INFLUENCE OF BIOACTIVATOR DOSAGE ON MICROBIAL DENSITY AND PHYSICOCHEMICAL DEVELOPMENT DURING FOOD WASTE COMPOSTING

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Abstract

Food waste composting is strongly influenced by microbial activity, particularly during the initial degradation and stabilization stages. The addition of bioactivators can introduce or stimulate microorganisms capable of accelerating organic matter decomposition. However, the response may vary depending on the type and dosage of bioactivator applied. This study investigated the effect of different bioactivator dosages on microbial density and composting performance of food waste mixed with chopped dry leaves. The experiment was conducted using three bioactivator types, namely stale-rice bioactivator (A1-A3), papaya bioactivator (B1-B3), and a combination of stale rice and papaya bioactivators (C1-C3), each applied at low, medium, and high dosages. Microbial density was determined using the Total Plate Count (TPC) method with serial dilution, while composting performance was evaluated based on temperature, pH, colour, odor, and the progression of decomposition. The results showed that the response of microbial density to increasing dosage was bioactivator-dependent. The papaya treatment exhibited the clearest dose-dependent increase, with microbial densities of 3.1×10^5, 8.7×10^5, and 4.2×10^6 CFU/mL in B1, B2, and B3, respectively. In contrast, stale rice and combined bioactivators showed non-linear responses, indicating that higher dosage did not necessarily produce a higher culturable microbial density. The E1/E1 control treatment showed slower composting progression without bioactivator addition, with the temperature gradually decreasing and pH stabilizing near neutral as decomposition progressed. Nevertheless, the high dose treatments generally showed stronger temperature responses, while pH gradually shifted from acidic to near-neutral conditions as decomposition progressed. Changes in colour and odor further supported the transition from active decomposition toward stabilization. These findings indicate that microbial density alone cannot fully explain composting performance, as microbial, oxygen conditions, and microbial interactions. Therefore, bioactivator dosage should be evaluated based on the integrated response of microbial density and physicochemical indicators to determine its effectiveness in accelerating food waste composting.

Keywords: *Bioactivator Dosage, Microbial Density, Food Waste Composting, Total Plate Count, Composting Performance, Microbial Activity.*

A. INTRODUCTION

Food waste is highly biodegradable organic material containing readily degradable compounds, making it suitable for composting but also susceptible to rapid acidification, odor formation, and physicochemical fluctuations during early decomposition. The composting process is primarily driven by microorganism that degrade organic substrates and regulate the transformation of organic matter, temperature, pH, and humification (Y. Wang et al., 2022a). The addition of bioactivators or microbial inoculants has therefore been widely investigated to accelerate organic matter degradation and improve composting efficiency by stimulating microbial activity and succession (He et al., 2022). However, the effectiveness of bioactivators is not necessarily proportional to their dosage because microbial growth and activity are also affected by substrate availability, moisture, oxygen, temperature, pH, and interactions among microbial populations (Zhu et al., 2023). Consequently, a higher bioactivators dosage may increase the initial microbial activity or decomposition rate. This distinction is particularly important when microbial density is evaluated using the Total Plate Count (TPC) method, because culturable microbial density does not necessarily represent the entire microbial community or its metabolic activity. Changes in temperature and pH can therefore provide complementary evidence of microbial activity and decomposition, while colour and odor can indicate the progression of organic matter transformation and stabilization (Wang et al., 2024). Previous studies have demonstrated that microbial inoculation can enhance organic matter degradation, microbial succession, and humification during food-waste composting (Mironov et al., 2024), but the relationship between bioactivator dosage, culturable microbial density, and composting progression remains insufficiently understood, particularly for locally prepared bioactivators with different microbial sources (Liu et al., 2023).

