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Biocomposting rice straw using fermented papaya as a bioactivator agency and its characterization

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ABSTRACT

This study aimed to identify microorganisms and analyze the nutrient content of a bioactivator derived from fermented papaya, as well as assess the effect of bioactivator administration on the composting process and the chemical properties. The study process was conducted in Telang Sari Village, Indonesia, from May–July 2025. The materials used were rice straw, biochar, cow dung, fermented papaya as a bioactivator, and clean water. A completely randomized design (CRD) was used with four treatments and three replications, including P0 (0 L bioactivator), P1 (0.25 L), P2 (0.5 L), and P3 (0.75 L). The variables observed were the type of microorganisms and nutrient content of the bioactivator, composting temperature, and the chemical properties of the compost. The results showed that fermented papaya contained isolates (*Rhizopus oryzae* and *Aspergillus niger*), 0.890% N, 0.244% P, and 0.250% K, which were used as a bioactivator. The addition of a bioactivator increased compost temperature and cation exchange capacity (CEC). The temperatures of P3 (32.3 ± 0.6 °C) and P2 (31.7 ± 0.6 °C) were higher and significantly different ($P < 0.05$) compared to P1 (31.0 ± 0.0 °C) and P0 (31.0 ± 0.0 °C) in the first week. Similarly, the CEC values of P3 (30.28 ± 1.38 cmol/kg) and P2 (31.06 ± 5.19 cmol/kg) were higher and significantly different ($P < 0.05$) compared to P1 (21.50 ± 2.82 cmol/kg) and P0 (20.42 ± 3.56 cmol/kg). The use of bioactivator from fermented papaya facilitated biocomposting while improving the compost quality.

Keywords: bioactivator, cellulolytic microorganisms, composting, cation exchange capacity, C/N ratio.

INTRODUCTION

Microorganisms are tiny living things that can only be seen through the use of a microscope. There are various types of microorganisms with diverse roles. One type often found in nature plays a role in breaking down organic materials into nutrients used as a bioactivator during compost preparation. Microorganisms have an important role in converting organic compounds into simpler forms of rice straw through biochemical mechanisms such as hydrolysis, fermentation, and oxidation (Ziliwu and Lase, 2025). Bacteria, fungi, and actinomycetes are the main decomposers, which break down complex molecules such as lignin, cellulose, and hemicellulose (Nemet et al., 2021; Kumaresan et al., 2024). This decomposition process occurs in several distinct phases through the activity of microorganisms that cause changes in temperature and organic substrate. Abiotic environmental factors playing a crucial role in the process include the carbon/nitrogen (C/N) ratio, humidity, temperature, pH, and oxygen content. Decomposition produces carbon dioxide, heat, water, and stable organic products (compost), which shows the fundamental role of microorganisms in the ecosystem nutrient cycle (Kumaresan et al., 2024).

Various types of fermented and unfit fruits, such as papaya, are used as a source of microorganisms for a bioactivator. Using fermented papaya accelerates rice straw decomposition into

nutrients, while also providing an environmentally friendly, affordable, and readily available alternative bioactivator. Papaya waste effectively promotes the decomposition of organic matter, although evidence is limited to specific composting contexts. Baharudin et al. (2016) found that papaya waste as an inoculant was used to accelerate composting, with an average composting time of 32.3 days. Apriani et al. (2023) further emphasized the potential of papaya fruit waste in the decomposition process as a biostarter, specifically when processing fish waste and mangrove leaves. South Sumatra is among the producers of papaya with a volume of 43,909 tons/year and fermented papaya can be used as a bioactivator.

Compost is an organic fertilizer prepared from rice straw, biochar, and cow dung. The combination of these three ingredients with a bioactivator derived from fermented papaya fruit that is not suitable for consumption is expected to produce compost of better quality, both in terms of nutrient content, C/N ratio, and chemical characteristics. The combination of a bioactivator and organic materials significantly influences composting acceleration and improves compost quality, with substantial variations in the chemical and physical properties depending on the specific materials as well as microbial agents used. Several studies showed these effects across different experimental designs. Allaily et al. (2022) stated that the combination of materials significantly affected pH, humidity, and temperature, without changing the C/N ratio in six weeks. Pratiwi et al. (2023) reported EM-4 specifically as the best bioactivator for compost quality. Resman et al. (2021) further stated that the Orgadec and PROMI bioactivators produced the highest-quality compost with a wide range of nutritional parameters. This evidence, which includes three to four studies with fixed factorial experimental designs, provides confidence in the results.

