

Production of Liquid Organic Fertilizer from Pineapple Peel Waste Using EM4 as a Bioactivator

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ARTICLE INFO

Received: 14 July 2025

Accepted: 02 August 2025

Key word:

Liquid organic fertilizer

Pineapple peel

EM4

Fermentation

Plant nutrients

ABSTRACT

Organic waste, particularly fruit peels, remains underutilized despite its abundance and potential as a raw material for environmentally friendly fertilizer. This study aims to produce Liquid Organic Fertilizer (LOF) from pineapple peel waste through anaerobic fermentation using EM4 bioactivator. Additional materials such as cow dung, rice washing water, and brown sugar were added to enrich the fermentation medium. Over a 30-day period, during which temperature and pH were monitored on a daily basis. Post-fermentation, nutrient analyses were conducted to determine the contents of nitrogen (N), phosphorus (P), potassium (K), and organic carbon (C-organic). The results showed that the temperature ranged from 27.9°C to 32.3°C, and pH levels remained between 3.0 and 4.0, both within the optimal range for microbial activity. However, the nutrient contents of N (0.153%), P (0.116%), K (0.105%), and C-organic (1.58%) did not meet the Indonesian National Standard (SNI 261/2019). This indicates that pineapple peels alone are insufficient to produce standard-compliant LOF. The study highlights the potential of pineapple peel waste as a sustainable fertilizer base, while recommending the use of nutrient-rich additives and optimized fermentation conditions to enhance quality. This research supports waste valorization and sustainable agriculture through eco-friendly fertilizer innovation.

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Introduction

Waste is a common problem encountered in various regions, both in urban and rural areas, and requires an appropriate management strategy. According to the World Health Organization (WHO), waste refers to the by-products of human activities that are no longer utilized, consisting of both organic and inorganic materials [1]. Population growth also contributes significantly to the increase in the volume of waste generated. Organic waste usually comes from kitchen waste such as food waste, vegetable waste, and fruit peels. However, most organic and inorganic waste is still disposed of without proper treatment, causing problems such as foul odor, health hazards, and environmental pollution. To solve these problems, this study proposes to convert

organic waste into Liquid Organic Fertilizer (LOF) as a sustainable alternative.

Liquid Organic Fertilizer (LOF) is a nutrient-rich solution derived from the decomposition of organic matter and contains essential nutrients needed for plant growth. The main nutrients in LOF include macronutrients such as potassium (K), nitrogen (N), phosphorus (P), and organic carbon (C-organic), all of which play an important role in maximizing plant development. According to the Minister of Agriculture Regulation No. 261 of 2019, this type of fertilizer must meet the minimum quality standards set. Several previous studies have successfully produced LOF from various organic waste sources. For example, fermentation of vegetable waste for 17 days produced liquid fertilizer with a nitrogen

content of 0.19%, phosphorus 0.28%, and organic carbon 0.38%. Similarly, fermentation of used soybean cooking water for 10 days produced fertilizer with a nitrogen content of 0.30% and phosphorus of 0.01%. In another study by [2]. Fermentation of banana and papaya peels for 24 days produced LOF with C-organic contents ranging from 3.96% to 7.34%, nitrogen ranging from 1.37% to 3.21%, phosphorus ranging from 2.22% to 3.81%, and potassium ranging from 2.48% to 4.24%. These findings suggest that anaerobic fermentation, especially with the addition of EM4, can produce LOF with variable but high-value nutrient contents.

Fruit peels generally have a higher nutritional potential than vegetable waste, making them a potential source of environmentally friendly organic fertilizer, especially as a substitute for chemical fertilizers. This approach is all the more relevant given that many Micro, Small and Medium Enterprises (MSMEs) in the fruit processing sector such as juice and chips production generate significant amounts of fruit peel waste. Instead of being discarded, this waste can be processed into raw materials for LOF production. In this study, pineapple peels were selected as the main raw material. Pineapple, a tropical crop suitable for areas with even rainfall such as Kalimantan, has a harvest cycle of up to three times per year, which contributes to its high economic value. The peel, which is tough and usually underutilized, is a major waste product. Pineapple peel was selected not only due to its high production volume and underutilized status, but also because of its favorable composition. Studies have shown that pineapple peel contains fermentable sugars, organic acids, and micronutrients that can promote microbial activity during fermentation [3] [4]. While it may not contain the highest nutrient levels compared to other organic waste, its biodegradability and availability make it a suitable substrate for LOF production.

