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Changes in Chemical Properties of Banana Pseudostem, Mushroom Media Waste, and Chicken Manure through the Co-Composting Process

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Abstract: Co-composting is an effective approach to biowaste management. The co-composting potential of banana pseudostem (BPS) and mushroom media waste (MMW) with chicken manure (CM) has not been explored, let alone their suitable ratios of co-composting being determined. Meanwhile, the imbalance ratios of the feedstocks used in the process severely restrict the physicochemical properties and quality of the finished product. For this reason, six different ratios of BPS, MMW, and CM, viz. 1:1:1, 1:2:1, 1:3:1, 2:1:1, 2:2:1, and 2:3:1, respectively (T₁–T₆), were composted together in aerobic conditions to identify the suitable ratio by evaluating the changes in the physicochemical properties in the composting process. According to the ratio of treatments, the feedstocks were mixed on fresh weight basis. The turning process of co-composting piles was repeated at seven-day intervals to maintain the uniform aeration throughout the composting period. The piles having BPS, MMW, and CM at ratios of 1:2:1, 1:3:1, and 2:3:1, respectively, demonstrated a longer thermophilic phase, indicating more complete decomposition and earlier maturity compared to piles with higher amount of BPS. Of the ratios, BPS:MMW:CM at 1:2:1 ratio (T₂) resulted in the highest total nitrogen (1.53%), lowest C:N ratio (12.4), organic matter loss (54.5%), and increased CEC (41.3 cmol/kg). The highest germination index (129%) was also recorded in the T₂ compost, indicating that it was toxic-free and safe for seed germination. The nutrient-rich compost with high alkaline pH (≥ 10) can effectively ameliorate soils of an acidic nature, for example, the acidity of Ultisols and Oxisols.

Keywords: banana pseudostem; mushroom media waste; chicken manure; chemical properties; co-compost



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1. Introduction

Agricultural waste can potentially be recycled through composting processes (composting and co-composting) that convert it into useful resources for plant nutrition and soil health (through adding humus-like materials) [1]. One of the key considerations of composting and co-composting is the sources and types of organic materials used. Mainly, co-composting involves mixing nitrogen-rich organic wastes such as nutshells, sewage sludge, and animal manure with carbon-rich organic wastes (bulking agent) such as saw-dust, crop residue, biochar [2,3], and mushroom spent substrate [4]. On the other hand, banana pseudostem has huge potential as a co-composting material [5]. The global

production of pseudostem currently amounts to approximately 336 million tonnes [6] at the rate of 60–70 tonnes ha⁻¹ as post-harvest waste. It mostly remains unused and is simply creating more pollution. Yet, it can be a vital source of nutrients that will regulate and assist plant growth [7]. Similarly, mushroom production has risen worldwide resulting in an estimated 53 million tons of mushroom media waste (MMW) (1 kg mushroom is produced from 5 kg mushroom media substrate). Carbon (C)-rich mushroom media waste has immense promise for composting [8] because of its large surface area and contains carbohydrates, protein, fat, and many kinds of enzymes as well as fungus mycelium and residual nutrients [9,10]. The demand for livestock and the production of poultry has increased significantly with the rising human population, which has resulted in producing large quantities of manure [11,12]. With comparatively high nitrogen (N), co-composting with chicken manure helps turn various organic solid wastes into suitable composts by controlling the activity of microorganisms [11].

Silva and Bras [13] showed that chicken manure is usually rich in N but poor in C, leading to a low C:N ratio, which restricts the composting process. Apart from these, chicken manure enhanced the microbial growth and activity for efficient composting by shortening the composting period [10]. Being rich in C, the addition of mushroom media waste can act as an adsorbent of readily available N and allows the microbial population to multiply and immobilize N present in chicken manure. Conversely, banana pseudostem may help check N loss through the formation of struvite with ammonium-N (NH₄⁺-N). Moreover, 80–90% water by weight [14] may ensure the best possible moisture content in the process. Considering the above individual properties, these materials have the potential to produce quality compost.

