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Effect of Straw and Cattle Manure Ratio on Bokashi Quality Based on C/N Balance and Nutrient Availability

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ABSTRACT

Bokashi is an anaerobically fermented organic fertilizer whose quality depends on the balance between carbon-rich and nitrogen-rich feedstocks. This study evaluated five bokashi formulations prepared from different proportions of leaf straw (JD) and cattle manure (PK), namely: JD100, JD75PK25, JD50PK50, JD25PK75, and PK100. Bokashi was fermented under anaerobic conditions for 21 days and assessed for temperature, moisture content, pH, organic carbon, C/N ratio, total nitrogen, P_2O_5, K_2O, and magnesium (Mg). The experiment was arranged in a Completely Randomized Design, while treatment performance was evaluated using descriptive statistics, including mean ± standard deviation, coefficient of variation, and trend analysis. Results showed that increasing the proportion of manure generally enhanced nutrient availability. Total nitrogen increased from 1.54% in JD100 to 2.72% in JD25PK75, while Mg concentration increased from 3,506 mg kg^{-1} in JD100 to 10,999 mg kg^{-1} in PK100. In contrast, straw-dominated formulations maintained higher organic carbon content (27.86%) and more neutral pH conditions (7.7). The C/N ratio declined from 18.10 in JD100 to 8.72 in PK100, indicating greater decomposition and compost maturity. Among the treatments, JD50PK50 exhibited comparatively balanced characteristics, combining relatively high organic carbon, moderate nutrient levels, near-neutral pH (6.8), and a moderate C/N ratio (11.48). These findings suggest that balanced straw–manure mixtures can improve bokashi maturity, nutrient retention, and chemical stability for sustainable organic fertilizer production.

1. INTRODUCTION

Bokashi is an organic fertilizer produced through the anaerobic fermentation of organic materials using effective microorganisms (EM), such as the commercial EM4 inoculant. Compared with conventional aerobic composting, bokashi fermentation requires a shorter processing period and produces fewer unpleasant odors, making it a practical alternative for rapid organic fertilizer production (Vukojević Medvidović *et al*., 2024). Nevertheless, the quality of bokashi is strongly influenced by the composition of the raw materials used, particularly the balance between carbon-rich and nitrogen-rich substrates. In the composting process, carbon functions primarily as an energy source and structural component for microbial metabolism, whereas nitrogen supports microbial growth and enzymatic activity (Shen *et al*., 2024). An appropriate initial carbon-to-nitrogen (C/N) ratio, generally around 25–30:1, promotes efficient decomposition, while the final compost maturity is commonly indicated by a reduced C/N ratio of approximately 10–15:1 (Azis *et al*., 2023).

Agricultural organic residues are widely available but are often not optimally utilized, despite their potential contribution to sustainable nutrient recycling. Leaf straw represents a carbon-rich organic material containing high levels of lignocellulosic compounds (Assaye, 2024; Fu *et al*., 2023). Such materials generally possess high C/N ratios ranging from 40–100:1 (Shaukat *et al*., 2011), indicating an excess of carbon relative to nitrogen. As a result, bokashi produced solely from straw tends to decompose more slowly and may temporarily immobilize nitrogen during the early stages of decomposition. In contrast, cattle manure is characterized as a nitrogen-rich organic material with a lower C/N ratio, commonly ranging from 5–25:1 (Li *et al*., 2022). In addition to nitrogen, cattle manure supplies essential macronutrients such as phosphorus (P) and potassium (K), as well as secondary nutrients including magnesium (Mg) and calcium (Ca) (Hidalgo *et al*., 2025). The readily available nitrogen in manure can accelerate microbial activity and organic matter decomposition during fermentation. However, excessive manure application may create an imbalance in the composting substrate by supplying nitrogen beyond microbial requirements, thereby increasing risk of nitrogen losses through volatilization and reducing the stability of the final product (Zhang *et al*., 2020).

Because straw and manure possess contrasting chemical characteristics, determining an appropriate balance between carbon-rich and nitrogen-rich materials becomes essential for producing high-quality bokashi. Previous studies have demonstrated that the interaction between organic amendments and soil management practices can significantly influence nutrient dynamics and the effectiveness of organic inputs in improving soil quality and plant productivity (Masria *et al*., 2025). In bokashi production, the balance between straw and manure is expected to affect not only the C/N ratio but also nutrient availability and compost maturity. A mature organic fertilizer is generally characterized by a balanced C/N ratio, stable pH, and sufficient nutrient availability. A C/N ratio ranging from 10–20 is commonly considered suitable for mature compost because it supports nutrient release without causing nitrogen immobilization in soil (Shen *et al*., 2024). In addition, pH plays an important role in microbial activity and nutrient solubility, with a near-neutral pH (approximately 6–8) considered optimal for compost stability and plant nutrient uptake (Peña *et al*., 2020).

