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Optimization of Local Microorganism (MOL) from Market Waste as a Bioactivator for Composting Fruit and Vegetable Residue

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ABSTRACT

Untreated organic waste can negatively impact public health and the environment. In traditional markets, accumulated organic waste leads to pollution, increased disease risk, and reduced market aesthetics. Composting offers a practical solution by converting solid organic waste into beneficial products using local microorganisms (MOL) as bioactivators. This study aims to determine the optimal MOL concentration and composting duration for various types of market waste, and to evaluate pH changes and methane production during composting. The MOL was prepared from 5000 g of cabbage waste, 25 g of salt, 250 g of brown sugar, and 5 L of rice washing water. Research variables included waste type and compost-to-MOL ratios. The compost mixture was placed in 5 L sealed jars connected to water-filled bottles and allowed to decompose anaerobically for 30 days. pH measurements were taken every 3 days, gas production was monitored, and N, P, and K levels were analyzed on days 20, 25, and 30. Results indicate that cabbage-based MOL effectively functions as a composting bioactivator. Compost meeting SNI standards for NPK content was produced from fruit peel waste at a fruit peel-to-MOL ratio of 5:1.5 with a 30-day composting period. The pH profile showed a trend toward neutrality throughout the process. Methane detection revealed that controlled anaerobic aeration plays an essential role in improving composting efficiency while potentially reducing greenhouse gas emissions.

1. Introduction

The growth of the world's population has driven increased food demand, leading to greater food waste. It is estimated that around 1.3 billion tons of waste are generated per year [1]. Food waste is one of the most significant sources of waste. EPA (United States Environmental Protection Agency) estimates that approximately 24% of municipal solid waste is food waste [2]. Fruit waste (FWs) accounts for 57 million tons of global waste each year and contributes to environmental pollution and health issues [3]. The processing of fruits and vegetables produces significant amounts of waste, most of which consists of fruit and vegetable peels (~90–92%). These wastes are usually very rich in bioactive molecules [4]. Food waste is generally considered green waste. Green waste consists of naturally biodegradable materials from gardens and kitchens that can be used as raw materials for the production of biofuels such as bioethanol, biobutanol, pellets, and even biochar [5].

One method of processing solid organic waste that can add value and improve environmental sanitation is composting [6]. Composting is a reliable and economical technology for organic waste treatment compared to other methods such as incineration and landfill disposal [7]. Composting is the partial breakdown of organic materials, which various microbial populations can artificially accelerate under warm, moist conditions, whether anaerobic or aerobic. Stirring and adding microorganisms will improve product quality and shorten composting time [8], [9]. Composting improves the physical, chemical, and biological properties of soil, thereby increasing crop productivity [10]. During the composting process, pathogens are destroyed, and nutrients are recycled to provide the soil with the nutrients it needs [11], [12].

Local microorganisms (MOL) are a collection of microorganisms derived from natural materials that accelerate the decomposition of organic matter, thereby converting it into compost/organic fertilizer [13]. Local organic waste can serve as a food source for microbes, enabling them to grow well and maximizing composting results. This study aims to determine the optimal MOL concentration and the optimal time for MOL growth during composting of organic waste. Microorganisms decompose organic matter in compost (OM) into small molecules and polymerize them into humus [14].

The organic waste materials used are vegetable waste, fruit peel waste, and dry leaf waste. It is challenging to convert vegetable waste with a water content of 80–90% into a safe, environmentally friendly product [15]. The fruit, skin, and seeds of avocados contain secondary metabolites such as flavonoids and tannins [16]. Mango peel, which was initially considered waste material, has been found to contain bioactive compounds, including mangiferin, flavonoids, phenolic acids, carotenoids, dietary fiber, and several enzymes [17]. Guava seeds are rich in dietary fiber and contain protein, unsaturated fatty acids, iron, zinc, vitamin C, and carotenoids [18]. Therefore, soft seeds are an essential trait in guava breeding. This trait is vital for guava and other fruits [19,20]. Meanwhile, dried leaf waste is typically utilized as compost fertilizer. The use of co-composting accelerates the composting process and improves the quality of the final product [21]. The objective of this study was to develop a formula for a mixture of local microorganisms derived from organic waste, including vegetable waste, fruit waste, and dry leaves. These local microorganisms act as bioactivators during composting. This study hypothesizes that MOL derived from local market waste can effectively accelerate the composting process of various organic wastes. The specific objectives were to: (1) Determine the effect of MOL concentration on the NPK content of compost from different waste materials; (2) Monitor the evolution of pH and methane production during composting; and (3) Identify the optimal composting time for each waste type to meet Indonesian compost quality standards (SNI 19-7030-2004).

