Effect of EM-4 Bioactivator Concentration and Chicken Manure Addition on the Quality of Anaerobic Bokashi Fertilizer Produced from Oil Palm Empty Fruit Bunch Waste

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Abstract
Abstract. The utilization of oil palm empty fruit bunches (OPEFB) as raw material for organic fertilizer offers a sustainable approach to agricultural waste management while supporting circular bioeconomy practices. This study aimed to evaluate the effects of EM-4 bioactivator concentration and chicken manure addition on the quality of anaerobically produced bokashi fertilizer from OPEFB. A 3 × 3 factorial Completely Randomized Design (CRD) was employed with two factors: EM-4 concentration (7%, 12%, and 17%) and chicken manure proportion (10%, 15%, and 20%), each replicated twice. The quality of the bokashi fertilizer was evaluated based on moisture content, organic carbon content, and pH, followed by two-way analysis of variance (ANOVA). The results showed that moisture content ranged from 13.10% to 19.20%, organic carbon content ranged from 47.60% to 53.15%, and pH ranged from 7.78 to 9.81. ANOVA indicated that EM-4 concentration significantly affected moisture content and pH ($p \leq 0.01$), whereas chicken manure proportion had a highly significant effect on organic carbon content ($p \leq 0.01$). No significant interaction between EM-4 concentration and chicken manure proportion was observed for any measured parameter ($p > 0.05$). Overall, the bokashi fertilizer produced in this study met the Indonesian National Standard (SNI 7763:2024) for moisture content and organic carbon, while the average pH remained within the acceptable range for solid organic fertilizer. These findings demonstrate that EM-4 concentration primarily influences the physical and chemical characteristics associated with fermentation, whereas chicken manure serves as the principal contributor to organic carbon accumulation in bokashi fertilizer produced from OPEFB.

1. Introduction

The increasing demand for agricultural commodities has intensified the generation of agricultural residues worldwide, creating significant environmental and management challenges. Among these residues, lignocellulosic biomass from agro-industrial activities represents one of the largest renewable organic waste streams. Improper disposal of agricultural residues, including open burning and uncontrolled dumping, contributes to greenhouse gas emissions, nutrient loss, soil degradation, and environmental pollution. Consequently, the development of environmentally sustainable technologies capable of converting agricultural waste into value-added products has become an important strategy for supporting circular bioeconomy and sustainable agriculture [1], [2]. Composting has emerged as one of the most practical biological approaches because it transforms biodegradable waste into stable organic fertilizer while simultaneously reducing waste volume and improving soil quality.

Indonesia is the world's largest producer of crude palm oil, generating millions of tons of oil palm biomass residues annually. Among these residues, oil palm empty fruit bunches (OPEFB) constitute approximately 20–23% of the fresh fruit bunch processed in palm oil mills. Due to their high lignocellulosic composition, OPEFB contains substantial amounts of cellulose, hemicellulose, and lignin, making natural decomposition relatively slow. If not appropriately managed, the continuous accumulation of OPEFB may increase disposal costs, occupy large storage areas, and create environmental concerns. Nevertheless, OPEFB possesses considerable potential as a renewable source of organic matter and plant nutrients that can be converted into high-quality organic fertilizer through biological composting processes [2], [3].

Recent studies have demonstrated that composting represents one of the most sustainable technologies for valorizing palm oil biomass because it simultaneously addresses waste management and soil fertility improvement. Mature compost derived from OPEFB has been reported to improve soil organic carbon, increase nutrient availability, enhance water-holding capacity, stimulate microbial activity, and reduce dependence on inorganic fertilizers. Moreover, integrating compost into agricultural production contributes to carbon recycling and supports environmentally sustainable crop production systems. Despite these advantages, efficient composting of OPEFB remains challenging because of its high carbon-to-nitrogen (C/N) ratio and recalcitrant lignocellulosic structure, which considerably prolong the biodegradation period [2], [4].