The optimal combination depends on the context, the type of organic waste, and the microbial activator used. Rice straw is an abundant agricultural waste during the harvest season, but has not been optimally used as animal feed or compost material. The potential for rice straw in South Sumatra is 3,330,000 tons per harvest. Most of the rice straw is still burnt, which tends to pollute the environment. Rice straw contains high levels of organic matter, such as cellulose, hemicellulose, and lignin, which have great potential as raw materials for composting. The decomposition process is slow due to the high lignocellulose content, which is difficult to decompose naturally because of the high C/N ratio (around 50:1 to 80:1). Therefore, efforts are needed to accelerate the composting process by using a natural local bioactivator capable of enhancing organic matter decomposition into nutrients. Rice straw can be effectively converted into high-quality compost through a strategic composting method, significantly improving organic waste management and soil fertility. Several studies have shown the potential of rice straw composting under various conditions. Omar et al. (2020) stated that composting rice straw in 42 days with effective microorganisms as well as biochar produced mature and high-quality organic fertilizer. Khalib et al. (2019) showed that maintaining an initial C/N ratio of 30 optimized decomposition, with temperatures exceeding 55 °C.

Biochar is occasionally prepared from rice husks and serves as a soil conditioner, increasing porosity, enhancing water-holding capacity, and providing a growth medium for decomposing microorganisms. The addition of this material significantly improves the quality and characteristics of compost (Zhou et al., 2021). Biochar was previously found to increase the values of some parameters to 5.90% pH, 26.6% germination index, 56.6% nitrate nitrogen, 9.50% total nitrogen, and 10.1% total potassium. Simultaneously, ammonium nitrogen (-33.7%), heavy metals, and greenhouse gas emissions were reduced. Biochar mechanistically increased microbial activity, reduced nutrient loss, and promoted organic matter decomposition (Xiao et al., 2017; Bong et al., 2021).

Cow manure is an excellent composting ingredient that serves as a source of macro and micro nutrients as well as provides active microbes to support organic matter decomposition. This is an effective bioactivator in the composting process, which significantly improves compost quality by promoting decomposition and increasing nutrient content (Sondang et al., 2014). The compost prepared from cow dung contains N ranging from 0.7867–0.8000%, P_2O_5 of 0.5883–0.6000%, and K_2O of 0.5733–0.5883% (Hidayati et al., 2010). Cow dung facilitates the composting process and reduces the C/N ratio (Sondang et al., 2014). A 50:50 combination of cow dung and other animal waste produces the best compost characteristics (Fatimah et al., 2022). Although results vary, cow manure is a valuable component in producing high-quality compost.

This study aimed to identify microorganisms from fermented papaya and determine the bioactivator nutrient content, as well as analyze the effect on composting temperature and the chemical properties of compost prepared from a mixture of rice straw, rice husk biochar, and cow dung. The results provide new information regarding the types of microorganisms, nutrient content, and the optimum dosage of the bioactivator from fermented papaya that is not suitable for consumption, as well as the chemical properties of the produced compost. Furthermore, the results are expected to contribute to the development of efficient, economical, and environmentally friendly natural material-based composting technology.

MATERIALS AND METHODS

Identification of bioactivator microorganisms from fermented papaya

Identification of bioactivator microorganisms was conducted in May 2025 at the Microbiology Laboratory, Sriwijaya University. The bioactivator was prepared from 10 kg of moldy, unfit papaya, which was chopped, blended until smooth, and filtered through a cloth. The resulting liquid was identified for the microbial content. Identification was carried out by growing microorganisms in solid carboxymethylcellulose (CMC) media at 28 °C and an incubation time of 72 hours. Next, visual and microscopic observations were performed using a light microscope with 10x magnification. The CMC media were prepared by dissolving 1.36 g of KH_2PO_4, 1 g of $(NH_4)_2SO_4$, 0.2 g of $MgSO_4 \cdot 7H_2O$, 1 g of yeast extract, 0.01 g of $CaCl_2 \cdot 2H_2O$, 2 g of NaCl, 5 g of CMC, and 15 g of agar in 1.000 mL of distilled water. The solution was placed in an Erlenmeyer flask and heated on a hotplate until boiling and homogeneous. Subsequently, the media was sterilized using an autoclave at a temperature of 121 °C and a pressure of 2 atm for 15 minutes (Gupta et al., 2012).

Nutritional content of fermented papaya as a bioactivator

N content

A total of 10 ml of fermented papaya extract was placed in a boiling flask, then a little boiling stone powder and distilled water were added until the volume reached half the flask. A container for the released ammonia gas (NH_3) was prepared in the form of an Erlenmeyer flask containing 10 ml of 1% boric acid solution with two drops of Conway indicator (red), and connected to the distillation apparatus. Subsequently, 10 ml of 40% NaOH was added to the boiling flask containing the sample and closed immediately. The distillation process was carried out until the volume of distillate in the container reached 50–75 ml and changed color to green. The distillate was titrated with 0.050 N H_2SO_4 until a pink color appeared. The titration volume of the sample (Vc) and blank (Vb) was recorded (Eviati et al., 2023).

P content

A total of 1 ml of the extract and a standard series of PO_4 0–200 ppm were placed into a test tube, then 9 ml of deionized water was added and shaken until homogeneous. Approximately 1 ml of each diluted sample and standard solution was transferred to another test tube, and 10 ml of color reagent P was added. The mixture was shaken using a tube shaker until homogeneous, and left for 30 minutes. The concentration of phosphate (P) in the solution was measured using a spectrophotometer at a wavelength of 889 nm (Eviati et al., 2023).