The purpose of this research is to produce Liquid Organic Fertilizer (LOF) with the main raw material of pineapple peel waste, facilitated by Effective Microorganisms 4 (EM4) as a bioactivator. The fermentation process was carried out for 30 days with the addition of

complementary materials such as cow dung, used rice washing water, and brown sugar solution. After fermentation was complete, the resulting fertilizer was tested with parameters such as temperature, pH, and concentration of key nutrients, including potassium (K), nitrogen (N), phosphorus (P), and organic carbon (C-organic).

Materials and Methods

Materials and Tools

The materials used in this research are pineapple peel, cow dung, rice washing water, brown sugar, and EM4. While the tools used are standard laboratory equipment such as thermometers, pH paper, measuring cups, and UV-Vis spectro Shimadzu brand type AA-7000.

Methods

Preparation of LOF

The initial stage began with washing the pineapple skin using clean running water, then cutting it into small pieces with a total weight of approximately 3 kg. Next, 6 L of rice washing water, 1.2 kg of brown sugar, and 900 mL of EM4 solution were prepared and dissolved into 6 L of clean water. After all the ingredients were ready, the chopped pineapple peels were put into the digester and mixed with the rice washing water. Brown sugar solution, cow dung, and EM4 were then added to support the fermentation process. The mixture was stirred well, and the drum was sealed to prevent air from entering. Fermentation was carried out for 30 days, during which the mixture in the digester is stirred periodically to release the gases formed in it. The 30 days anaerobic fermentation period was chosen based on previous studies demonstrating optimal microbial nutrient transformation and stabilization within this timeframe [5].

Measurement of Temperature

Temperature monitoring was carried out every day in the morning using a digital thermometer. Before measurement, the fermentation solution was stirred to ensure homogeneity. The thermometer sensor was then inserted into the solution and left until the displayed temperature remained constant, indicating that thermal equilibrium had been

reached.

Measurement of pH

The pH measurement was carried out every day in the morning using pH test paper. Before the measurement, the solution was stirred first to ensure complete mixing.

Nutrient Analysis

Nitrogen (Kjeldahl Method)

To analyze nitrogen content, 1 g of sample was weighed, then 10 mL of concentrated H_2SO_4 and 2 g of catalyst were added. The mixture was then digested for approximately 1.5 hours. After deconstruction is complete, distillation is carried out by adding 35 mL of 40% NaOH solution. The distillate vapor was collected in 25 mL of H_3BO_3 solution, and the process was stopped after the volume of distillate collected reached approximately 50 mL. Next, the distillate was titrated with 1 N HCl solution, until it reached the end point of the titration which was marked by a color change from green to pink [6].

Phosphorus (Spectrophotometry)

A total of 2 g of pineapple peel sample was weighed and put into a bottle, followed by the addition of 10 mL of 25% HCl solution. The mixture was shaken for 30 minutes and then allowed to stand for 24 hours before being filtered using filter paper. The resulting filtrate was collected, and 0.5 mL was transferred into a test tube. This solution was then diluted with 2 mL of distilled water (1:5 dilution) and mixed using a vortex mixer until homogeneous. Next, 1 mL of diluted solution and 1 mL of standard phosphorus solution were added to a separate test tube. Then, 5 mL of phosphorus reagent was added to each tube and mixed again with a vortex mixer until well mixed. Phosphorus levels were measured using a spectrophotometer at a wavelength of 693 nm, with the standard solution serving as a reference [6].