2. Research Methodology

2.1. Materials

The organic materials used were sourced from the Central Vegetable and Fruit Market Giwangan, Yogyakarta. The dry leaves were sourced from trees on the campus of Universitas Ahmad Dahlan. The dependent variables in this study were MOL Cabbage, organic materials used as compost, namely vegetables waste (VW), fruit peels (FP), and dry leaves in 3 types: dry leaves1 (DL1), dry leaves2 (DL2), dry leaves3 (DL3), and the duration of composting. The independent variables in this study were pH and methane gas.

2.2. MOL Preparation

MOL is made from cabbage following the method described by Mulyono [22]. The ingredients are 5000 g of cabbage, 25 g of salt, 250 g of brown sugar, and 5 L of rice-washing water. The cabbage is chopped and placed in a bucket. Next, the cabbage is sprinkled evenly with salt and mixed with the rice water. Cover the bucket with plastic. The mixture is left at room temperature (28-31 °C) for about 3 weeks until the plastic bulges slightly. Then add brown sugar to the solution. To make compost, add 10 L of water and 200 g of brown sugar to every 1 L of solution.

2.3. Procedures

The research variables are the type of compost material and the compost-to-MOL ratio. Three types of compost materials were used in the variation: vegetable waste, fruit peels, and dry leaves, each weighing 500 g with 100 MOL cabbage. In the compost materials-to-MOL ratio, 500 g of leaves were used, with MOL volumes of 150, 200, and 250 ml. Composting was carried out by roughly cutting the compost materials. The compost material and MOL are placed in a 5 L sealed jar connected to a bottle filled with water. The bottle is fitted with a tube submerged in water on one side and inserted into a water container on the other. Composting is carried out anaerobically for 30 days. The pH value of each jar is measured every 3 days for 30 days. The amount of gas formed during composting is determined by the volume of water displaced by the gas, which exits the water-filled tube into the water collection container. Furthermore, N, P, and K tests were conducted on each jar on days 20, 25, and 30. The N, P, and K tests for compost fertilizer were based on SNI No. 19-7030-2004, the Compost Quality Standard. The tests were conducted at the Soil Laboratory, Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada.

3. Results and Discussion

The role of bioactivators, such as local microorganisms (MOL), and composting time are factors that influence the composition of the compost obtained. Therefore, testing these factors is necessary to achieve optimal results in line with standard compost quality parameters when using bioactivators with varying composting times. Laboratory conditions generally support compost production because they maintain a stable temperature daily and are protected from direct sunlight. The room temperature in the Laboratory ranges from 28°C to 31°C. The cabbage MOL used determines the number of microorganisms that grow, as the MOL source serves as the primary inoculum for cultivation [23]. Appropriate humidity determines bacterial growth, with growth temperatures ranging from 15°C to 45°C [24].

The production of compost is influenced by the C/N ratio, the properties and size of the material, moisture, temperature, and acidity (pH). The initial weight of organic material used in each treatment was 500 g. According to Kumar [25], the ideal C/N ratio is 15, while Li [26] states that the range is 25-30. The Indonesian compost quality standard, SNI 19-7030-2004, specifies a C/N ratio of 10-20. Organic matter 27–58%, Nitrogen 0.40–1%; Carbon 9.80–32%; Phosphorus (P_2O_5) 0.10%; Potassium (K_2O) 0.20%. The C/N ratio of the materials used in the composting process for this study is shown in Table 1.

Table 1. C and N Content of Several Raw Materials for Compost Production

Material	C/N	References
Vegetable waste	14	[27]
	18	[28]
Fruit peel	20-40	[29]
Dry leaves:	57	[28]

Compost substrates with a low C/N ratio have an excess of nitrogen compared to carbon. This excess nitrogen is lost as ammonia, as greenhouse gas emissions, or through leaching. However, at high C/N ratios, there is an excess of carbon, leading to very slow composting due to limited microbial growth from nitrogen deficiency [30]. A lower C/N ratio increases methane emissions [31]. The results of composting with varying composting materials and the MOL/materials ratio are shown in Table 2.