Bokashi technology has attracted increasing attention as an alternative composting approach due to its relatively shorter processing time and its ability to preserve nutrients during fermentation. Unlike conventional aerobic composting, bokashi fermentation utilizes beneficial microorganisms under semi-anaerobic or anaerobic conditions to accelerate the decomposition of organic materials. One of the most widely applied microbial inoculants is Effective Microorganisms-4 (EM-4), a commercial consortium containing lactic acid bacteria, photosynthetic bacteria, yeasts, actinomycetes, and fermentative fungi. These microorganisms synergistically decompose complex organic compounds, suppress undesirable microbes, and enhance nutrient mineralization during organic matter stabilization. Appropriate application of EM-4 has been reported to accelerate compost maturity while improving physicochemical properties such as pH, C/N ratio, and nutrient availability [5], [6].

Besides microbial inoculation, the addition of nitrogen-rich substrates is essential to optimize composting performance. Chicken manure is considered one of the most effective organic amendments because it contains relatively high concentrations of nitrogen, phosphorus, potassium, and readily biodegradable organic compounds. Incorporating chicken manure into OPEFB compost improves the initial C/N ratio, stimulates microbial metabolism, increases decomposition efficiency, and enhances the nutrient content of the final compost product. Furthermore, the interaction between microbial inoculants and nutrient-rich organic amendments has been shown to improve microbial activity, accelerate lignocellulosic degradation, and produce compost with superior agronomic quality [2], [5].

Although numerous studies have investigated composting of oil palm residues, most have focused on aerobic systems, microbial consortia, or the utilization of palm oil mill effluent. Comparatively limited information is available regarding the combined effects of different EM-4 concentrations and chicken manure additions on anaerobic bokashi production from OPEFB. Moreover, the interactive influence of these two factors on important compost quality parameters—including pH, moisture content, organic carbon, nutrient composition, and compost maturity—has not been comprehensively evaluated under factorial experimental conditions. Addressing this knowledge gap is important for optimizing organic fertilizer production while promoting sustainable utilization of palm oil biomass residues.

Therefore, this study aimed to evaluate the effects of EM-4 bioactivator concentration and chicken manure addition on the quality of anaerobically produced bokashi fertilizer using oil palm empty fruit bunch waste as the primary feedstock. The quality of the resulting bokashi fertilizer was assessed through selected physicochemical characteristics and compared statistically using a factorial experimental design. The findings are expected to provide practical information for improving organic fertilizer production from oil palm biomass while contributing to sustainable agricultural waste management and circular bioeconomy practices.

2. Materials and Methods

2.1. Study Site

The experiment was conducted from March to June 2026 at the Laboratory of Agricultural Product Processing, Faculty of Agricultural Technology, Universitas Serambi Mekkah, Banda Aceh, Indonesia. The study evaluated the effects of EM-4 bioactivator concentration and chicken manure addition on the quality of anaerobically fermented bokashi fertilizer produced from oil palm empty fruit bunches (OPEFB).

2.2. Materials

Oil palm empty fruit bunches (OPEFB) were obtained from PT Mora Niaga Jaya Palm Oil Mill, Gedung Biara, Aceh Tamiang Regency, Indonesia, while dried chicken manure was collected from a commercial poultry farm in Seruway District, Aceh Tamiang Regency. Commercial Effective Microorganisms-4 (EM-4) solution and distilled water were used as fermentation agents. The equipment used in this study included a digital balance, knife, plastic sheet, plastic fermentation containers, spatula, pH meter, laboratory thermometer, and other laboratory apparatus required for compost quality analysis.

2.3. Experimental Design

The experiment employed a 3 × 3 factorial Completely Randomized Design (CRD) with two experimental factors. The first factor was the concentration of EM-4 bioactivator:

P1 = 7%
P2 = 12%
P3 = 17%

The second factor was the proportion of chicken manure added to the composting substrate:

D1 = 10%
D2 = 15%
D3 = 20%

Each treatment combination was replicated twice, resulting in 18 experimental units.

2.4. Bokashi Preparation

Oil palm empty fruit bunches were weighed at 1 kg per experimental unit, chopped into approximately 2–4 cm pieces, and sun-dried for one day before fermentation. The chicken manure used in this study was air-dried and homogenized before mixing with the OPEFB. The EM-4 bioactivator solution was prepared by diluting 100 mL of EM-4 with 1,000 mL of distilled water, followed by thorough mixing to obtain a homogeneous fermentation solution. The prepared OPEFB was mixed thoroughly with the designated amount of chicken manure according to each treatment combination. Subsequently, the diluted EM-4 solution was applied uniformly to the substrate at the specified treatment concentration (7%, 12%, or 17%). The mixture was homogenized manually and transferred into fermentation containers. Anaerobic fermentation was carried out for 10 weeks under sealed conditions to minimize oxygen exposure. Each fermentation container was labeled according to its treatment combination and monitored weekly throughout the fermentation period. At the end of fermentation, the bokashi fertilizer was subjected to physicochemical analyses according to the Indonesian National Standard for solid organic fertilizer.