Previous research has studied the quality of composts produced by the co-composting method and generally proved that the method of composting, combinations between them, and the ratio at which the co-composting materials are used, determine the quality of the final compost. Accordingly, the rate of degradation and mineralization process was enhanced through the co-composting of banana peels with poultry manure [15]. Soto-Paz et al. [16] evaluated the potential of biowaste and sugarcane filter cake for composting. They recorded that the composting of biowaste and sugarcane filter cake at the 4:1 ratio showed faster maturity and stability of the final compost. Similarly, the composting of poultry manure, cellulosic sludge, and wood chips together showed faster decomposition with the increment of nutrients and organic matter (OM), while also maintaining the C:N ratio below 20 as quality compost [13]. Meunchang et al. [17] observed the rapid loss of OM from the composting of (2:1) sugarcane filter cake with its bagasse. Moreover, the co-composting of 25% wood chips and 25% green waste resulted in a quality compost with optimum pH, electrical conductivity (EC), cation exchange capacity (CEC), and germination index (GI > 80%) value [18]. As the C:N ratio of chicken manure is comparatively low, it tends to emit more ammonia than from other organic sources [19]. To deal with this problem, other materials can be used at different ratios to suppress the emissions by adjusting the material's C:N ratio. Studying the effects of initial mixtures on the characteristics of organic matter in composts, Francou et al. [20] found little stabilization of organic matter during composting of green wastes with their large lignin content. Chicken manure compost with 42.5% (*w/w*) bark in the feedstock had the best quality as a soil improver in terms of organic matter content, C:P ratio, C:N ratio, and stability [21].

Likewise, research on the composting of animal manure with bulking materials such as cereal crop residues [22,23], cotton crop waste [24], and wood shavings, leaves, and sawdust [25,26] have been undertaken throughout the world. Several analyses have explored co-composting of chicken manure with farmyard manure, pig manure, animal dung, garden waste, green waste material, sawdust, animal farm litter, and bedding material [27–30]. Kalemelawa et al. [15] evaluated the aerobic and anaerobic composting of banana peels treated with inoculums. He et al. [29] used pig manure, wheat straw, and rice straw biochar in composting. Kumar et al. [30] executed simultaneous composting of sugarcane waste with mushroom substrate and wheat straw to improve compost quality.

Similarly, Czekala et al. [31] also investigated biochar with poultry manure and wheat straw in the aerobic co-composting process in their study.

However, not enough research has been published on co-composting using banana wastes and the subsequent physicochemical changes that occur during composting. Most research has been done in the laboratory, but here, the nutrient parameters are limited. Such studies' results did not truly reflect the utility of crop demand in agriculture. Banana pseudostem is a highly alkaline organic waste that contains cellulose and lignin with 75–85% moisture [32]. The addition of excessive moisture and inappropriate ratios of a mixture may lead to delaying the process through the poor window, which does not favor microbe and quality compost [33].

The inherent moisture in the banana pseudostem along with a suitable ratio of MMW and frequent turning would create a congenial condition for faster decomposition in the process. Composting of these materials together may alleviate the negative impacts of individual waste on crops and might turn the compost into a balanced organic fertilizer able to synchronize the release of nutrients with the demand of crops in acidic soil. To the best of our knowledge, no research has investigated the decomposition of banana pseudostem and mushroom media waste with chicken manure to utilize them as organic fertilizer through co-composting. Therefore, in order to make effective compost, the ratio of the substrate mixture must first be determined. The objective of the study was to identify the suitable ratio of banana pseudostem to mushroom media waste in co-composting with chicken manure.