K content

A total of 1 ml of the extract as in chapter N content and the standard series were introduced into a test tube, then 9 ml of 0.25% La solution was added. The mixture was shaken with a tube shaker until homogeneous. The potassium (K) content was measured using SSA with the standard series as a comparison (Eviati et al., 2023).

Biocomposting and the characteristics

This study was conducted in Telang Sari Village, Tanjung Lago District, Banyuasin Regency, South Sumatra Province, Indonesia, from May to June 2025. The materials used were rice straw, biochar, cow dung, fermented papaya as a bioactivator, and clean water. The biochar nutrient content was pH 8.46, N 1.36%, P 0.68%, K 0.41%, Na 0.23%, Ca 0.54%, Mg 0.11%, C-organic 14.48%, Fe 1.334.34 ppm, Cu 26.52 ppm, Mn 756.23 ppm, Zn 129.13 ppm, S 0.37%, and cation exchange capacity (CEC) 25.42 cmol/kg (Eviati et. al., 2023). Cow dung consisted of moisture content 28.73%, N 1.53%, P 1.18%, K 1.30%, C-organic 14.78%, and C/N ratio 14,32 (Novitasari

and Caroline, 2021). Rice straw contained N 40%, P 30–35%, K 80–85%, and S 40–45% (Center for Agricultural Libraries and Literacy, Ministry of Agriculture, Indonesia, 2025). This study used a completely randomized design (CRD) with four treatments, as presented in Table 1, and each treatment was replicated three times. The variables observed were composting temperature and the chemical properties of the compost, including pH, nitrogen (N), phosphorus (P), potassium (K), organic carbon (C-organic), C/N ratio, CEC, sodium (Na), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn). The data obtained were analyzed using analysis of variance (ANOVA) and continued with Duncan's test at a significance level of 5%.

Biocompost was prepared by weighing 2.25 kg of rice straw, 2 kg of biochar, and 5 kg of cow dung for each experimental unit. The volumes of bioactivator and clean water given to each treatment were P0 = 0 and 0.75 L, P1 = 0.25 and 0.5 L, P2 = 0.5 and 0.25 L, and P3 = 0.75 and 0 L. The composting process was carried out anaerobically using 80 x 60 cm black plastic bags. Composting started by placing about one-third of the rice straw into the plastic bags as the first layer, then spraying with a mixture of bioactivator and clean water until moist. One-third of the cow manure was sprinkled evenly over the straw as a second layer, and sprayed again until moist. The third layer consisted of one-third of the biochar, sprinkled evenly and sprayed until moist. This step was repeated for the remaining rice straw, cow dung, and biochar until all the ingredients were spent. When all the ingredients were added, the plastic bags were tightly tied and kept in a place protected from rain and direct sunlight. Each week, the plastic bags were opened and the compost was removed to be mixed thoroughly, then re-filled and tied. The composting process persisted for four weeks, and the compost was removed from the plastic bags, dried in the sun, and ground for chemical analysis using the following procedure (Eviati et. al., 2023):

a) pH – a total of 5.00 g of 4 mm fine compost was weighed and placed into a shaker bottle, then 25 mL of deionized water was added. The mixture was shaken in a shaker for 30 minutes, and the pH was measured using a pH meter that had been calibrated with buffer solutions of pH 4.0, 7.0, and 10.0.
b) C-organic – a total of 0.05–0.10 g of fine compost was weighed and placed into a 100 mL volumetric flask. Approximately 5 mL of 2 N $K_2Cr_2O_7$ solution was added and shaken, followed by the addition of 7.5 mL of p.a. H_2SO_4 (98%) and another shaking process. The mixture was left for 30 minutes while shaking occasionally. During the preparation of a 250 ppm C standard solution, 5 mL of a 5.000 ppm C standard solution was placed into a 100 mL volumetric flask, then 5 mL of H_2SO_4 and 7 mL of 1 N $K_2Cr_2O_7$ solution were added with the same treatment as before. A blank solution was prepared as a 0 ppm C standard. Each solution was diluted with deionized water, and after cooling, the volume was adjusted to the calibration mark (100 mL), shaken until homogeneous, and left overnight. The next day, absorbance was measured using a spectrophotometer at a wavelength of 587 nm.
c) N-total

- N-organic – a total of 0.500 g of fine compost was placed in a Kjeldahl flask or digester tube. Approximately 0.25–0.50 g of selenium mixture and 3 mL of H_2SO_4 p.a. were added, and shaken until the mixture was even and left for 2–3 hours. The mixture was gradually destroyed at 150 °C until it reached a maximum temperature of 350 °C and a clear liquid was obtained (about 3–3.5 hours). After cooling, the solution was diluted with small distilled water to prevent crystallization. The digestion solution was quantitatively transferred into a