Potassium (Atomic Absorption Spectroscopy)

A total of 2 g of pineapple peel was put into a bottle, then 10 mL of 25% HCl solution was added. The mixture was shaken for 30 minutes, then allowed to stand for 24 hours. After this

process, the mixture was filtered using filter paper, and the resulting filtrate was collected. Next, 0.5 mL of filtrate was taken and mixed with 9.5 mL of distilled water to produce a 1:20 dilution. The diluted solution was then homogenized using a vortex mixer. The next step was the analysis of potassium content, which was done using a Atomic Absorption Spectroscopy (AAS) by comparing the readings with the standard potassium solution [6].

Results and Discussion

Preparation of Liquid Organic Fertilizer

The liquid organic fertilizer research was made by mixing a number of main ingredients, namely pineapple peel waste, brown sugar, cow dung, rice washing water, and EM4 bioactivator. Before the mixing process, the pineapple peels were first cleaned with running water, then cut into small pieces and finely ground using a blender. All prepared ingredients were mixed until evenly distributed and put into a closed container as a fermentation medium.

Fermentation is a biochemical process that utilizes the activity of microorganisms, both those that require oxygen (aerobic) and those that do not (anaerobic), to convert complex compounds into simpler ones. The main objective is to decompose organic matter through microbial action at an appropriate temperature. During fermentation, there are two main types of reactions:

1. Organic compounds + Oxygen $\rightarrow$ Water + Carbon dioxide + Nutrients + Humus (via aerobic microorganisms)
2. Organic compounds $\rightarrow$ Methane + Nutrients + Humus (via anaerobic microorganisms)

Pineapple peel is used as the main raw material for fertilizer due to its high nutritional value and benefits to plants. Brown sugar provides energy for microbial growth, while rice washing water provides additional nutrients such as starch, vitamins, phosphorus, and potassium to enrich the fertilizer and enhance microbial activity. Cow manure contributes natural microbes that accelerate the decomposition of organic matter and also serves as an important source of nitrogen for leaf and stem development. While EM4 is a consortium

of more than 80 microbial species including photobacteria, *Lactobacillus* sp., *Streptomyces* sp., yeast, and actinomycetes, is added to further enhance the fermentation process. However, its effectiveness greatly depends on the composition of raw materials and environmental conditions. The low nutrient results in this study suggest that the use of EM4 alone is insufficient without nutrient-rich substrates [7].

Measurement of Temperature

Temperature greatly affects microbial activity, especially for EM4 microorganisms such as lactic acid bacteria, photosynthetic bacteria, and actinomycetes. Fermentation was conducted under ambient conditions (room temperature), ranging from 27.9–32.3°C. The digester was kept in a shaded area to minimize fluctuations and maintain consistency within the optimal microbial activity range. During the 30-day fermentation process of Liquid Organic Fertilizer (LOF), the temperature ranged from 27.9°C to 32.3°C, falling within the optimal range of 20–40°C for microbial effectiveness, with most values close to the ideal range of 25–30°C. The absence of extreme fluctuations indicates stable conditions, which is important to prevent microbial interference and ensure proper decomposition of organic matter. Maintaining consistent environmental conditions and avoiding direct sunlight or extreme heat is essential to support efficient fermentation and produce high-quality LOF.

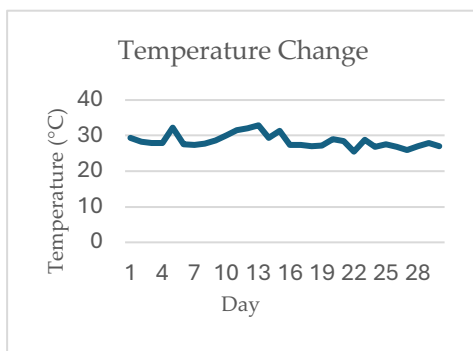


Figure 1. Daily temperature changes during 30-day fermentation

Measurement of pH

During the 30-day fermentation of the Liquid Organic Fertilizer (LOF), the pH levels consistently ranged between 3.0 and 4.0,

indicating a typical acidic environment in the early stages due to the production of organic acids from the pineapple peel. Although the optimal pH range for microbial activity in EM4 is 4–7, acid-tolerant microbes such as lactic acid bacteria can still function effectively under slightly acidic conditions. However, prolonged exposure to pH below 4 can inhibit some microbial activities, thus slowing down fermentation. Maintaining pH stability is essential, as values above 8.0 or below 3.0 can inactivate microorganisms. Adjustments using lime, rice husk ash, or acidic ingredients can help balance the pH. Overall, pH along with temperature are key factors that affect microbial performance and the success of LOF fermentation.