2. Materials and Methods

2.1. Materials Collection, Preparation, and Pile Management

The required amounts of semi-humified chicken manure (CM), mushroom media waste (MMW), and banana pseudostem (BPS) samples were collected from QL Ansan Poultry Farm Sdn Bhd, Rawang (3°27'31.97" N and 101°35'21.23" E), Nas Agro Farm, Sepang (2°50'52.64" N and 101°44'38.23" E), and Banting, (2°48'16.1" N and 101°30'10.99" E), Malaysia, respectively. The collected CM and MMW were properly cleaned, sieved, and preserved separately in an open polyshade house at ambient temperature (25 °C to 28 °C). The day before composting, fresh banana pseudostems were chopped down into desirable sizes then crushed with a 14 HP, woodchipper machine (Model: Ohashi-GS122GB, Obashi Ecological technology, Sakimura Chiyoda Kanzaki Saga, Japan). Banana pseudostem sap was collected through the outlet pipe during the crushing of banana pseudostem. The sap was subjected to the addition of an extra 250 g urea and maintained moisture (at 60–70%) in the composting piles. In each pile, the 250 g of urea was evenly sprinkled in each layer of feedstock mixtures with pseudostem sap and water. It was uniformly spattered in different layers in the final mixture during pile preparation to promote decomposition. The piles were protected with a rainproof, non-transparent and thick plastic canvas from any unexpected weather disturbance. Turning and mixing (manually by shovel) were done weekly to allow uniform airflow throughout the composting period. The initial chemical properties of individual materials were measured prior to the co-composting process (Table 1).

Table 1. Physicochemical characteristics of the raw materials used in the co-composting process.

Properties	Banana Pseudostem (BPS)	Chicken Manure (CK)	Mushroom Media Waste (MMW)
Moisture (%)	59.23 ± 4.74	14.52 ± 0.59	28.50 ± 0.35
pH	10.41 ± 0.18	9.53 ± 0.33	6.19 ± 0.13
EC (dSm ⁻¹)	4.74 ± 0.14	4.66 ± 0.13	0.70 ± 0.02
Total C (%)	35.14 ± 1.23	23.57 ± 1.08	40.12 ± 1.42
OM (%)	77.78 ± 2.10	50.0 ± 1.95	94.94 ± 3.03
C:N ratio	73.20 ± 1.56	8.93 ± 0.26	16.05 ± 0.51
Total N (%)	0.48 ± 0.07	2.64 ± 0.06	2.50 ± 0.06
CEC (cmol (+)/kg ⁻¹)	30.00 ± 1.25	24.85 ± 1.14	24.35 ± 0.88

Table 1. Cont.

Properties	Banana Pseudostem (BPS)	Chicken Manure (CK)	Mushroom Media Waste (MMW)
Potassium (K, g kg ⁻¹)	14.06 ± 0.57	12.59 ± 0.47	3.24 ± 0.16
Calcium (Ca, g kg ⁻¹)	9.60 ± 0.35	12.36 ± 0.43	12.27 ± 0.55
Magnesium (Mg, g kg ⁻¹)	2.52 ± 0.09	3.60 ± 0.14	2.41 ± 0.08
Sodium (Na, g kg ⁻¹)	0.87 ± 0.04	2.48 ± 0.09	0.55 ± 0.04
Total P (g kg ⁻¹)	7.40 ± 0.31	6.20 ± 0.24	8.02 ± 0.37
Copper (mg kg ⁻¹)	35.40 ± 1.70	41.60 ± 1.66	14.10 ± 0.59
Manganese (Mn, mg kg ⁻¹)	160.3 ± 6.25	360.2 ± 13.69	101.2 ± 5.06
Zinc (Zn, mg kg ⁻¹)	60.2 ± 2.40	32.72 ± 0.98	163.8 ± 7.17

Mean ± Standard deviation are the average of three replicated samples (dry basis).

2.2. Research Design

The raw materials of BPS, MMW, and CM were mixed manually with six ratios, viz., T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively, before the compost piles were prepared for each treatment. The compost pile was 2 m length × 1.2 m width × 1.0 m height in size volume. According to the treatment ratio, each compost pile received in total 500 kg of three feed stocks as fresh weight basis where the initial moistures of CM, MMW, and BPS were 14.5%, 8.5%, and 59.2%, respectively. Each pile had two replications and samples were replicated three times following Randomized Complete Block design.