Table 1. Treatments for biocompost preparation

Material	Treatment			
	P0	P1	P2	P3
Rice straw (kg)	2.25	2.25	2.25	2.25
Biochar (kg)	2	2	2	2
Cow dung (kg)	5	5	5	5
Bioactivator (L)	0	0.25	0.5	0.75
Clean water (L)	0.75	0.5	0.25	0

250 mL distillation boiling flask, then deionized water was added to half the volume of the flask and several boiling stones. As a distillate container, 10 mL of 1% boric acid solution was prepared in a 100 mL Erlenmeyer flask with three drops of Conway indicator added. Distillation was carried out by adding 20 mL of 40% NaOH. The distillation process was stopped when the volume of liquid in the Erlenmeyer flask reached ± 75 mL. The distillate obtained was titrated with 0.05 N H_2SO_4 until the final point, which was a change in the color of the solution from green to light pink (A mL). The blank determination was conducted using the same procedure (A_1 mL).

- N-NH_4 – a total of 0.500 g of fine compost was placed in a distillation flask, then a few boiling stones, 0.5 mL of liquid paraffin, and 100 mL of deionized water were added. A blank solution was prepared from 100 mL of deionized water added with boiling stones and liquid paraffin. As a distillate container, 10 mL of 1% boric acid solution was prepared in a 100 mL Erlenmeyer flask, and three drops of Conway indicator were added. Distillation was conducted by adding 10 mL of 40% NaOH solution, and the process was stopped when the volume of liquid in the Erlenmeyer flask reached ±75 mL. The distillate obtained was titrated with a standard solution of 0.05 N H_2SO_4 until the final point, which was the phase the solution changed from green to light pink (B mL). The blank determination was carried out using the same procedure (B_1 mL).
- N-NO_3 – the used solution from the previous determination ($N–NH_4^+$) was allowed to cool, and deionized water (including the blank) was added until it reached the original volume. As a distillate container, 10 mL of 1% boric acid solution was prepared in a 100 mL Erlenmeyer flask, then three drops of Conway indicator were added. Distillation was carried out by adding 2 g of Devarda alloy. The distillation process was started without heating to prevent foam overflow. After the foam was nearly gone, heating was carried out gradually from low temperature to boiling, and raised to normal temperature. Distillation was stopped when the volume of liquid in the Erlenmeyer flask reached ± 75 mL. The distillate obtained was titrated with a standard solution of 0.05 N H_2SO_4 until the final point, namely the color change of the solution from green to light pink (C mL). The blank determination was carried out using the same procedure (C_1 mL).

d) Essential macro and micro elements – a total of 0.5 g of 4 mm fine compost was placed into a digestion vessel, and 5 mL of HNO_3 p.a. was added. The predigestion process was conducted at room temperature for a few moments. The vessel was tightly closed and positioned in a microwave digester, and the power was adjusted according to the type of vessel used. The temperature was raised to 200 °C for 15 minutes, then maintained for 30–60 minutes. The vessel was cooled when the process completed, and the resulting digestion solution was diluted with deionized water to a volume of exactly 50 mL. The solution was shaken until homogeneous and left overnight or filtered using filter paper to obtain the sample extract.

- Measurement of K and Na – a 1 mL sample extract was placed into a 20 mL chemical test tube, and 9 mL of deionized water (or a diluent) was added as well as shaken using a vortex mixer until homogeneous. This solution was the result of a 10-fold dilution process. The potassium (K) and sodium (Na) contents were determined using a flame photometer or atomic absorption spectrophotometer (AAS), then the absorbance value was recorded.
- Measurement of P – A total of 1 mL of sample extract and 1 mL of each standard phosphorus (P) series solution were placed in a chemical test tube. Approximately 9 mL of deionized water was added and shaken until homogeneous (10-fold dilution), then 1 mL of phosphorus dye reagent was added. The solution was shaken using a test tube shaker until homogeneous and allowed to stand for 30 minutes. The phosphorus content in the solution was measured using a spectrophotometer at a wavelength of 889 nm. Dilution was carried out when the sample absorbance exceeded the highest absorbance of the standard series.
- Measurement of Ca and Mg – a total of 1 mL of sample extract was placed into a 20 mL chemical tube, and 9 mL of deionized water and 1 mL of 25,000 ppm La solution were added. Approximately 10 mL of each standard series solution of calcium (Ca) and magnesium (Mg) (standard mixture I) were placed into the chemical tube, and 1 mL of 25,000 ppm La solution was added to each. The solution was shaken with a vortex mixer until

homogeneous, then measured using an AAS and the absorbance value was recorded.

- Measurement of micro elements (Fe, Mn, Cu and Zn)

The microelements in the sample extract were measured directly using AAS, and the results were compared to a standard series. To determine iron (Fe), the sample extract was diluted up to 10 times before measurement.

RESULTS AND DISCUSSION

Identification of bioactivator microorganisms

The bioactivator isolation results showed 20 microbial species, consisting of 11 bacterial isolates and nine fungal isolates. After being grown on CMC media, six fungal isolates signified the potential to produce cellulolytic enzymes, as evidenced by the formation of clear zones. However, morphological identification results showed that the six isolates shared several similarities, leaving three fungal isolates with distinct morphological characteristics. Macroscopic and microscopic identification of the bioactivator showed the presence of *Rhizopus oryzae* and *Aspergillus niger* fungi, which presented cellulolytic activity (Figures 1–2, Table 2).