Besides the C/N ratio and pH, nutrient composition also serves as an important indicator of bokashi quality. Phosphorus and potassium are essential macronutrients that contribute to plant growth and soil fertility. Their concentrations in bokashi are influenced by the characteristics of the raw materials and the effectiveness of the fermentation process in retaining or mineralizing nutrients. Phosphate (P_2O_5) content may increase as microbial activity mineralizes organic phosphorus compounds from straw and manure. Likewise, potassium (K_2O) is generally abundant in plant residues and tends to remain available during composting (Sihotang & Hanik, 2025). Magnesium, although required in smaller amounts, also contributes to plant physiological functions such as chlorophyll formation and is commonly found in higher concentrations in animal manure.

Previous studies on bokashi and composting have mainly focused either on compost maturity indicators or on general nutrient characteristics, while limited information is available regarding the simultaneous optimization of C/N balance, nutrient availability, and pH stability in bokashi formulations combining leaf straw and cattle manure under different composition ratios. In addition, the interaction between carbon-rich straw and nitrogen-rich manure during fermentation remains insufficiently characterized, particularly in relation to nutrient retention, compost maturity, and chemical stability. Therefore, this study evaluated five combinations of leaf straw and cattle manure to identify formulations showing comparatively balanced chemical characteristics for bokashi production, based on C-organic, total nitrogen, phosphorus, potassium, magnesium, pH, and C/N ratio. It was hypothesized that a balanced combination of straw and manure would produce a more stable and nutrient-rich bokashi with improved maturity characteristics.

2. MATERIALS AND METHODS

2.1. Materials and Treatments

The experiment was conducted at the Integrated Farming System Laboratory (Bokashi Production Unit) of the State Agricultural Polytechnic of Kupang. The raw materials used for bokashi production consisted of dry leaf straw and cattle manure as the primary carbon and nitrogen sources, respectively. The straw was air-dried and chopped into approximately 2–3 cm particle size, whereas cattle manure was collected from local livestock production units and used under semi-moist conditions. Additional materials included commercial Effective Microorganisms (EM4) as the microbial inoculant, molasses as an easily available carbon source for microbial activation, and water.

Five bokashi formulations were prepared using different straw-to-manure ratios on a dry weight basis. The treatments were coded as follows:

1. JD100 : 100% leaf straw + 0% cattle manure
2. JD75PK25 : 75% leaf straw + 25% cattle manure
3. JD50PK50 : 50% leaf straw + 50% cattle manure
4. JD25PK75 : 25% leaf straw + 75% cattle manure
5. PK100 : 0% leaf straw + 100% cattle manure

These formulations were designed to represent gradual changes from carbon-dominant to nitrogen-dominant compositions in order to evaluate their effects on bokashi fermentation characteristics, nutrient composition, C/N balance, and pH stability. Each treatment mixture weighed approximately 5 kg on a dry weight basis.

Because this study was conducted as a preliminary formulation evaluation, each treatment was prepared as an individual fermentation unit and subjected to repeated physicochemical observations throughout the fermentation period. Fermentation monitoring data were collected periodically to evaluate treatment trends and variability during decomposition. Therefore, treatment evaluation focused primarily on descriptive comparison and trend interpretation rather than inferential statistical testing.

2.2. Bokashi Fermentation Procedure

Bokashi preparation followed standard anaerobic fermentation techniques. The weighed straw and manure materials for each treatment were thoroughly homogenized in a plastic mixing container. A microbial activation solution was prepared by diluting 10 mL EM4 and 10 mL molasses in 1 L of water. The solution was evenly sprayed onto the substrate mixture while turning the material until moisture content reached approximately 30–40%. Moisture adequacy was evaluated using the manual squeeze test, in which the material remained cohesive when pressed without releasing free water.

Each moistened mixture was subsequently transferred into a sealed airtight plastic fermentation drum (20 L total capacity with approximately 15 L working volume) to maintain anaerobic conditions throughout the fermentation process. Fermentation was conducted for 21 days under ambient tropical conditions. Internal substrate temperature was monitored periodically and generally remained within the mesophilic to early thermophilic range (approximately 30–40 °C), while temperatures above 45 °C were avoided to minimize excessive microbial inhibition.