Table 2. Yield of Compost

Code	Initial weight (gram)	Final weight (gram)	Yield, %
VW (500 g) : MOL (150 ml)	654.5	319.5	48.81
FP (500 g) : MOL (150 ml)	654.5	349.8	53.44
DL1 (500 g) : MOL (150 ml)	654.5	144.3	22.05
DL2 (500 g) : MOL (200 ml)	703.0	145.9	20.75
DL3 (500 g) : MOL (250 ml)	754.0	167.5	22.21

The highest yield is obtained from fruit peel. This is consistent with the findings of [30], who reported that a high C/N ratio in dry leaves slows the composting process. Nitrogen deficiency limits the growth of microorganisms. Compost materials in the form of VW and FP are excellent sources of nutrients for microorganisms [32].

3.1. Total Nitrogen (N) in Compost

Nitrogen is essential for plant growth and is required in large quantities [33]. Organic nitrogen (ON) can sustain stable nitrogen fertility during composting. High-molecular-weight ON can be broken down into low-molecular-weight ON, which can be converted to NH^{4+} [34]. Microorganisms and plants can directly absorb that compound [35]. Microorganisms such as *Oceanobacillus*, *Staphylococcus*, and *Fictibacillus* contribute to the biosynthesis and morphological change of ON from kitchen waste compost [36]. The effect of time on the nitrogen test results for compost materials is shown in Fig. 1.

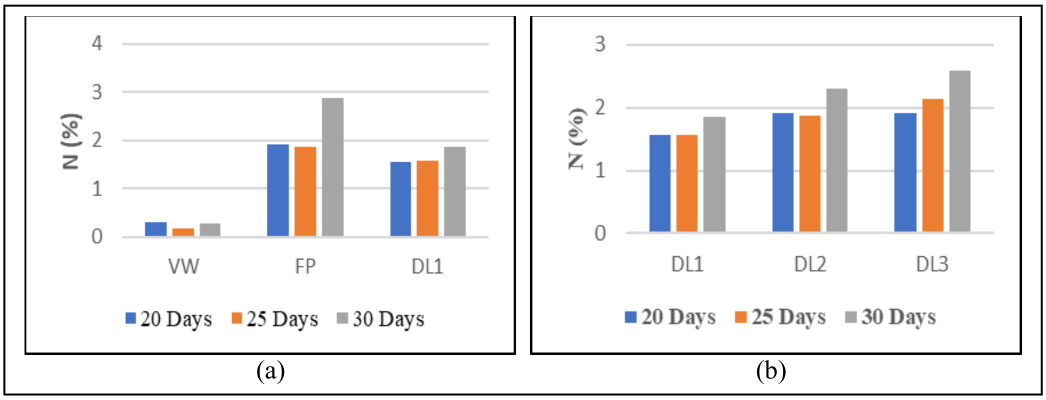


Fig. 1. The effect of composting time on the amount of nitrogen (a) at various material compost (b) at various ratios of MOL and dry leaves

Based on Fig. 1, which shows the effect of time on the N content in the material, the average total N value ranged from 0.18 to 2.88%. Vegetable waste (VW) obtained average values of 0.31%, 0.18%, and 0.28%, fruit peel (FP) received 1.88%, 1.94%, and 2.88%, then dry leaves1 (DL1) obtained 1.56%, 1.57%, and 1. 85%, followed by dry leaves 2 (DL2) at 1.85%, 1.87%, and 2.30%, and finally DL3 at 1.92%, 2.13%, and 2.59%, respectively, at 20, 25, and 30 days. The highest average total N value was recorded by FP on day 30 at 2.88%, while the lowest was recorded by VW on day 25 at 0.18%. The degradation of organic matter and microbial activity are influenced by water content [37]. Low initial water content and a continuous decrease in water content negatively impact denitrifying bacterial activity during composting [38]. High water content in vegetable waste promotes denitrification (loss of N as gas), resulting in lower compost yield from VW than from FP, even though VW's C/N ratio is lower than FP's. From Fig. 1, it can be seen that most materials increased their average total N values, meeting compost quality standards, except for the VW material, which decreased. The average total N values obtained at different time intervals did not meet the compost quality standards set by SNI 19-7030-2004, which requires a minimum total N content of 0.4% in organic compost.

3.2. Total Phosphorus (P) in Compost

Phosphorus (P) is a macronutrient that is very important for plant growth and development. The content of organic matter, including water-stable aggregates, available phosphorus, available nitrogen, and organic carbon, will affect interactions among soil organisms [30]. The effect of time on phosphorus test results for compost materials is shown in Fig. 2.