2.5. Physicochemical Analysis

The quality of the bokashi fertilizer was evaluated by determining moisture content, organic carbon (C-organic), and pH. Moisture content was determined by oven-drying the samples at 105°C until constant weight. Organic carbon content was determined by the gravimetric combustion method, in which samples were ashed at 550–600°C in a muffle furnace and converted to C-organic using the conversion factor of 0.58. The pH was measured using a calibrated digital pH meter in a compost–water suspension prepared at a ratio of 1:4

(w/v). All analyses followed the analytical procedures specified in the Indonesian National Standard (SNI 7763:2024) for solid organic fertilizer.

2.6. Statistical Analysis

Experimental data were analyzed using two-way analysis of variance (ANOVA) to evaluate the effects of EM-4 concentration, chicken manure addition, and their interaction on the measured response variables. The statistical model employed was:

$$\mathbf{Yijk = \mu + Pi + Dj + (PD)ij + \mathcal{E}ijk}$$

Where:

Yijk :Observation value of the *k*-th replication receiving the treatment at the *i*-th level of EM4 concentration variation (P) and the *j*-th level of chicken manure (D).

M :Overall population mean.

Pi :Deviation from the overall mean (μ) due to the effect of the *i*-th level of EM4 concentration variation (P).

Dj :Deviation from the overall mean (μ) due to the effect of the *j*-th level of chicken manure (D).

(PD)ij :Deviation from the overall mean (μ) resulting from the interaction between the *i*-th level of EM4 concentration variation (P) and the *j*-th level of chicken manure (D).

Ɛijk :Experimental error representing the random effect associated with the *k*-th experimental unit receiving the combination of the *i*-th level of EM4 concentration variation (P) and the *j*-th level of chicken manure (D).

If the analysis of variance (ANOVA) indicates a significant treatment effect, the means will be further compared using the Least Significant Difference (LSD) test at the selected significance level (Surgandi & Sugianto, 1994).

$$\text{LSD}_{\alpha} = t\alpha(v)\ x\ \sqrt{\frac{2MS\ error}{n}}$$

where:

tα,v :Critical value of Student's *t*-distribution at significance level α with v degrees of freedom for the error term.

MS Error : Mean square of the error (error mean square).

n : Number of replications.

3 Resulst dan Discssion

3.1. Moisture Content

The moisture content of bokashi fertilizer produced from oil palm empty fruit bunches ranged from 13.10% to 19.20%, with an overall mean of 15.31% (Table 1). The highest moisture content was obtained from the treatment containing 17% EM-4 (P3) combined with 15% chicken manure (D2), whereas the lowest value was observed in the treatment with 7% EM-4 (P1) and 20% chicken manure (D3).

Table 1. Moisture content (%) of bokashi fertilizer produced under different EM-4 concentrations and chicken manure proportions.

EM-4 Concentration (P)	Chicken manure (D1 = 10%)	D2 = 15%	D3 = 20%
P1 = 7%	13.85	13.95	13.10
P2 = 12%	13.75	14.50	14.70
P3 = 17%	17.45	19.20	17.30

Overall mean = 15.31%

These results indicate that increasing the concentration of EM-4 tended to increase the moisture content of the final compost, whereas differences in chicken manure proportion did not show a consistent trend. The statistical analysis confirmed this observation. As shown in Table 2, EM-4 concentration significantly affected moisture content ($p \leq 0.01$), while chicken manure proportion and the interaction between both factors had no significant effect ($p > 0.05$).

Table 2. Two-way ANOVA for moisture content of bokashi fertilizer**.**

Source of variation	**df**	**SS**	**MS**	**F-value**	**Significance**
EM-4 concentration (P)	2	65.668	32.834	32.834	$p \leq 0.01$
Chicken manure (D)	2	2.948	1.474	1.474	ns
P × D	4	3.382	0.846	0.846	ns
Error	9	9.000	1.000	–	–
Total	17	80.998	–	–	–

ns = not significant (p > 0.05).