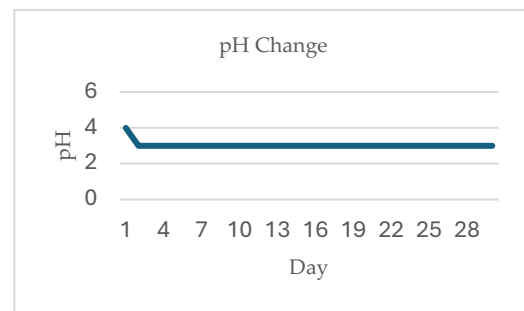


Figure 2. Daily pH changes during 30-day fermentation

Nutrient Content Analysis

Each nutrient analysis was conducted in triplicate ($n = 3$), and values reported in Table 1 represent the average of these replicates. Standard deviation and coefficient of variation were also calculated to validate the reliability of results.

Table 1. Results of LOF nutrient content analysis

Test Parameter	Test Result	Quality Standard	Testing Method
N (Nitrogen)	0.153	≥ 0.5	Kjeldahl Microscopy
P (Phosphorus)	0.116	2–6	Spectrophotometry
K (Potassium)	0.105	2–6	Atomic Absorption Spectroscopy
C (Organic Carbon)	1.58	≥ 10	Spectrophotometry

Notes: Quality standards refer to Indonesian National Standard (SNI) 261/KPTS/SR.310/M/4/2019 on Organic Fertilizers, Biofertilizers, and Soil Improvers.

Table 1. shows the results of nutrient analysis of Liquid Organic Fertilizer (LOF) made from pineapple peel waste, including potassium (K), nitrogen (N), phosphorus (P), and organic carbon (C-organic), which are essential for plant growth. These values were then compared with the minimum quality standards listed in the Decree of the Minister of Agriculture No. 261/KPTS/SR.310/M/4/2019 to assess whether the LOF meets national fertilizer quality requirements.

Nitrogen (N)

Nitrogen (N) is an essential macronutrient that significantly affects the vegetative growth of plants. Nitrogen plays an important role in the synthesis of proteins, chlorophyll and enzymes required for photosynthesis. Adequate nitrogen supply promotes healthy and lush leaf growth and overall plant vigor. Nitrogen deficiency is often characterized by yellowing leaves, stunted growth, and low yields. However, excess nitrogen can result in unbalanced leaf and stem development, reduced flower and fruit production, and ultimately lead to suboptimal plant performance.

Based on the results of laboratory analysis, the nitrogen (N) content in the tested liquid organic fertilizer (LOF) was 0.153% w/w, while the minimum quality standard set by SNI 261/KPTS/SR.310/M/4/2019 is $\geq 0.5\%$ w/w. This shows that the nitrogen content in the LOF sample is far below the quality standard value required for liquid organic fertilizer. Nitrogen content analysis was carried out using the Kjeldahl method, which is a conventional method but is still an international standard for the determination of total nitrogen in organic matter due to its accuracy in measuring organic and inorganic bound nitrogen.

This low nitrogen content can be caused by several factors, including organic waste raw materials that have low nitrogen content, a less than optimal fermentation process, loss of nitrogen during the 30-day fermentation when nitrogen can turn into nitrate and hydrogen ions. Studies have shown that fermentation duration and material composition play a key role in nitrogen retention. For example, [8] found that the addition of elephant grass ash

and the extension of fermentation to 35 days increased nitrogen to 2.98%.

Studies by [9] indicate that certain agricultural wastes, such as fruit peels, have low initial N content and require additional nitrogen-fixing agents to bring the resulting fertilizer up to standard. [5] The study also mentioned that LOF from fruit waste without additional nitrogen treatment usually only has an N content of 0.1-0.2%, far from the minimum standard.