B. METHOD

This experimental study evaluated the effect of bio-activator dosage on microbial density and composting time using stale rice-based local microorganism (LMO), papaya-based LMO, and mixed papaya and stale rice, comparing without LMO. Papaya LMO was prepared on 22-31 May 2026 which B1 and B2 treatment was surveying on 22 May-31 May 2026 and B3 from 23 May-1 June 2026, stale rice LMO was examined from 11 June-16 June 2026 for A1 and 12 June-16 June for A2 and A3, and mixed papaya-stale rice LMO was surveyed for C1 on 2 July-10 July 2026 and 3 July-10 July 2026 and compared with controlled treatment (E1/E1) for 12 May-30 May 2026. Composting was conducted using 1 kg of food waste collected from the cafeteria of PLN Ketintang, Surabaya, mixed with 0.8 kg of chopped dry leaves in a 15 L used gallon reactor with passive aeration and manually stirred every 24 hours (Putri et al., 2024). Each bio-activator was applied at three dosage levels, namely 25% (low), 50%, (medium) and 75% (high) as a method of experimental (Setiani et al., 2023). Microbial density was determined through laboratory analysis using the Total Plate Count (TPC) method with serial dilution and expressed as CFU/mL (Olu-Taiwo et al., 2021). The microbial density results were analyzed descriptively by comparing microbial density among the low, medium, and high bio-activator dosage treatments and relating the results to composting time to evaluate the effectiveness of each dosage in accelerating the composting process. Composting performance was also supported by observations of temperature, pH, colour, texture, odor, and shrinkage based on SNI 19-7030-2004 (Nasional Indonesia, 2004).

C. RESULTS AND DISCUSSION

The effect of stale-rice bioactivator dosage was evaluated based on microbial density and changes in composting characteristics, including temperature, pH, colour, odor, texture, and shrinkage. Microbial density reflects the population of viable microorganisms, while these physical and chemical changes indicate the progression of organic matter decomposition. The addition of local microorganisms can enhance microbial activity and accelerate organic matter decomposition during composting (Alimuddin et al., 2024).

Table 1. Treatment, Dosage and Microbial Density of Papaya

Treatment	Dosage	Microbial density
A1	Low (25%)	85 x 10^3 CFU/mL
A2	Medium (50%)	35 x 10^1 CFU/mL
A3	High (75%)	26 x 10^3 CFU/mL

Table 2. Treatment, Dosage and Microbial Density of Stale Rice

Treatment	Dosage	Microbial density
B1	Low (25%)	3.1 x 10^3 CFU/mL
B2	Medium (50%)	8.7 x 10^1 CFU/mL
B3	High (75%)	4.2 x 10^3 CFU/mL

Table 3. Treatment, Dosage and Microbial Density of Mixture

Treatment	Dosage	Microbial density
C1	Low (25%)	72 x 10^3 CFU/mL
C2	Medium (50%)	9 x 10^3 CFU/mL
C3	High (75%)	34 x 10^3 CFU/mL

Density

The stale-rice bioactivator showed a non-lineat response to dosage, with A1, A2, and A3 recording microbial densities of 85 x 10^3, 35 x 10^1, and 26 x 10^3 CFU/mL, respectively, at 10^{-3} dilution, thus, increasing dosage did not directly increase culturable microbial density, although A3 produced the strongest thermal response at 45℃ compared with approximately 39℃ in A1 and 38℃ in A2, indicating that TPC does not necessarily represent microbial metabolic activity because temperature is more closely associated with microbial respiration and organic matter degradation (Mironov et al., 2021). The papaya bioactivator showed microbial densities of 3.1 x 10^3 CFU/mL in B1, 8.7 x 10^1 CFU/mL in B2, and 4.2 x 10^3 CFU/mL in B3, with the treatments initially reaching approximately 40-42℃ before decreasing as readily degradable substrate were consumed (Santosa et al., 2023). Similarly, the combined stale-rice and papaya bioactivator showed a non-linear response, with C1, C2, and C3 recording 72 x 10^3, 9 x 10^3, and 34 x 10^3 CFU/mL, respectively, while their temperatures increased from approximately 36℃, 38℃, and 39℃, indicating that C3 had greater metabolic activity despite its lower TPC than C1 (L. Zhang et al., 2023). The control treatment contained indigenous microorganisms exceeding 10^5 CFU/mL at 10^{-1} until 10^{-3} dilutions but showed slower composting without additional inoculation, with pH increasing from 4.5 to 8.5 and stabilizing at 7.0-7.3, temperature decreasing from approximately 39-41℃ to 32℃ over 19 days, and surface reduction reaching 16.2-17.5 cm compared with approximately 15.6-16.2 cm by Day 10 in papaya treatments. These results demonstrate that high TPC does not necessarily indicate faster composting because TPC measures only culturable microorganisms, whereas LMO addition can stimulate microbial activity and succession, thereby accelerating organic matter degradation, heat generation, pH stabilization, and physical shrinkage (Zhang et al., 2021).