Nutritional content of fermented papaya as a bioactivator

The analysis results showed that the bioactivator contained 0.890% N, 0.244% P, and 0.250% K. The presented nutrient contents support the activity of microorganisms in the composting process by promoting a more rapid decomposition of organic materials into nutrients. This can be observed from the increase in composting temperature in the treatment with the addition of the bioactivator (Table 3). The decomposition of organic matter is strongly influenced by nutrient content, with the effects appearing complex, being phase-dependent, and varying according to nutrient type. Gill et al. (2022) reported that nitrogen specifically increased the early phase of decomposition while slowing down the late phase process. This emphasizes the complex as well as nonlinear relationship between nutrient content and organic matter decomposition. Phosphorus plays a complex role in modulating the activity of microorganisms in organic matter decomposition, with effects varying depending on the phosphorus

Table 2. The results of identification of bioactivator microorganisms

No.	Isolate code	Clear zone width (mm)	Colony width (mm)	Cellulolytic index	Types of microorganisms
1.	I-1	38	34	0.12	Mold
2.	I-2	32	28	0.14	Mold
3.	I-3	34	30	0.12	Mold
4.	I-4	30	28	0.072	Mold
5.	I-5	10	8	0.25	Mold
6.	I-6	0	36	0	Mold
7.	I-7	0	37	0	Mold
8.	I-8	0	41	0	Mold
9.	I-9	30	29	0.035	Mold
10.	I-10	0	3	0	Bacteria
11.	I-11	0	2	0	Bacteria
12.	I-12	0	5	0	Bacteria
13.	I-13	0	4	0	Bacteria
14.	I-14	0	3	0	Bacteria
15.	I-15	0	5	0	Bacteria
16.	I-16	0	4	0	Bacteria
17.	I-17	0	3	0	Bacteria
18	I-18	0	3	0	Bacteria
19.	I-19	0	4	0	Bacteria
20.	I-20	0	5	0	Bacteria

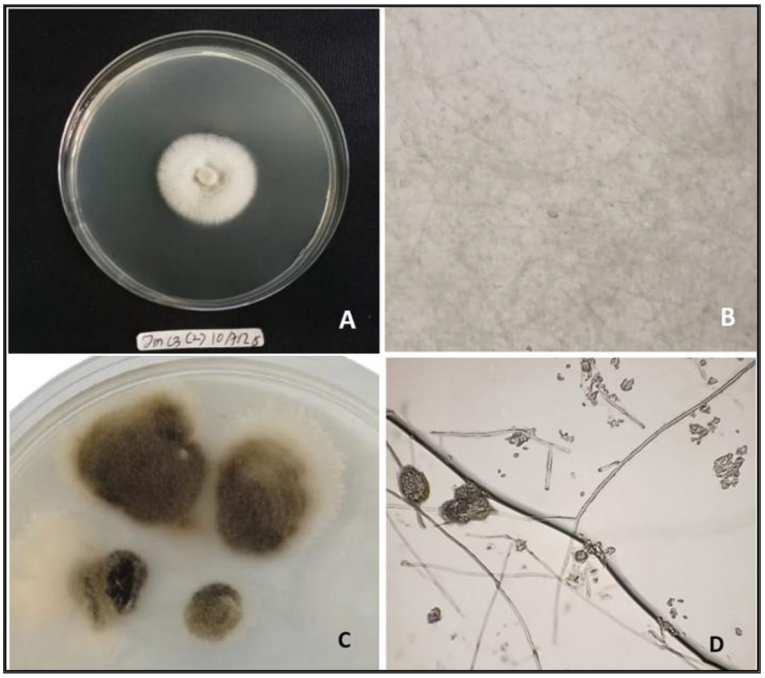

Figure 1. *Rhizopus oryzae* colony (A), microscopic *Rhizopus oryzae* (B), *Aspergillus niger* colony (C), and microscopic *Aspergillus niger* (D)