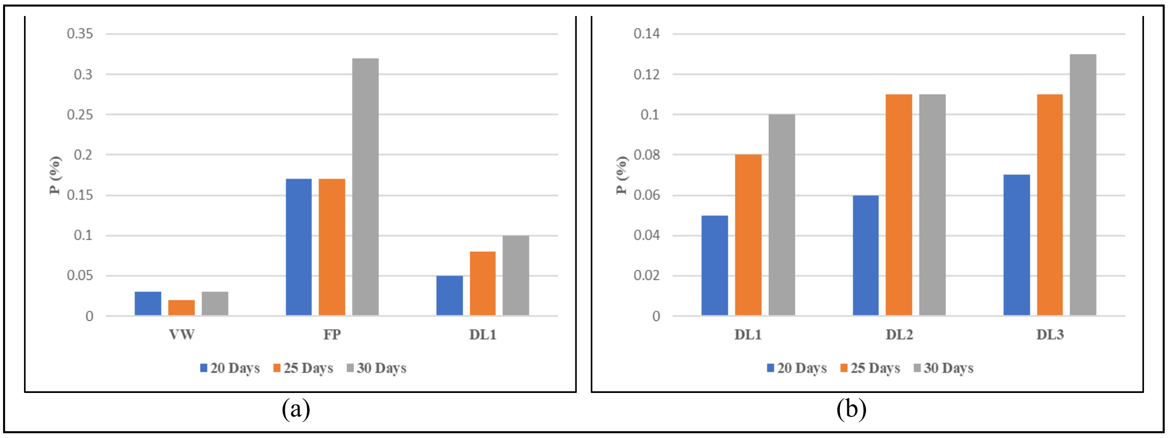


Fig. 2. The effect of composting time on the amount of phosphorus (a) at various material compost (b) at various ratios of MOL and dry leaves

The average total P content ranged from 0.02 to 0.32%. VW yielded average values of 0.03%, 0.02%, and 0.03%, FP yielded 0.17%, 0.17%, and 0.32%, and DL1 yielded 0.05%, 0.08%, and 0.10%, followed by DL2 with 0.06%, 0.11%, and 0.11%, and finally DL3 with average P values of 0.07%, 0.11%, and 0.13% respectively at 20, 25, and 30 days. The highest average P value was achieved by FP on day 30, at 0.32%, while the lowest was achieved by VW on day 25, at 0.02%. This figure shows that most materials increased in average total N, except for VW material, which decreased in average N over time. However, not all materials that showed an increase met the compost quality standards; material DL1 met the standard on day 30 at 0.1%, while materials DL2 and DL3 met the standard on days 25 and 30, respectively, at 0.11%-0.13%. The compost material that met the average total P value and compost quality standards at every time point was the FP material, as previously presented. The compost quality standards specified in SNI 19-7030-2004 require that the total P content of organic compost be at least 0.1%.

3.3. Total Potassium (K_2O) in Compost Material

Fig. 3 shows that the total K content in several materials is unstable (fluctuating) over time. In the materials, the average total P value ranges from 0.18 to 2.50%. VW obtained average values of 0.21%, 0.21%, and 0.18%, FP obtained 1.94%, 2.50%, and 2.04%, then DL1 obtained 0.48%, 0.47%, and 0.65%, followed by DL2 with 0.79%, 1.22%, and 0.95%, and finally DL3 with average K values of 0.95%, 0.93%, and 1.23% respectively at 20, 25, and 30 days. The highest average K value was achieved by fruit peel on day 25, at 2.50%, while the lowest was achieved by rotten vegetable on day 30, at 0.18%.