pH

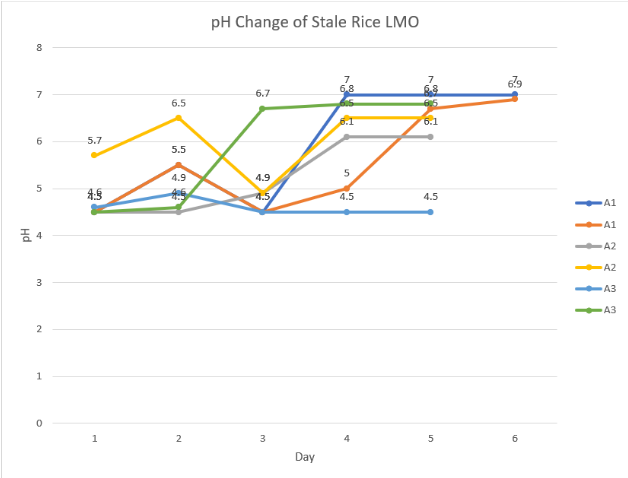

Figure 1. pH Change of Stale Rice LMO

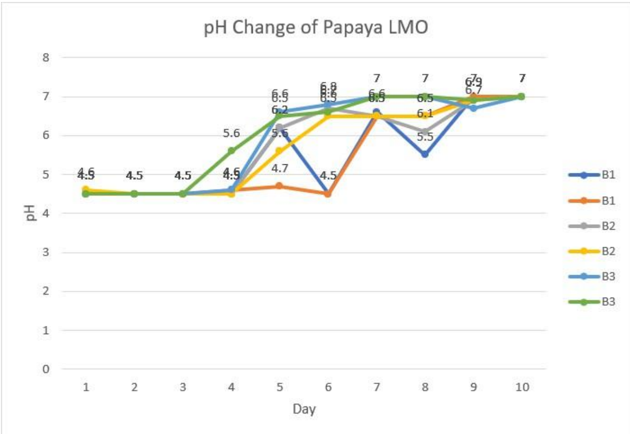

Figure 2. pH Change of Papaya LMO

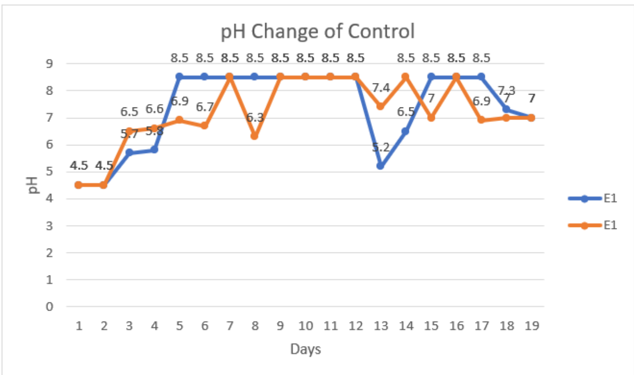

Figure 3. pH Change of Control

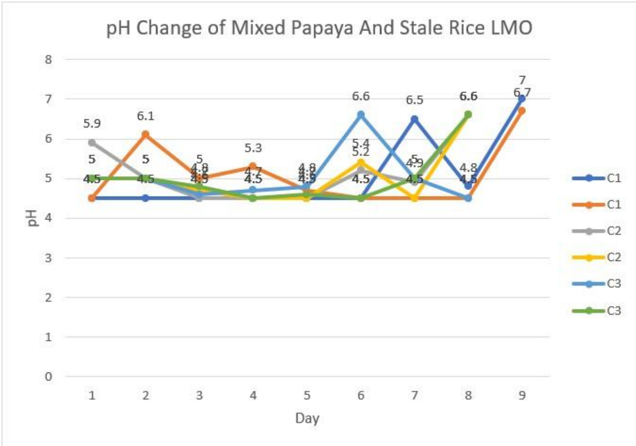

Figure 4. pH Change of Mixed Papaya and Stale Rice LMO

The pH of the compost varied among treatments and generally shifted from acidic toward neutral conditions. In stale rice treatments, A1 temporarily increased from pH 4.5 to 5.5 before reaching approximately 7.0, A2 gradually increased to 6.1-6.5, and A3 increased from 4.5-4.9 to 6.7-6.8 (Palaniveloo et al., 2020). In the papaya treatments, B1 remained acidic longer, B2 increased more rapidly, and B3 reached approximately 6.5-6.6 by 26-27 May 2026, indicating faster acid reduction at the higher dosage (Heureux et al., 2022). For the combined bioactivator, C1 remained at 4.5 from 2-6 July before reaching 7.0 on 10 July, while C2 and C3 fluctuated from approximately 5.9-5.0 and 5.0 to 4.5, respectively, before reaching 6.6 at end. These initial acidic conditions were associated with organic acid production from readily degradable carbohydrates, while the subsequent pH increase resulted from microbial degradation of these acids and nitrogen-containing compounds (Cheng et al., 2023). The control showed a similar but slower pattern, increasing from 4.5 on Days 1-2 to 5.7-6.6 on Days 3-4, reaching 8.5 from Day 5, and returning to 7.0-7.3 on Days 18-19, reflecting indigenous microbial activity and subsequent stabilization. Overall, bioactivator addition generally accelerated the transition from acidic to neutral conditions, although fluctuations depended on the balance between acid production and degradation (Hwang et al., 2020).