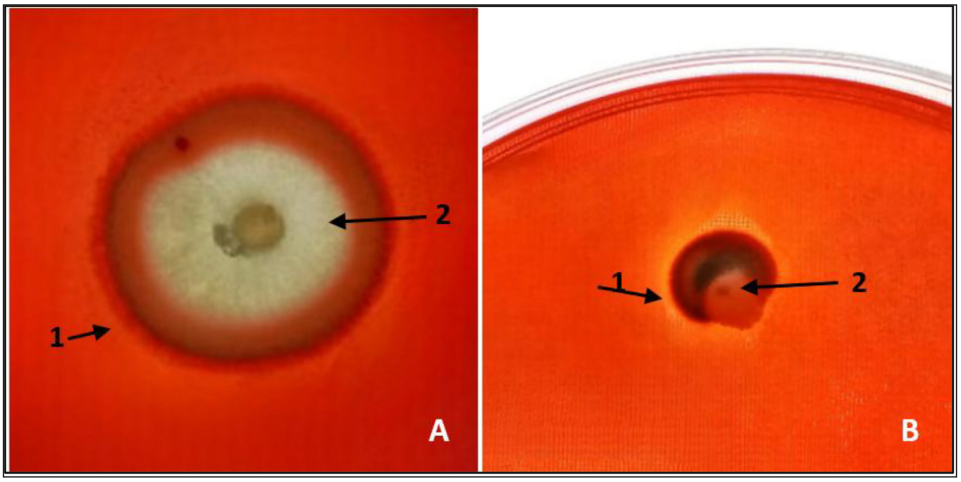

Figure 2. Clear zone (1) and colony of microorganisms (2) from the cellulolytic activity of *Rhizopus oryzae* (A) and *Aspergilus niger* (B)

source and the ecosystem. Several studies have shown that phosphorus significantly influences microbial decomposition processes. Mori et al. (2015) stated that the addition of P reduced microbial respiration in litter decomposition, potentially increasing the respiration efficiency. Chávez-Ortiz et al. (2024) further stated that different phosphate molecules have various impacts on microbial carbon mineralization and enzyme activity. Potassium from organic matter significantly affects the activity of microorganisms, with stimulatory and inhibitory effects depending on the concentration during organic matter decomposition. Pereira et al. (2019) reported that KCl doses above 400 mg dm-3 reduced soil microbial activity and nitrogen mineralization.

Biocomposting and characteristics

Composting temperature

Observations showed that there were temperature differences between treatments over the four weeks of observation. However, the overall pattern of temperature changes was relatively

similar (Figure 3). Temperatures increased from the onset to the second week of observation, then decreased until the fourth week. The increase until the second week signifies enhanced microbial activity, while the following decrease represents reduced microbial activity. The availability of organic matter in the compost mixture greatly influences the activity of the microorganisms. The higher the organic matter content, the higher the microbial activity, as microorganisms decompose organic matter into nutrients. The microorganisms that decompose organic matter, particularly sugars and simple carbohydrates, release heat as a by-product of this exothermic metabolic process. Oxygen availability, pile size, and water content influence the rate of decomposition and heat production. The better the aeration and the greater the number of microorganisms, the higher the temperature produced.

Bioactivator consistently accelerates organic matter decomposition during the composting process by influencing temperature dynamics. Ulhasanah et al. (2022) reported that the EM4 bioactivator increased the waste temperature to above 32 °C, compared to 31 °C without the bioactivator. Sumiyati et al. (2022) observed temperature variations between treatments with and without a local microorganism bioactivator (LMB). Yanqoritha et al. (2023) reported an ideal composting temperature of 30–45 °C, which was triggered and maintained by bioactivator. Temperature changes signify increased microbial activity, which facilitates organic matter decomposition. The specific temperature increase varies depending on the type of bioactivator and organic matter, but bioactivator effectively modulates the decomposition temperature, leading to a reduction in composting time and rise in overall process efficiency. Composting is complete when the temperature has reached approximately 30 °C (Dewilda *et al*., 2019).

Microbial activity and enzymatic processes are increased by the bioactivator to significantly enhance organic matter decomposition. Jurado et al. (2015) found that the inoculated composting piles showed 28% higher hemicellulose degradation, 21% increased cellulose breakdown, and 25% enhanced lignin decomposition compared to the uninoculated piles. Marques et al. (2022) reported that a bioactivator promoted higher soil microbial biomass carbon and basal respiration. Legawati et al. (2025) further confirmed that microbial consortia were more effective in reducing the C/N ratio of organic matter to optimal levels. A bioactivator not only accelerated decomposition but also increased the overall efficiency of organic matter conversion.

The temperatures of treatments P3 and P2 in the first week were higher and significantly different ($P<0.05$) compared to P0 and P1. These results show that the microbial activity in P3 and P2 was higher than in P0 and P1 due to the addition of a bioactivator containing microorganisms and nutrients. However, the addition of the bioactivator to P1 did not show significant results. Temperatures in the second to fourth weeks did not differ significantly between treatments. Composting temperature is influenced by the type of organic material through the chemical composition and microbial decomposition potential. Various organic materials produce different temperatures based on the C/N ratio and biodegradability (Zein et al., 2015).