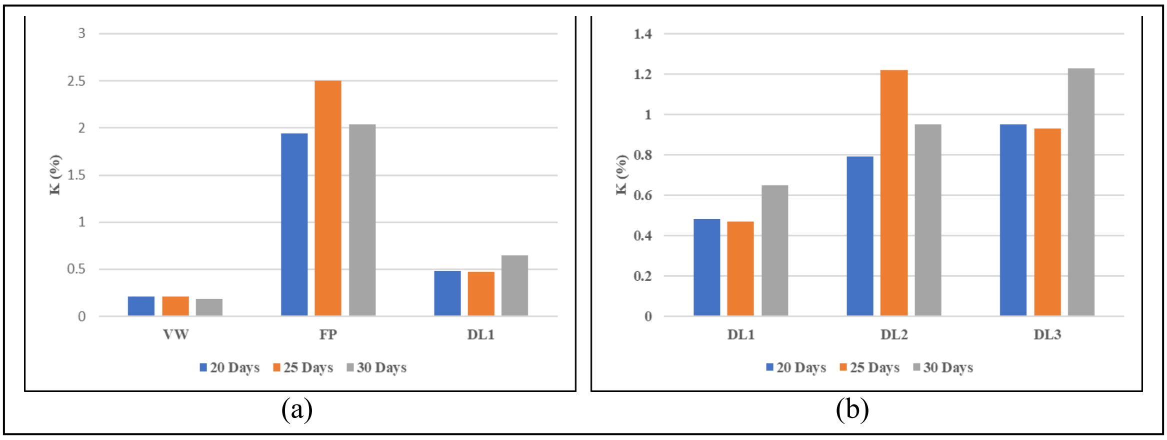
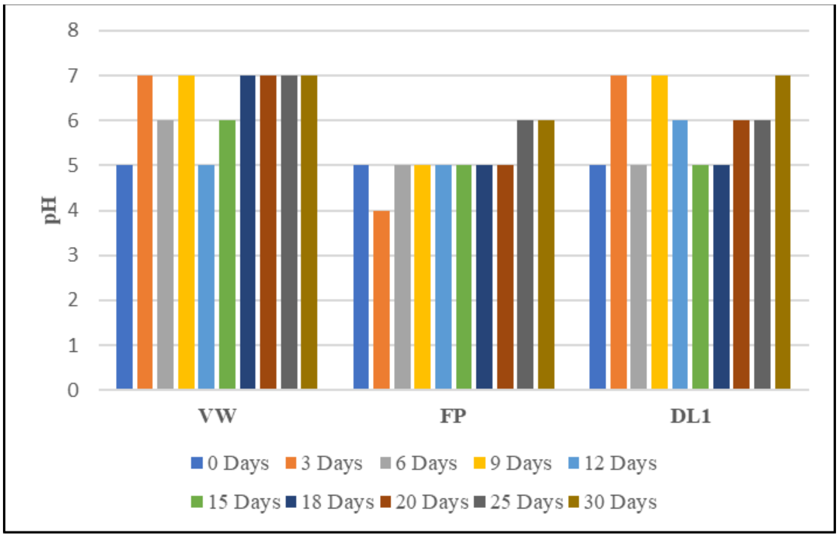


Fig. 3. The effect of composting time on the amount of potassium (a) at various material compost (b) at various ratios of MOL and dry leaves

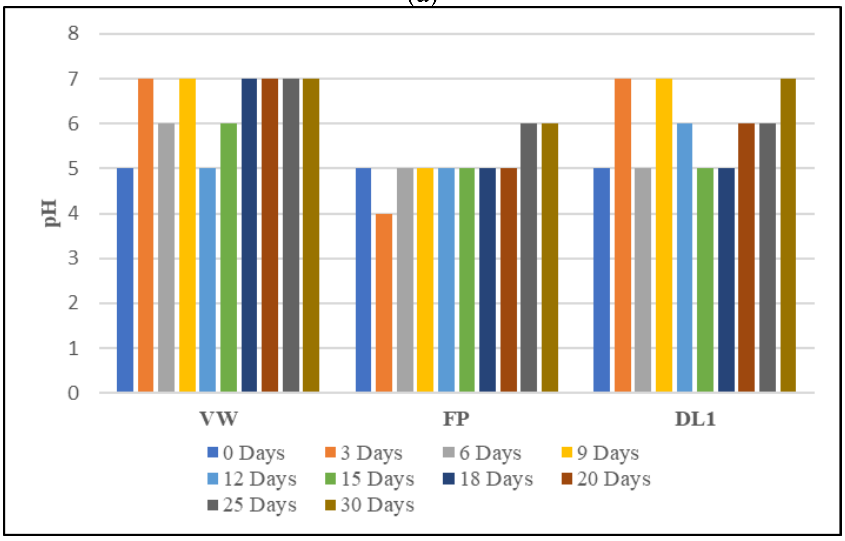
This figure shows that most of the materials meet compost quality standards, with an average total N value >0.20%, except for the rotten vegetable material on day 30, which declined, resulting in an average K value of 0.18%. The compost with the highest average total K value was fruit peel across all time variations. The compost quality standard, based on SNI 19-7030-2004, requires that the total K content in organic compost be at least 0.20%.