Temperature

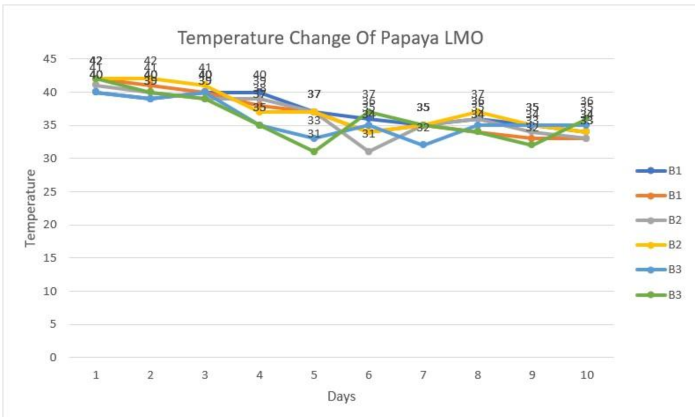

Figure 5. Temperature Change of Papaya LMO

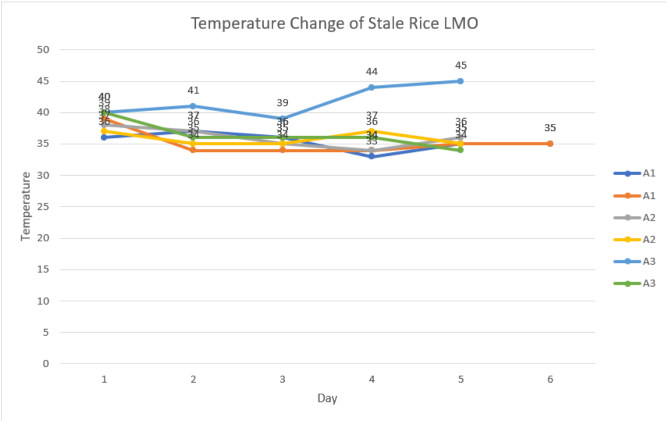

Figure 6. Temperature Change of Stale Rice LMO

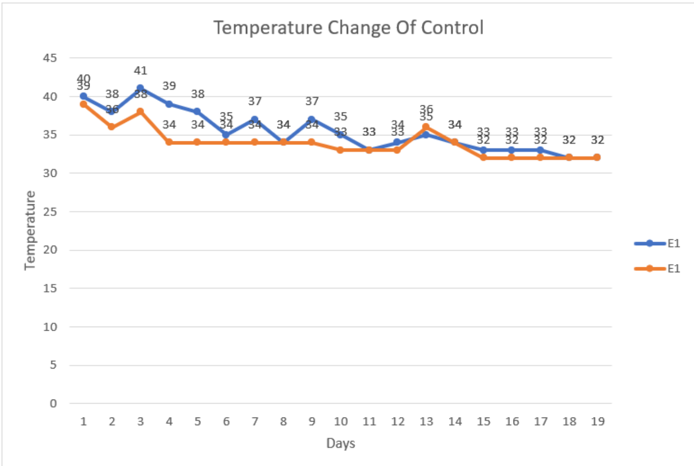

Figure 7. Temperature Change of Control LMO

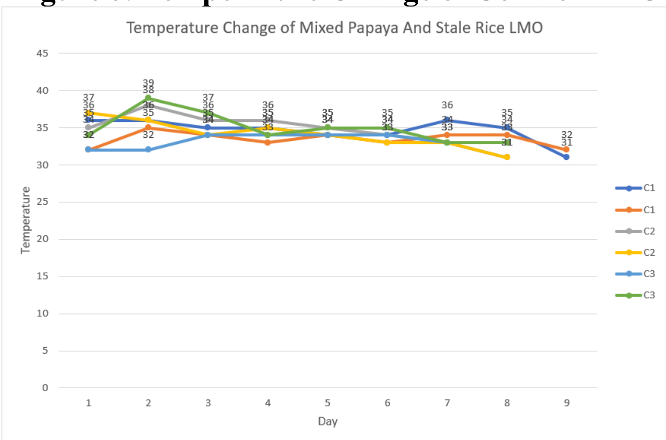

Figure 8. Temperature Change of Mixed Papaya and Stale Rice LMO

Temperature development reflected microbial activity during composting, with all treatments showing higher temperatures during initial decomposition stage followed by a decline as readily degradable substrates were depleted. In the stale rice treatments, A3 showed the strongest thermal response, reaching 45°C, compared with approximately 39°C in A1 and 38°C in A2, indicating greater microbial metabolic activity at the higher dosage (Palaniveloo et al., 2020). In the papaya treatments, B1, B2, and B3 initially reached approximately 40-42°C and decreased to around 33-35°C, 33-34°C, and 35-36°C, respectively, by the end of composting (Finore et al., 2023). The combined treatments showed lower initial temperatures, with C1 increasing from approximately 36°C and declining to 31°C, C2 reaching 38°C before declining to 31°C, and C3 reaching 39°C before remaining at approximately 33-35°C (Zhu et al., 2024). Meanwhile, the control initially reached approximately 39-41℃ and gradually decreased to 32℃ by Days 18-19. The initial temperature increase was associated with heat released through microbial respiration and organic matter degradation, while the subsequent decline indicated reduced availability of easily degradable substrates and progression toward stabilization. Differences among treatments may also have been influenced by moisture, oxygen availability, and the distribution of organic materials within the reactors (Nigussie et al., 2021).