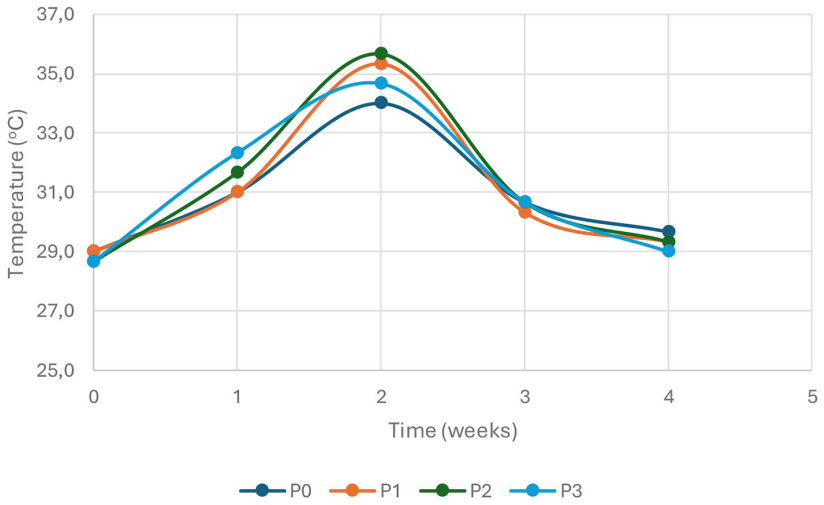

Figure 3. Temperature graph for the composting process

El Boudihi et al. (2024) (El Boudihi et al., 2024) reported that a compost mixture containing prunings, lignocellulosic materials, cow dung, and household waste showed different temperature dynamics. The composting process occurs through temperature phases, including initial mesophilic, thermophilic, and maturation (Nemet et al., 2021). The materials with high biodegradability and balanced nutritional content tend to produce more consistent and higher temperatures. The factors affecting temperature include substrate particle size, air content, and initial microbial population.

The large difference in decomposition time occurs because composting is an accelerated and controlled process, whereas natural rice straw decomposition takes place under uncontrolled field conditions. During composting, microbial activity, nutrient availability, aeration, moisture, and temperature are deliberately optimized to enhance decomposition, while natural decomposition is subject to variable and often unfavorable environmental conditions. The main factors contributing to this difference are explained as follows: (1) Microbial activity during composting is optimized by the addition of specific decomposer microorganisms, such as *Bacillus*, *Trichoderma*, *Aspergillus*, and effective microorganisms (EM), which increase the abundance of microbes capable of degrading cellulose and hemicellulose. Such microbial interventions can dramatically accelerate rice straw decomposition from 8–32 months under natural conditions to approximately 4 weeks under controlled composting. In this study, the addition of *Rhizopus oryzae* and *Aspergillus niger* derived from fermented papaya as bioactivator accelerated the decomposition of rice straw. Studies have shown that targeted microbial consortia significantly enhance lignocellulosic degradation. Sarma et al. (2022) demonstrated that a novel microbial consortium achieved complete compost maturation within 25 days, with cellulose and hemicellulose degradation rates of 64% and 87%, respectively. Similarly, Dash et al. (2021) reported that selected bacterial and fungal strains reduced lignin content from 8.9–9.5% to 6.6–7.9% within 28 days. This accelerated decomposition is driven by enhanced enzymatic activities, including β-glucosidase, cellulase, and laccase, which rapidly break down complex plant polymers. Consequently, microbial intervention transforms slow, passive natural decomposition into an active and controlled composting process; (2) Natural decomposition relies solely on native soil microorganisms, which are generally fewer in number and less efficient. On the other hand, microbial activity under natural conditions is often constrained by environmental stresses; (3) Controlled environmental conditions during composting are maintained by keeping moisture at an optimal level (approximately 50–60%) and ensuring adequate aeration through regular turning of the compost pile. These conditions enhance enzymatic activity and microbial metabolism; (4) During natural decomposition, environmental conditions, such as temperature, oxygen availability, and moisture fluctuate and remain largely uncontrolled. Rice straw is often waterlogged, creating anaerobic conditions that substantially slow the decomposition process; (5) In composting, the C/N ratio is adjusted by adding nitrogen-rich materials, such as manure, urea, or green biomass to maintain an optimal range of 25–30; (6) Under natural conditions, nitrogen supplementation does not occur, resulting in nitrogen limitation that restricts microbial growth; (7) Physical pretreatment of rice straw during composting, such as chopping or shredding, increases surface area and improves the contact between microorganisms, oxygen, and organic matter; (8) Under natural decomposition, rice straw remains largely intact and compact, resulting in limited surface area and reduced microbial access; (9) Accelerated decomposition during composting rapidly progresses through the mesophilic, thermophilic, and maturation phases, allowing easily degradable compounds to be broken down efficiently. Complete humification is not required to achieve compost maturity; (10) Natural

Table 3. Temperature in the composting process (°C)

Treatment	Time (week)				
	0	1	2	3	4
P0	29.0±0.0^{a}	31.0±0.0^{a}	34.0±1.0^{a}	30.7±0.6^{a}	29.7±0.6^{a}
P1	29.0±0.0^{a}	31.0±0.0^{a}	35.3±2.1^{a}	30.3±0.6^{a}	29.3±0.6^{a}
P2	28.7±0.6^{a}	31.7±0.6^{ab}	35.7±1.5^{a}	30.7±0.6^{a}	29.3±0.6^{a}
P3	28.7±0.6^{a}	32.3±0.6^{b}	34.7±0.6^{a}	30.7±0.6^{a}	29.0±0.0^{a}

Note: ^{a,b} different superscripts in the same column represent significant differences (P<0.5).