[10] It is important to select feedstock with an appropriate C/N ratio because this ratio greatly affects the final nitrogen content in the organic liquid fertilizer. Furthermore, [11] recommends partial substitution of feedstock with animal manure or N-rich legumes to avoid low yields in the Kjeldahl test.

Phosphorus (P)

Phosphorus is an essential macronutrient that is crucial for plant growth, especially in root development, flowering, and fruit production. Phosphorus plays a vital role in energy transfer in plants through the formation of ATP (Adenosine Triphosphate). Adequate phosphorus intake increases root strength, enabling better nutrient and water uptake. During the reproductive phase, phosphorus supports the production of quality flowers and fruits. Phosphorus deficiency can lead to poor flowering, stunted growth, and purple or reddish leaf discoloration, while excess phosphorus can inhibit the absorption of other essential micronutrients such as iron and zinc, potentially causing chlorosis in the leaves.

The analysis of phosphorus content in samples of liquid organic fertilizer (LOF) made from pineapple fruit peel and cow dung showed a value of 0.116% w/w, which significantly did not meet the national quality standards of SNI 261/KPTS/SR.310/M/4/2019 of 2-6% w/w. In fact, the formulation has used EM4 as a bioactivator. This shows that although EM4 is known to contain phosphate-solubilizing microbes, such as *Bacillus subtilis*, *Lactobacillus* spp. and *Actinomycetes*, the presence of these microbes does not necessarily guarantee an increase in P content if the basic raw material is phosphorus-poor or there is no inorganic phosphate that can be dissolved.

The study by [4] using a similar formulation of pineapple peel and cow dung with EM4 but also yielded only 0.18% P, confirms that despite the increase in pH and microelements, the P value remains low and insufficient. This is in line with the findings of [9] that tropical fruit wastes such as pineapple peels have very limited natural P levels, so relying solely on phosphate solubilizing microbial activity (in EM4) will not be sufficient without the presence of mineral phosphorus sources.

Addition of phosphorus-rich materials, such as bone residue, rock phosphate, or high-protein waste, to the fermentation substrate, which has been shown to increase P content to >2% within 2-3 weeks of fermentation. Other studies have also suggested that phosphorus levels in LOFs can be increased by using phosphate-rich feedstocks or optimizing fermentation parameters. For example, [12] obtained phosphorus of 2.68% using human urine and rice washing water, while [13] reported 2.05% by combining moringa leaf extract with EM4. Microbial interventions, such as using *Paecilomyces lilacinus*, have also proven effective in increasing phosphorus solubility. It is suggested that future formulations include bone meal, rice husk ash, or high-protein kitchen waste to significantly increase phosphorus and organic carbon levels [12] [13].

Potassium (K)

Potassium is a vital macronutrient that plays an important role in plant development by supporting fruit and seed growth, resulting in higher quality, sweeter and longer-lasting crops. Potassium also strengthens plant cell walls, increases resistance to environmental stresses such as drought and extreme temperatures, and improves disease resistance. Potassium deficiency is usually characterized by yellowing or drying of leaf margins, stunted growth, and low product quality. Meanwhile, excess potassium can interfere with the absorption of essential nutrients such as magnesium and calcium, impacting the overall health of the plant.

The analysis of potassium (K) content in liquid organic fertilizer (LOF) made from pineapple peel, cow dung, and EM4 showed a

value of 0.105% w/w, which is still far below the national quality standard according to SNI 261/KPTS/SR.310/M/4/2019, which is 2-6% w/w. The test method used Atomic Absorption Spectroscopy, which is widely recognized as an accurate method for detecting K content in solution form. Although cow dung is known to contain a certain amount of potassium, these low levels suggest that the K contribution from the feedstock is not sufficient, and the microorganism activity in EM4 is not enough to significantly increase K availability.

Research by [14] found that fruit peel waste, including pineapple, has a low natural potassium content, requiring enrichment from other organic sources to meet the minimum organic fertilizer limit. [4] also noted that fermentation of pineapple peels and cow dung yielded K of only 0.15% - still far from the standard. [7] EM4 can help accelerate the decomposition of organic matter, the increase in K content is highly dependent on the initial composition of the feedstock.