Anaerobic conditions were maintained by tightly sealing the drums and minimizing oxygen exposure during fermentation. To maintain substrate uniformity while preserving anaerobic conditions, the fermentation drums were gently shaken externally every 3–4 days without opening the fermentation system or introducing direct aeration. Gas accumulation was periodically released through a small outlet valve installed on the drum cover without prolonged exposure to ambient air. At the end of fermentation, bokashi maturity was evaluated based on stabilized temperature, dark-brown color formation, and the presence of fermented sweet–soil odor without foul smell.

2.3. Analysis of Chemical Properties

After completion of fermentation, bokashi samples from each treatment were collected and analyzed following standard procedures for compost and organic fertilizer characterization. Fermentation observation parameters included temperature, moisture content, pH, organic carbon, and C/N ratio. Temperature and moisture content were monitored periodically during fermentation to evaluate decomposition activity and substrate stability.

Moisture content (MC) was determined by oven-drying at 105 °C according to AOAC standard procedures. Organic carbon (C-organic) was analyzed using the Walkley–Black wet oxidation method following procedures of the Indonesian Soil Research Institute. Total nitrogen (Total N) was determined using the Kjeldahl digestion–distillation method based on AOAC protocols. Total phosphate (P_2O_5) was measured colorimetrically using UV–Vis spectrophotometry after $HClO_4$ digestion, whereas total potassium (K_2O) and magnesium (Mg) were analyzed using Atomic Absorption Spectroscopy (AAS) following SNI methods for organic fertilizer analysis and ICBB accredited laboratory protocols.

The C/N ratio was calculated from the ratio between organic carbon and total nitrogen. The pH value was measured in a 1:5 (w/v) water extract using a calibrated digital pH meter according to standard soil analysis procedures. Laboratory analyses were conducted at the Soil Chemistry Laboratory and the accredited ICBB Laboratory, Bogor, Indonesia.

2.4. Data Interpretation and Statistical Analysis

Fermentation observation data were evaluated descriptively for each treatment formulation. Periodic monitoring data, including temperature, moisture content, pH, organic carbon, and C/N ratio, were summarized as mean values accompanied by standard deviation (SD) to describe variability during the fermentation process. Graphical trend analysis was subsequently used to evaluate linear and non-linear response patterns among straw–manure formulations.

Final laboratory chemical analysis data for N, P_2O_5, K_2O, and Mg were interpreted as descriptive observed values because each formulation was represented by a single laboratory sample. Treatment comparisons focused on compost maturity indicators, nutrient composition, and pH stability as indicators of bokashi quality. Due to the preliminary nature of this formulation study, treatment evaluation emphasized descriptive statistical summaries, variability observation, and graphical trend interpretation to evaluate response patterns among bokashi formulations. Accordingly, treatment responses were interpreted using comparative descriptive terms such as “tended to be higher”, “comparatively lower”, and “showed more balanced characteristics” instead of statistical significance claims.

3. RESULTS AND DISCUSSION

3.1. Bokashi Composition under Different Straw–Manure Ratios

During the 21-day anaerobic fermentation process, the bokashi formulations showed different physicochemical characteristics depending on the proportion of leaf straw and cattle manure used (Table 1). Variations in carbon-rich straw and nitrogen-rich manure affected fermentation temperature, moisture stability, pH conditions, organic carbon retention, and C/N ratio during decomposition. Overall, mixed formulations tended to maintain more balanced fermentation conditions than the single-material treatments.

Table 1. Fermentation observation data of bokashi under different straw–manure ratios (Values presented as mean ± SD from periodic fermentation observations)

Treatment	Temperature (°C)	CV (%)	Moisture Content (%)	CV (%)	pH ( )	CV (%)	C-organic (%)	CV (%)	C/N Ratio ( )	CV (%)
JD100	34.2 ± 1.3	3.80	38.4 ± 2.1	5.47	7.7 ± 0.2	2.60	27.86 ± 0.41	1.47	18.10 ± 0.53	2.93
JD75PK25	35.8 ± 1.5	4.19	39.1 ± 1.8	4.60	7.3 ± 0.1	1.37	26.14 ± 0.38	1.45	12.82 ± 0.44	3.43
JD50PK50	36.7 ± 1.4	3.81	40.2 ± 1.9	4.73	6.8 ± 0.2	2.94	27.09 ± 0.36	1.33	11.48 ± 0.39	3.40
JD25PK75	37.4 ± 1.6	4.28	41.0 ± 2.0	4.88	7.0 ± 0.2	2.86	26.14 ± 0.35	1.34	9.61 ± 0.28	2.91
PK100	38.1 ± 1.7	4.46	42.5 ± 2.3	5.41	5.8 ± 0.3	5.17	23.30 ± 0.42	1.80	8.72 ± 0.25	2.87

Note: Mature compost according to SNI compost quality standards generally has a C/N ratio below 20.