Table 4. Chemical characteristics of compost results

Variable	Treatment			
	P0	P1	P2	P3
pH	9.64±0.12[a]	9.67±0.08[a]	9.65±0.10[a]	9.69±0.02[a]
N (%)	1.58±0.04[a]	1.61+0.04[a]	1.64±0.5[a]	1.59±0.02[a]
P (%)	0.75±0.03[a]	0.82±0.05[a]	0.80±0.04[a]	0.79±0.01[a]
K (%)	1.24±0.05[a]	1.14±0.03[a]	1.19±0.08[a]	1.16±0.09[a]
C-organic (%)	22.52±3.93[a]	22.31±1.61[a]	19.83±1.5[0]a	20.53±0.81[a]
C/N ratio	14.30±2.85[a]	13.88±1.35[a]	12.08±0.67[a]	12.89±0.63[a]
CEC (cmol/kg)	21.50±2.82[a]	20.42±3.56[a]	31.06±5.19[b]	30.28±1.38[b]
Na (%)	0.16±0.00[a]	0.17±0.01[a]	0.16±0.01[a]	0.16±0.01[a]
Mg (%)	0.56±0.13[a]	0.41±0.03[a]	0.33±0.16[a]	0.53±0.13[a]
Fe (ppm)	1,565.93±15.02[a]	1,665.91±458.00[a]	1,683.40±808.16[a]	1,738.28±213.61[a]
Cu (ppm)	61.12±4.10[a]	50.73±10.51[a]	44.16±15.02[a]	47.49±9.26[a]
Mn (ppm)	1,972.94±31.15[a]	2,008.68±145.36[a]	1,967.84±47.37[a]	1,920.38±63.37[a]
Zn (ppm)	250.06±17.66[a]	264.09±28.63[a]	243.63±3.03[a]	243.64±15.58[a]

Note: [a,b]different superscripts in the same row represent significant differences (P<0.5).

decomposition proceeds slowly, particularly for lignin- and silica-rich rice straw, and full stabilization into soil organic matter requires a much longer time; (11) The end goals of the two processes differ: composting (≈4 weeks) produces a biologically stable material that is safe for soil application, whereas natural decomposition (8–32 months) results in the full integration of rice straw into soil organic matter (humus).

Chemical characteristics of the compost produced

The observations on the chemical properties of biocompost showed that bioactivator addition had a significant effect (P<0.05) on the CEC value, while other chemical properties had no significant effect (P>0.05) (Table 4). However, bioactivator addition tended to decrease the C-organic content and C/N ratio. As presented in Table 4, the CEC values in treatments P3 and P2 were higher and significantly different (P<0.05) compared to P0 and P1. This is attributed to the higher negative charge in P3 and P2 compared to P0 and P1 because of the rapid decomposition process of organic matter, as previously explained. During the composting process, organic matter decomposes into stable, negatively charged humus. This negative charge attracts and retains cations such as K^+ (potassium), Ca^{2+} (calcium), and Mg^{2+} (magnesium), thereby increasing the CEC value. Microorganism bioactivator can significantly increase the CEC of organic matter during decomposition by promoting microbial activity and organic matter transformation. Specifically, Valarini et al. (2002) found that incorporating effective microorganisms increased polysaccharide production and enzyme activities, directly correlating with improved CEC.

CONCLUSIONS

In conclusion, macro and microscopic identification of the bioactivator derived from fermented papaya showed the presence of Rhizopus oryzae and Aspergillus niger containing cellulolytic activity. The bioactivator addition improved the composting process, as signified by increased temperature and CEC, and tended to decrease the organic carbon content as well as the C/N ratio of the compost. A decrease in the latter two variables represented successful biocomposting. The maximum temperature occurred in the second week of observation. In the first week, the highest temperature was in treatment P3 (32.3 ± 0.6 °C), followed by P2 (31.7 ± 0.6 °C), P1 (31.0 ± 0.0 °C), and P0 (31.0 ± 0.0 °C). In the second week, the highest temperature was in P2 (35.7 ± 1.5 °C), followed by P1 (35.3 ± 2.1 °C), P3 (34.7 ± 0.6 °C), and P0 (34.0 ± 1.0 °C). The highest CEC value was obtained at P2 (31.06 ± 5.19 cmol/kg), followed by P3 (30.28 ± 1.38 cmol/kg), P1 (21.50 ± 2.82 cmol/kg), and P0 (20.42 ± 3.56 cmol/kg). The lowest C-organic levels were found in P2 (19.83 ± 1.50%), followed by P3 (20.53 ± 0.81%), P1 (22.31 ± 1.61%), and P0 (22.52 ± 3.93%). The

lowest C/N ratio was in P2 (12.08 ± 0.67), followed by P3 (12.89 ± 0.63), P1 (13.88 ± 1.35), and P0 (14.30 ± 2.85), signifying that bioactivator administration was optimal at P2.

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