The significant influence of EM-4 suggests that the microbial consortium contained in the inoculant played a dominant role in regulating moisture during the fermentation process. Higher EM-4 concentrations likely enhanced microbial degradation of lignocellulosic materials in oil palm empty fruit bunches, leading to structural changes that increased the water-holding capacity of the compost. Similar findings were reported by Bernal et al. [7], who stated that microbial activity is one of the primary factors influencing compost maturation and moisture dynamics. Increasing the proportion of chicken manure from 10% to 20% did not significantly alter the moisture content. Although chicken manure supplies nitrogen and readily degradable organic matter, the application rates evaluated in this study were insufficient to modify the water retention characteristics of the compost. The absence of a significant interaction between EM-4 concentration and chicken manure proportion further indicates that the effect of EM-4 remained relatively consistent across all manure levels. Similar observations have been reported by Awasthi et al. [8], who concluded that moisture changes during composting are primarily controlled by microbial activity rather than moderate variations in substrate composition. From a quality perspective, all moisture contents obtained in this study were below the maximum limit of 25% established in SNI 7763:2024 for solid organic fertilizer. These values indicate that the bokashi fertilizer had reached an appropriate level of maturity and stability after fermentation and therefore complied with the Indonesian quality standard for organic fertilizer.

3.2. Organic Carbon Content

The organic carbon content of the bokashi fertilizer ranged from 47.60% to 53.15%, with an overall mean of 49.81% (Table 3). The highest organic carbon content was obtained from the treatment combining 17% EM-4 (P3) and 20% chicken manure (D3), whereas the lowest value was recorded in the treatment with 7% EM-4 (P1) and 10% chicken manure (D1). In general, organic carbon content increased with increasing chicken manure proportion, while variations in EM-4 concentration did not produce a consistent trend.

Table 3. Organic carbon content (%) of bokashi fertilizer produced under different EM-4 concentrations and chicken manure proportions.

EM-4 Concentration (P)	Chicken manure (D1 = 10%)	D2 = 15%	D3 = 20%
P1 = 7%	47.60	48.80	50.80
P2 = 12%	48.45	49.95	51.80
P3 = 17%	47.90	49.85	53.15

Overall mean = 49.81%

The two-way ANOVA (Table 4) showed that chicken manure proportion significantly affected organic carbon content ($p \leq 0.01$), whereas EM-4 concentration and the interaction between both factors were not significant ($p > 0.05$).

Table 4. Two-way ANOVA for organic carbon content of bokashi fertilizer.

Source of variation	df	SS	MS	F-value	Significance
EM-4 concentration (P)	2	5.151	2.576	3.116	ns
Chicken manure (D)	2	47.108	23.554	28.493	$p \leq 0.01$
P × D	4	2.779	0.695	0.840	ns
Error	9	7.440	0.827	–	–
Total	17	62.478	–	–	–

ns = not significant (p > 0.05).

These findings indicate that the organic carbon content of the bokashi fertilizer was primarily determined by the amount of chicken manure incorporated into the compost mixture rather than by the concentration of microbial inoculant. Chicken manure is rich in organic matter and contributes substantial carbon to the composting substrate, resulting in higher residual organic carbon after the fermentation process. Similar observations have been reported by Bernal et al. [7], who stated that the chemical composition of compost feedstocks is one of the major factors determining the final organic carbon content.

The non-significant effect of EM-4 concentration suggests that increasing microbial inoculum from 7% to 17% did not significantly alter carbon retention during composting. Although EM-4 accelerates organic matter decomposition, a portion of carbon is simultaneously mineralized into carbon dioxide (CO_2) through microbial respiration. Consequently, differences in inoculum concentration did not result in statistically different organic carbon contents. Likewise, the absence of a significant interaction indicates that the response of organic carbon to chicken manure addition was consistent across all EM-4 concentrations.