The fermentation temperature tended to increase with higher manure proportion, indicating greater microbial activity in manure-rich formulations due to higher nitrogen availability. In contrast, straw-dominant treatments maintained lower temperatures because straw contains lignocellulosic compounds that decompose more slowly (Pian *et al*., 2023). Moisture content also increased slightly with increasing manure proportion, whereas straw-rich treatments showed comparatively lower moisture retention because straw has greater porosity and lower water-holding capacity.

The pH values ranged from slightly acidic to neutral conditions. The manure-only treatment (PK100) tended to produce lower pH values, likely due to organic acid accumulation during anaerobic fermentation (Sadeli *et al*., 2022). In contrast, straw-rich formulations maintained more neutral to slightly alkaline conditions because straw contributes higher concentrations of base-forming minerals such as potassium. Among the evaluated formulations, JD50PK50 maintained near-neutral pH conditions (6.8), which are generally favorable for nutrient stability and soil application (Mohd Ghazali *et al*., 2024).

The C/N ratio gradually decreased with increasing manure proportion, indicating enhanced decomposition and compost maturity. All treatments produced C/N ratios below 20, which fall within the acceptable maturity range according to SNI compost quality standards. The mixed formulations, particularly JD50PK50 and JD25PK75, showed comparatively more balanced C/N ratios together with moderate pH and organic carbon retention. Similar trends have been reported in composting systems where balanced carbon and nitrogen inputs accelerate decomposition and improve compost stability (Shen *et al*., 2024).

Figures 1 and 2 were generated from fermentation observation data, whereas Figures 3 and 4 were based on final laboratory chemical analysis obtained from ICBB Laboratory. The graphical analysis was used to evaluate linear and non-linear response patterns among straw–manure formulations. The C/N ratio decreased progressively with increasing manure proportion, indicating improved decomposition and compost maturity. However, the decline was not entirely linear, suggesting that intermediate straw–manure combinations contributed to more balanced microbial decomposition dynamics.

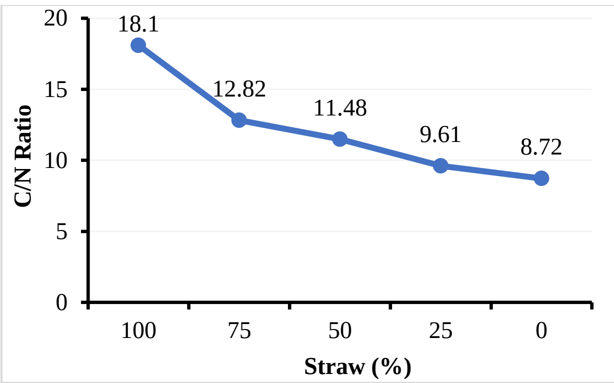

Figure 1. Relationship between straw proportion and C/N ratio of bokashi after 21 days of anaerobic fermentation

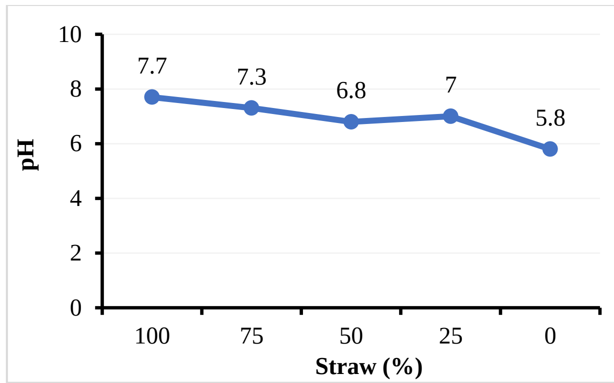

Figure 2. Relationship between straw proportion and pH of bokashi after 21 days of anaerobic fermentation

The pH values tended to decline as manure proportion increased. Straw-rich formulations maintained neutral to slightly alkaline conditions, whereas the manure-only treatment showed more acidic characteristics. The balanced JD50PK50 formulation maintained near-neutral pH conditions favorable for compost stability and nutrient availability.