Surface Height

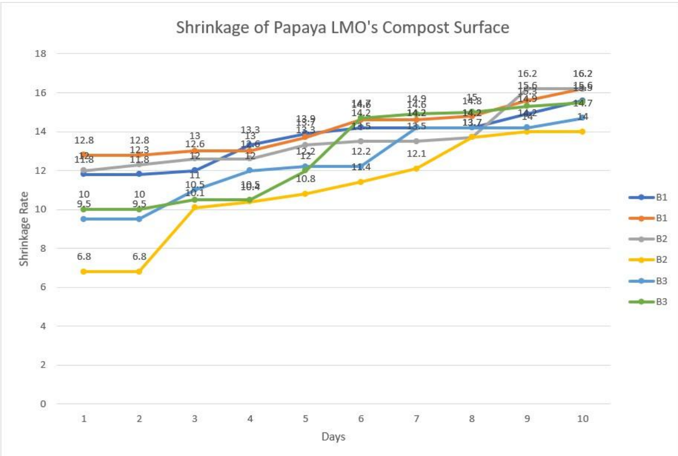

Figure 9. Shrinkage of Papapya LMO's Compost Surface

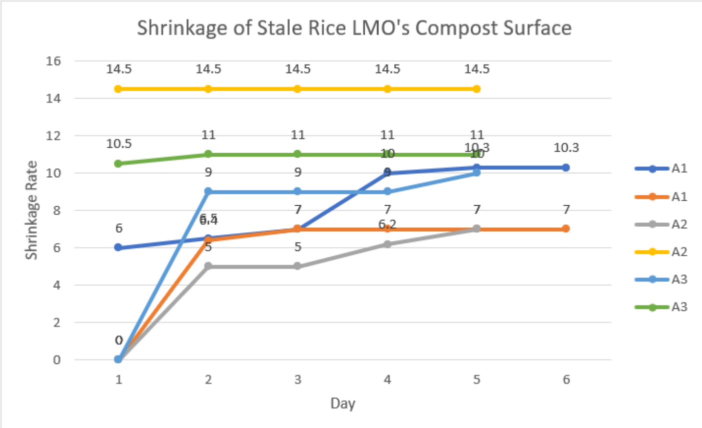

Figure 10. Shrinkage of Stale Rice LMO's Compost Surface

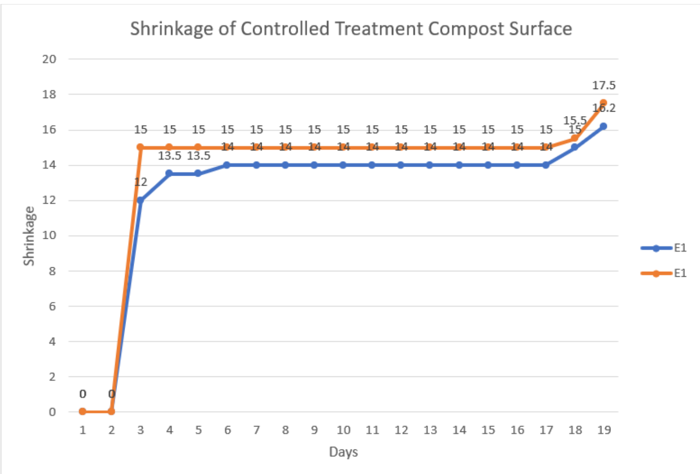

Figure 11. Shrinkage of Controlled Treatment Compost Surface

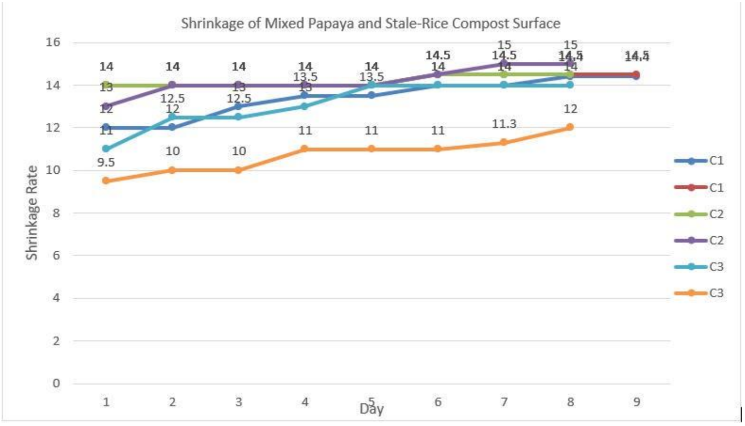

Figure 12. Shrinkage of Mixed Papaya and Stale Rice Compost Surface

The reduction in compost surface height indicated physical changes resulting from organic matter degradation, carbon loss, water loss, and particle settling during composting. In the stale-rice treatments, A1 increased from 6 cm to 10.3 cm, A2 showed differences between replicates of 5-7 cm and 14.5 cm, while A3 increased from 9-10 cm to 10.5-11 cm (Murugesan & Amarnath, 2020). In the papaya treatments, B1 increased from 11.8-12.8 cm to 15.6-16.2 cm, B2 from 6.8 cm to 14.0-16.2 cm, and B3 from 9.5-10 cm to 14.7-15.5 cm, with B2 showing the greatest early reduction from 6.8 to 10.1 cm by Day 3 (Ye et al., 2023). The combined treatments showed smaller changes, with C1 increasing from 12-14 cm to 14.4-14.5 cm, C2 from 13-14 cm to 14.5-15 cm, and C3 from 9.5-11 cm to 12-14 cm (F. Wang et al., 2024). Meanwhile, the control showed little reduction during the first two days but reached 16.2-17.5 cm by Day 19. The greater and earlier surface reduction in the bioactivator treatments indicates that microbial activity accelerated decomposition and structural breakdown, although differences between replicates may have resulted from variations in moisture, aeration, microbial activity, and material distribution within the reactors. This indicates that LMO addition enhance microbial activity and accelerate substrate degradation, thereby promoting greater material shrinkage within shorter (Murugesan & Amarnath, 2020).

Color Change

Color changes in A1-A3 indicated gradual decomposition, with all treatments changing from brown to dark brown by June 13-16, while A2 showed the most advanced darkening with a blackish color on June 14 (Kong et al., 2024). In B1-B3, decomposition progressed from recognizable food waste to increasingly blackish material, with B3 showing earlier decomposition and better integration with dry leaves, suggesting a faster decomposition process at the higher LMO dose (Sokač Cvetnić et al., 2024). While C1-C3 showed similar color development from dark brown toward black, indicating that dosage differences were more apparent during early stage than in the final appearance (Gao et al., 2021). In E1/E1, the compost gradually changed from brown to pale brownish-black by May 29-30. These color changes occurred because microbial decomposition continued, the original food waste became darker due to the formation and accumulation of more stable organic matter. The darker color therefore indicated that the composting materials were undergoing further degradation and stabilization (Duan et al., 2021).

Odor

Odor changes in A1-A3, B1-B3, C1-C3, and E1/E1 reflected the progressive decomposition of organic matter through microbial activity. In A1-A3, the odor generally decreased from strong or mild sour odors toward neutral or earthy odors, although A3 still showed a rotten odor in one replicate, which May indicate localized oxygen limitation or undecomposed food residues (Tran et al., 2024).