[15] The use of a combination of organic materials such as banana stems and coconut husks in the production of organic liquid fertilizer can increase the potassium content in Alfisol soil. This treatment significantly improved soil K-total levels and supported the growth of corn plants. These results prove that raw materials containing organic ash such as coconut husk or high cellulose components can release K ions through microorganism activity during fermentation, making it a practical solution to meet the quality standards of liquid organic fertilizer.

C-Organic (Organic Carbon)

Organic carbon (C-organic) is a major component in liquid organic fertilizer (LOF) that plays an important role in maintaining soil fertility, improving soil structure, and supporting microbial activity and plant root growth. In this context, C-organic has a vital function as a cation exchange capacity buffer, soil aggregate builder, and energy source for soil microorganisms. However, the analysis of LOF formulated from pineapple peel waste and EM4 in this study showed a C-organic content of only 1.580%, far below the national minimum

standard of 10% set in the Decree of the Minister of Agriculture No. 261/KPTS/SR.310/M/4/2019.

This shows that pineapple peel substrate has limitations as a carbon source if used without carbon-rich additives [16]. The initial C/N ratio of the fermentation mixture was not directly measured; however, based on literature, pineapple peel generally has a high C/N ratio (>40), which may explain the low nitrogen and carbon retention (Pandi et al., 2023). Fermentation process used [17] and microbial activity that consumes carbon as an energy source, causing a decrease in C content faster than other nutrients [18].

[19] LOF made from used cooking oil shows that raw materials with high carbon content can produce C-organic by 2.10%, although it still does not meet quality standards. Meanwhile, [20] the use of compost from kitchen waste can significantly increase the accumulation of organic carbon in the soil, along with an increase in tomato plant yield. This finding confirms that the use of kitchen waste as a base material for compost has the potential to improve fertilizer quality and soil fertility in a sustainable manner.

In addition to raw materials, [14] emphasizes that an ideal C/N ratio (25-30) supports carbon stability during fermentation because microorganisms will not consume excess carbon as an energy source. [3] Emphasizes that the sequence and type of pre-treatment of pineapple peel waste, such as washing, shredding, drying, and chemical treatment, have a great influence on the chemical composition and thermal stability of organic matter. Controlling these pre-treatment stages is very important to slow down the rate of carbon degradation during the fermentation process. With this strategy, the formulation of liquid organic fertilizer (LOF) from pineapple peels is expected to maintain C-organic content in accordance with national quality standards.

This study did not include microbial or heavy metal contamination analyses. Future work should address this limitation, particularly for LOF intended for edible crops, as potential contamination from raw materials or bioactivators like EM4 must be assessed to ensure safety and compliance.

Acknowledgments

The authors would like to express their deepest gratitude to the Institute for Research and Community Service (LPPM) and the Chemistry Study Program, which have provided moral support and laboratory facilities during this research process. Also, the author would like to thank colleagues, students and laboratory technicians who took an active role in the fermentation process and analysis of fertilizer nutrient content. Hopefully, the results of this research can make a real contribution to the utilization of agricultural waste, especially pineapple fruit peels, as raw material for environmentally friendly liquid organic fertilizer that supports sustainable agriculture.

Conclusion

This study shows that pineapple peel waste has the potential to be processed into liquid organic fertilizer (LOF) through fermentation for 30 days with the addition of EM4, cow dung, rice washing water, and brown sugar. Although the fermentation temperature and pH were within the optimal range, the results of the analysis of nitrogen content (0.153%), phosphorus (0.116%), potassium (0.105%), and organic carbon (1.58%) were still below the national quality standard SNI 261/KPTS/SR.310/M/4/2019. The low nutrient content is due to the limited nutrients from pineapple peel as a single ingredient and the suboptimal fermentation composition. Therefore, it is necessary to add additives such as husk ash, bone residue, or carbon and phosphate-rich materials, as well as adjusting the C/N ratio so that the LOF produced can meet standards and support sustainable agriculture.

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