3.2. Final Laboratory Chemical Characteristics of Bokashi

Final chemical analysis indicated that variations in straw–manure composition were associated with differences in nutrient availability in the resulting bokashi (Table 2). Increasing manure proportion generally tended to increase nitrogen and magnesium contents, whereas straw-containing treatments maintained relatively stable potassium levels.

Nitrogen content tended to increase with higher manure proportion because cattle manure acted as the primary nitrogen source during fermentation (Le & Marschner, 2018). The manure-rich formulations showed comparatively higher nitrogen concentrations than straw-dominant treatments. JD25PK75 showed the highest observed nitrogen content (2.72%), followed by PK100 (2.67%) and JD50PK50 (2.36%). Increased nitrogen availability is known to stimulate microbial growth and enzymatic activity during organic matter decomposition (Hoang *et al*., 2022).

Table 2. Final laboratory chemical analysis of bokashi under different straw–manure ratios

Treatment	P_2O_5 (%)	K_2O (%)	N Total (%)	Mg (mg/kg)
JD25PK75	1.38	1.39	2.72	9592.43
JD100	0.49	1.37	1.54	3506.01
JD75PK25	0.54	1.27	2.04	5266.70
JD50PK50	1.00	1.38	2.36	7359.62
PK100	1.85	0.94	2.67	10999.34

Source: ICBB Laboratory, Bogor, Indonesia.

Phosphorus content also varied among formulations. The highest observed P_2O_5 content was detected in PK100 (1.85%), followed by JD25PK75 (1.38%) and JD50PK50 (1.00%). This result indicates that manure contributed substantially to phosphorus enrichment during fermentation. However, the response pattern was not entirely linear, suggesting that nutrient retention during fermentation may also be influenced by pH conditions and microbial mineralization processes (Velasco-Sánchez *et al*., 2024).

Potassium content showed a relatively stable pattern among straw-containing formulations, ranging from 1.27–1.39%, whereas the manure-only treatment showed lower K_2O content (0.94%). This suggests that straw contributed substantially to potassium retention during bokashi fermentation because plant residues generally contain considerable potassium concentrations (Li *et al*., 2022). The balanced formulations JD50PK50 and JD25PK75 maintained comparatively favorable potassium levels together with moderate pH conditions.

Magnesium content increased progressively with increasing manure proportion, confirming that cattle manure served as the major source of secondary nutrients in the bokashi formulations (Dědina *et al*., 2022). The highest magnesium concentration was observed in PK100 (10999 mg/kg), while JD100 showed the lowest Mg content (3506 mg/kg). The mixed formulations showed intermediate magnesium concentrations, indicating that combining straw and manure improved overall nutrient completeness of the bokashi.

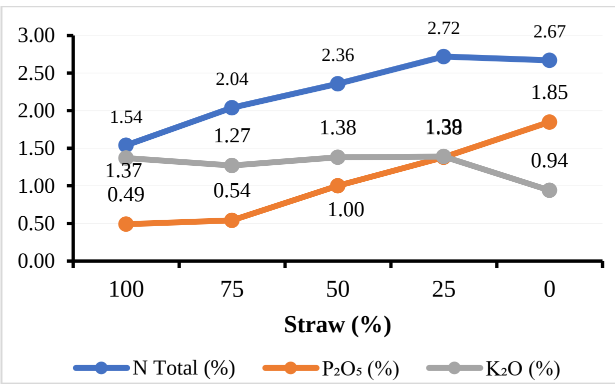

Figure 3. Relationship between straw proportion and nutrient contents

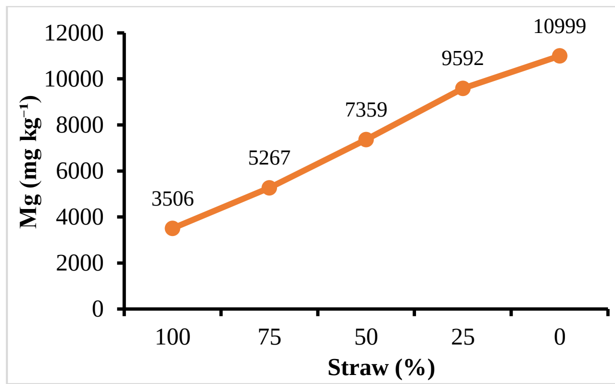

Figure 4. Relationship between straw proportion and magnesium content

Nitrogen and magnesium contents tended to increase with increasing manure proportion, whereas potassium content remained relatively stable in mixed formulations before declining in the manure-only treatment. Phosphorus content also increased under manure-rich formulations, although the response pattern was not entirely linear. Magnesium content increased progressively with increasing manure proportion, confirming that cattle manure served as the primary source of secondary nutrients during bokashi fermentation.

