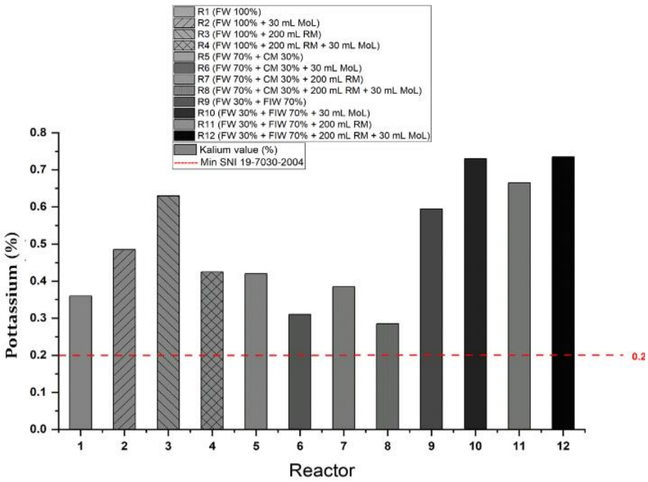

Figure 8. Potassium (K2O) of compost

Figure 8 shows that the content of Potassium (K_2O) in all treatments has a higher value than the quality standard of SNI 19-7030 compost in 2004, which is >0.20%.Potassium (K_2O) in compost comes from the basic material of compost in the form of food or vegetable waste in which the element of Potassium (K_2O) already exists, but the element of potassium (K_2O) is still in the form of complex organic matter so that it is not available to plants (Kaswinarni and Nugraha, 2020). Microbes in the starter use K for their activities and the process of decomposition of complex organic matter into simpler organic matter during composting will make K elements available to plants (Wirosoedarmo et al., 2019). Based on research by Hidayati (2013), Potassium (K_2O) is used by microorganisms in the substrate material as a catalyst, with the presence of bacteria and their activities greatly affecting the increase in potassium content. The availability of potassium elements in plants can reduce the disturbance of pests, diseases and drought and produce quality agricultural products. In the study of Subandi, 2013, potassium as an essential nutrient is needed in large quantities by plants, for rice and cassava plants the need for potassium (K) is more than the need for nitrogen (N), although it requires a large amount of potassium element is an ion that mostly exists in cell fluids.

According to Hidayati (2013), potassium (K_2O) is used by microorganisms in the substrate material as a catalyst, with the presence of bacteria and their activities greatly affecting the increase in potassium content. The measurement results of potassium (K_2O) content in each treatment did not have much difference. Based on Figure 4.12, the highest potassium value is found in R10 and R12, with 70% FIW and 30% FW compost materials. This is in line with the statement of Ekawandani et al. (2018), the higher the potassium content in compost, the better for plant growth. While the lowest value was found in R8 at 0.285%. Although there is the lowest value, the potassium value in all reactors has met the SNI 19-7030-2014 standard. The result of study of Cesaria et al., 2014 showed that Potassium in compost comes from the basic material of compost in the form of forage vegetables in which there is already K element, but the K element is still in the form of complex organic matter so that it is not available to plants.

Basically, organic materials already contain potassium, but the potassium is still in a complex organic form so it cannot be absorbed directly by plants (Seyawati et al., 2021). Base on Ekawandani et al., 2018, with the decomposition process, the complex organic matter will break down into simpler organic matter to produce potassium elements that can be absorbed by plants. For plants, potassium has an important role in the photosynthesis process in the formation of protein and cellulose which serves to strengthen plant stems. The higher the potassium content in compost, the better for plant stem growth.

4. Conclusions

The conclusion of this research shows that the results of the analysis of pH, moisture content, C-organic, phosphorus (P_2O_5), potassium (K_2O), N-Total and C/N ratio from the processing of food waste have met the compost quality standards (SNI 19-7030-2004) which means that compost from food waste is technically feasible to be used as organic fertilizer. The best composition of variation was R1 -R10. In contain 100% FW and 70% : 30% CM. Further research is recommended to analyze food waste composting with different types of animal manure. This is because the content of animal manure has the potential to affect the quality of compost.

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