3.4. Acidity Level (pH) of Compost

Observing changes in compost pH helps identify the degradation process during composting. Factors that influence compost maturity and the humification process include pH, temperature, water content, and additives such as clay and zeolite [41]. The optimal pH for reducing nitrogen loss is 5.5–8.5 [42]. Fig. 3 shows that differences in time affect the pH produced by each compost material. The initial acidity (pH) of all materials was 5, recorded on day 0, following the pH of the cabbage MOL used. The rotten vegetable had a pH of 5 to 7, the fruit peel had a pH of 4 to 6, the DL1 had a pH of 5 to 7, the DL2 had a pH of 5 to 6, and the DL3 had a pH of 4 to 6. The pH levels obtained showed fluctuations, influenced by factors including the pH testing process. The final pH, meeting the SNI No. 19-1703-2004 standard, ranging from 6.8 to 7.49, is compost made from rotten vegetable material and dry leaf material 1, each with a material-to-MOL ratio of 500 grams:150 ml, resulting in a final pH of 7. Meanwhile, compost made from other materials has a final pH of 6. The longer the composting time, the higher the pH value. A pH near neutral indicates that the compost is mature. At the beginning of composting, the reaction tends to be acidic because decomposed organic matter produces simple organic acids. As composting progresses, microbial activity decreases as the amount of decomposed matter decreases, leading to the formation of base cations and a neutral pH [43].



(a)



(b)

Fig. 4. The effect of composting time on pH (a) at various material compost (b) at various ratios of MOL and dry leaves

3.5. Methane Yield

Previous research stated that anaerobic composting produces methane (CH_4), carbon dioxide (CO_2), and low-molecular-weight organic acids, such as acetic acid, propionic acid, butyric acid, lactic acid, and succinic acid [44]. The initial C/N ratio is one of the most critical factors affecting methane production during composting. A lower C/N ratio causes increased methane emissions [31]. In contrast, [30] states that at high C/N ratios, there is an excess of degradable carbon, which significantly slows the composting process. Therefore, the C/N ratio substantially affects the composting process and methane release. The presence of methane causes increased carbon loss and drives greenhouse gas (GHG) emissions [45], [46].

The effect of time on gas pressure development (ml of water volume) is shown in Table 3. Table 3 shows that composting duration affects only certain materials in producing methane gas, with DL1 compost at a material-to-MOL ratio of 500 grams:150 ml producing more methane gas than other materials. The final total volumes of DL1 compost and DL2 compost were 6.1 ml and 9.7 ml, respectively.

Table 3. Effect of Time on Gas Pressure (based on water volume)

Day	Water Volume (ml)				
	VW	*FP*	*DL1*	*DL2*	*DL3*
0	0	0	0	0	0
3	0.5	0.3	0	0	0.9
6	0	0	2.3	0	0
9	0.2	0.2	1.1	0	0.5
12	0.5	0	0	3.5	0
15	0.1	0	0	2.7	3.1
18	0	0	0.2	1.6	0.6
20	0.2	0	0.2	0.5	0.4
25	0	0.1	0	0	0
30	0	0	2.3	1.4	0
Total	1.5	0.6	6.1	9.7	5.5

The lowest production was obtained from fruit peel material with a MOL concentration of 150 ml, and the highest was obtained from compost DL2 with a MOL concentration of 200 ml. Dry leaves with the highest C/N ratio produce the most methane gas. This reinforces Wang's (2024) statement that the C/N ratio slows composting and causes carbon to decompose into methane.

4. Conclusion

This study demonstrated that MOL from cabbage waste can be used as a bioactivator for composting. The optimal parameters were found to be waste-specific: For fruit peel waste, 150 ml of MOL and a 30-day composting period yielded compost that met all SNI standards for NPK content. For dry leaf waste, a higher MOL concentration may be beneficial for biogas production, but the compost did not consistently meet N standards, likely due to a high initial C/N ratio. Vegetable waste performed poorly, likely due to its high moisture content, which promoted anaerobic conditions and nitrogen loss. The pH trends indicated successful composting, with the pH evolving towards neutrality. The detection of methane highlights that the process was anaerobic, suggesting that aeration could be a key factor for improving efficiency and reducing greenhouse gas emissions in future applications.

Notation

C = Carbon
DL1 = Dry leaves type 1
DL2 = Dry leaves type 2
DL3 = Dry leaves type 3
EPA = United States Environmental Protection Agency
FP = Fruit peel
K = Phosphorus
MOL = Local microorganism
N = Nitrogen
ON = Organic nitrogen
P = Potassium
VW = Vegetable waste

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