3.3. Effect of Straw–Manure Balance on Bokashi Quality

The overall results demonstrated that the balance between carbon-rich straw and nitrogen-rich manure played an important role in determining bokashi maturity, nutrient composition, and chemical stability during anaerobic fermentation. Straw-dominant formulations tended to maintain higher organic carbon and more neutral pH conditions, whereas manure-rich formulations generally supported higher nitrogen, phosphorus, and magnesium availability. These contrasting responses indicate that the interaction between carbon-rich and nitrogen-rich substrates influenced microbial decomposition dynamics and nutrient retention throughout the fermentation process (Fan *et al*., 2023; Shen *et al*., 2024).

The graphical trend analysis further suggested that nutrient responses among formulations were not entirely linear. Increasing manure proportion generally promoted nutrient enrichment and accelerated decomposition, as reflected by lower C/N ratio values, while excessive manure composition tended to reduce organic carbon retention and produce more acidic conditions during fermentation (Sadeli *et al*., 2022). In contrast, straw-rich formulations maintained greater organic carbon stability but comparatively lower nutrient concentrations. These findings indicate that balanced combinations of straw and manure contributed to more stable fermentation conditions and more balanced bokashi characteristics than single-material formulations.

Among the evaluated formulations, JD50PK50 showed comparatively balanced chemical characteristics by maintaining moderate nutrient composition together with favorable organic carbon retention, near-neutral pH conditions, and moderate C/N ratio values. Such characteristics suggest suitable compost maturity and chemical stability for organic fertilizer application. Similar observations have been reported in previous composting studies, where balanced carbon and nitrogen inputs improved microbial activity, nutrient conservation, and compost stability during organic matter decomposition (Fan *et al*., 2023; Shen *et al*., 2024).

Overall, the results suggest that combining carbon-rich agricultural residues with nitrogen-rich animal manure may improve bokashi quality more effectively than using either material alone. Balanced formulations tended to support more stable decomposition processes, improved nutrient retention, and acceptable maturity characteristics for sustainable organic fertilizer production (Mohd Ghazali *et al*., 2024).

4. CONCLUSIONS

The proportion of leaf straw and cattle manure strongly influenced the chemical characteristics and maturity of the resulting bokashi. Increasing manure proportion tended to increase nitrogen content from 1.54% in JD100 to 2.72% in JD25PK75, while magnesium concentration increased from 3506 mg kg^{-1} in JD100 to 10999 mg/kg in PK100. In contrast, straw-rich formulations maintained comparatively higher organic carbon (27.86%) and more neutral pH conditions (7.7). The C/N ratio progressively decreased from 18.10 in JD100 to 8.72 in PK100, indicating improved decomposition and compost maturity during fermentation. Among the evaluated formulations, JD50PK50 showed comparatively more balanced characteristics, including relatively high organic carbon (27.09%), balanced nutrient composition, near-neutral pH (6.8), and moderate C/N ratio (11.48), suggesting suitable chemical stability and nutrient availability for organic fertilizer application. These findings indicate that balancing carbon-rich straw with nitrogen-rich manure may improve bokashi maturity and nutrient retention, thereby addressing the challenge of producing stable and nutrient-balanced organic fertilizer from agricultural residues.

For practical application, combining carbon-rich crop residues with nitrogen-rich animal manure in balanced proportions may improve bokashi quality and nutrient retention. Future studies are recommended to evaluate the agronomic performance of the resulting bokashi under field conditions and to investigate additional quality indicators such as microbial activity, nutrient release dynamics, and plant growth response.

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AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
YEB	✓	✓	✓	✓	✓	✓		✓	✓	✓				
JCA	✓	✓				✓	✓				✓			
MJP		✓	✓	✓			✓		✓	✓				
JAK		✓				✓		✓						
MSRR					✓		✓			✓	✓			

C: Conceptualization; M: Methodology; So: Software; Va: Validation; Fo: Formal Analysis; I: Investigation; D: Data Curation; R: Resources; O: Writing - Original Draft; E: Writing - Review & Editing; Vi: Visualization; Su: Supervision; Fu: Funding Acquisition; P: Project Administration

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