Similarly, B1-B3 showed decreasing sour or food waste like odors, but B3 retained a slight sour odor despite its higher microbial density, indicating that odor development was influenced not only by microbial density but also by organic acid production, substrate availability, moisture, and oxygen conditions (Xie et al., 2023). In C1-C3, sour odors during the early stage gradually decreased and an earthy odor appeared by approximately July 9, indicating reduced accumulation of organic acids and volatile compounds as decomposition progressed (Jiang et al., 2023). In E1/E1, the odor changed from fresh or strong organic during May 12-18 to milder and increasingly earthy from May 19-30 as readily biodegradable compounds such as carbohydrates, proteins, and lipids were consumed by indigenous microorganisms, while the remaining dry leaves could prolong stabilization because cellulose, hemicellulose, and lignin degrade more slowly. Overall, the transition from sour or organic odors toward earthy odors indicated progressive substrate degradation and stabilization, although odor alone is not sufficient to determine compost maturity because it is strongly affected by moisture and aeration, excessive moisture can restrict oxygen diffusion and promote the formation of malodorous can restrict oxygen diffusion and promote the formation of malodorous compounds such as NH_3, H_2S, and other volatile compounds (Y. Wang et al., 2022b).

The Best Treatment

If microbial density is represented by TPC, B1 (papaya LMO) was the best treatment, because a higher microbial density does not necessarily produce more mature compost. Previous studies have shown that an optimum inoculum does exists, and increasing the inoculum concentration does not always proportionally improve compost quality. In this study, B1 had a TPC of 3.1 x 10^3 CFU/mL, compared with 8.7 x 10^1 CFU/mL for B2 and 4.2 x 10^3 CFU/mL for B3. Although B3 had the highest TPC, B1 showed more consistent maturity characteristics, with the temperature decreasing from 40-42°C at the beginning of composting to 33-35°C on 31 May, while the pH increased from 4.5 to approximately 7.0, which falls the SNI 19-7030-2004 range of 6.80-7.49. The color changed from visibly recognizable materials during 22-26 May to dark brown/blackish on 27 May and uniformly black on 31 May, while the initially sour and food waste like odor gradually decreased. In contrast, B3, despite having a higher TPC of 4.2 x 10^3 CFU/mL, maintained a pH 4.5 during days 1-3, increased to 4.6-5.6 on day 4, and only reached 6.5-7.0 during 5-8, with a slight sour odor still observed toward the end of the process. These results indicate that the microbial density of 3.1 x 10^3 CFU/mL in B1 was sufficient to support effective microbial activity without requiring the highest microbial density, resulting in changes in pH, temperature, color, and odor that were more favorable for compost maturation. Therefore, B1 was selected as the best treatment (Indasah & Fitriani, 2021)(Fitria et al., 2025).

D. CONCLUSION

The result showed that the effect of bioactivator dosage on microbial density and composting performance was dependent on the type of bioactivator applied. Increasing the dosage did not consistently increase culturable microbial density, as shown by the non-linear response of stale rice and combined bioactivators, while papaya LMO showed clearer dose-dependent response. However, microbial density alone did not determine composting performance because the temperature, pH, colour, odor, and surface reduction showed different responses among treatments, indicating that microbial activity was also influenced by substrate availability, moisture, oxygen conditions, and microbial interactions. Overall, the bioactivator treatments generally accelerated the transition from acidic to near-neutral conditions, increased temperature during active decomposition, promoted colour and odor changes, and produced earlier physical shrinkage compared with the control. Among the tested treatments, B1 (25% papaya LMO) was identified as the treatment with the most consistent composting characteristics, with the temperature decreasing to 33-35°C, pH reaching approximately 7.0 and the compost developing a blackish colour with decreasing sour or food waste like odor by the end of the observation period. These findings indicate that an appropriate bioactivator dosage, rather than the highest dosage, is important for supporting effective food waste composting.

Further research is recommended to evaluate bioactivator effectiveness using more comprehensive indicators of compost maturity, including C/N ratio, organic matter degradation, nutrient content, and microbial community composition, in addition to TPC and physicochemical parameters. Process conditions such as moisture content, oxygen availability, aeration, and substrate composition should also be controlled and monitored more consistently because these factors can influence microbial activity and composting performance. Future studies may further optimize the dosage of papaya LMO, particularly around the 25% treatment, by testing additional dosage levels and replication to determine the optimum application rate and improve the consistency of compost maturation.

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