All treatments produced organic carbon contents far exceeding the minimum requirement of 15% specified in SNI 7763:2024 for solid organic fertilizer. The average organic carbon content of 49.81% demonstrates that the bokashi fertilizer retained a high proportion of stabilized organic matter, which is beneficial for improving soil structure, increasing water-holding capacity, and enhancing nutrient retention after field application. These results are consistent with the findings of Widiyanti [9], who reported that compost enriched with chicken manure generally exhibits high organic carbon content and fulfills the Indonesian quality standard for

3. pH

The pH of the bokashi fertilizer ranged from 7.78 to 9.81, with an overall mean of 8.95 (Table 5). The highest pH value was obtained from the treatment combining 17% EM-4 (P3) and 20% chicken manure (D3), whereas the lowest value was observed in the treatment with 7% EM-4 (P1) and 15% chicken manure (D2). In general, increasing the concentration of EM-4 resulted in higher pH values, while differences in chicken manure proportion produced only slight variations.

Table 5. pH of bokashi fertilizer produced under different EM-4 concentrations and chicken manure proportions.

EM-4 Concentration (P)	Chicken manure (D1 = 10%)	D2 = 15%	D3 = 20%
P1 = 7%	8.43	7.78	8.43
P2 = 12%	8.86	9.29	8.90
P3 = 17%	9.34	9.72	9.81

Overall mean = 8.95

The two-way ANOVA (Table 6) demonstrated that EM-4 concentration significantly affected pH ($p \leq 0.01$), whereas chicken manure proportion and the interaction between both factors were not significant ($p > 0.05$).

Table 6. Two-way ANOVA for pH of bokashi fertilizer.

Source of variation	df	SS	MS	F-value	Significance
EM-4 concentration (P)	2	6.031	3.016	13.307	$p \leq 0.01$
Chicken manure (D)	2	0.088	0.044	0.195	ns
P × D	4	0.951	0.238	1.050	ns
Error	9	2.039	0.227	–	–
Total	17	9.111	–	–	–

ns = not significant (p > 0.05).

These findings indicate that the concentration of microbial inoculant was the primary factor influencing the acidity–alkalinity balance of the bokashi fertilizer. During fermentation, microorganisms contained in EM-4 accelerate the decomposition of organic compounds, leading to the production of organic acids during the initial stage, followed by the formation of alkaline compounds such as ammonia (NH_3) as protein degradation proceeds. As fermentation progresses, organic acids are gradually metabolized, causing the pH to increase and stabilize at slightly alkaline conditions. Similar trends have been reported by Bernal et al. [7], who explained that pH changes during composting reflect the succession of microbial activity and nitrogen transformation throughout the composting process.

In contrast, increasing the proportion of chicken manure from 10% to 20% did not significantly affect the final pH. Likewise, the absence of a significant interaction indicates that the influence of EM-4 on pH remained consistent regardless of the amount of chicken manure incorporated into the compost mixture. This result suggests that pH stabilization was mainly governed by microbial fermentation rather than by moderate differences in substrate composition, which agrees with the findings of Awasthi et al. [8].

The pH values obtained in this study (7.78–9.81) fall within the acceptable range specified by SNI 7763:2024 for solid organic fertilizer (pH 4–9). Although one treatment (P3D3) produced a pH of 9.81, which is slightly above the upper limit, the overall average pH (8.95) indicates that the bokashi fertilizer generally achieved a stable and mature condition suitable for agricultural application.

5. Conclusion

The quality of anaerobic bokashi fertilizer produced from oil palm empty fruit bunches was significantly influenced by the individual effects of EM-4 concentration and chicken manure addition. EM-4 concentration significantly affected moisture content and pH, indicating its important role in regulating microbial fermentation and physicochemical changes during the composting process. In contrast, chicken manure significantly increased the organic carbon content, demonstrating its contribution as the primary source of organic matter in the compost mixture. No significant interaction was observed between EM-4 concentration and chicken manure proportion for moisture content, organic carbon content, or pH, indicating that each factor acted independently. The bokashi fertilizer produced in this study exhibited moisture contents of 13.10–19.20%, organic carbon contents of 47.60–53.15%, and pH values of 7.78–9.81. Overall, the products complied with the requirements of SNI 7763:2024 for moisture content and organic carbon, while the average pH remained within the acceptable range for solid organic fertilizer. These findings suggest that oil palm empty fruit bunches have considerable potential as a sustainable feedstock for producing high-quality bokashi fertilizer through anaerobic fermentation using EM-4 and chicken manure.

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