2.3. Collection and Preparation of Compost Samples for Physicochemical Analysis

A 300 g of bulk sample was randomly collected from different places (6) of two compost pile in each round of turning and mixture and divided into two parts. The first part of these samples was air-dried and passed through the 0.25- and 0.1-mm sieves and sample repeated three times for physicochemical analysis. Each sub-sample was considered as replication. The second part of the compost samples was immediately preserved in a refrigerator at 4–5 °C for seed germination test.

2.4. Monitoring of Temperature Profile (°C) and Moisture in the Composting Process

The temperature was recorded daily in the morning (before 8 am) and evening (after 5 pm) from the three places of the piles (central, mid-peripheral, and lower-peripheral positions) by portable Mercury thermometer (Alchl Thrmtmr, Labworld, India). In that case, half portion of the thermometer was dipped into the pile from the top centre while the whole portion was dipped from the mid and lower-peripheral position to get the actual average temperature [16]. The ambient temperature was also recorded by the same thermometer at the same times. The daily six readings per compost pile recorded in the morning (3) and evening (3) were averaged. The compost moisture was measured by the gravimetric method where sample was dried at 105 °C until reaching the constant weight [34]. The moisture (%) was calculated following the equation: moisture (%) = $\frac{(W_1 - W_2)}{W_1} \times 100$, where weight of compost before oven drying (W₁) and weight of compost after oven drying (W₂).

2.5. Chemical Analysis of the Compost Samples

The pH was measured from the compost samples by a digital pH meter (HI 2211 pH meter, Hanna instrument, Woonsocket, RI, USA) at the ratio of 1:10 (w/v) water-soluble extract, whereas 1:20 (w/v) ratio of the sample with water was used to determine EC by digital EC meter (Hanna 2300) as described by Gaiind [35]. The total C, N, and sulfur (S) were determined by Leco TruMac CNS analyzer. The C:N ratio was calculated from the total C and total N values. The TOC and OM contents of compost samples were estimated by loss on ignition method [36]). The CEC was determined by the ammonium acetate (pH 7.0) leaching method [37]. Inorganic N was determined using the method of Keeney and Nelson [38]. The total contents of K, Ca, Mg, Na, Mn, Cu, and Zn were determined by atomic absorption spectrophotometer (A Analyst 800, PerkinElmer Corporation, Norwalk,

CT, USA) followed by dry ashing method, based on Cottenie [37], and the amount of P was determined by auto-analyzer (Yellow method) from the same sample.

2.6. Compost Toxicity Test

The germination index of radish seeds was tested via the water extraction procedure as suggested by Guo et al. [39]. Briefly, the compost samples and deionized water at the ratio of 1:10 (*w/v*) was centrifuged for 15 min at 4000 rpm and filtered through 0.45 µm filter paper. A 5 mL of filtrate was pipetted in to 20 mm × 100 mm triplicate sterilizer Petri dish after placing double filter papers on it. Thirty randomly selected radish seeds were placed evenly on filter paper, sealed, and kept on the Petri dish in a dark place for 72 h at room temperature. The total number of germinated seeds were counted in the Petri dish and recorded as a percentage. Root length of the germinated seeds was measured by image J. software [40]. The germination index (GI) was calculated by the following equation:

$$GI (\%) = [SG (\%) \text{ of treatment} \times RL] / [SG \text{ of control} (\%) \times RL \text{ of control}] \times 100,$$

where SG = seed germination of treatments, RL = root length of the treatments (cm).

2.7. Statistical Analysis

Data were subjected to analysis by PROC ANOVA in the RCBD design (SAS, 9.4). The treatment means were compared by protected Least Significant Difference Test (LSD) at the 5% probability level [41].

3. Results

3.1. Monitoring Temperature Profile during the Composting Period

Irrespective of treatments, the temperature rise from the first day and reached the peak at 4–5 days. The use of BPS, MMW, and CM at different ratios had varied temperatures over the co-composting period (Figure 1a,b). The temperature reaching the thermophilic phase for piles T₂ (1:2:1 BPS:MMW:CM), T₃ (1:3:1 BPS:MMW:CM), and T₆ (2:3:1 BPS:MMW:CM) lasted up to 29 days, while for T₁ pile (1:1:1 BPS:MMW:CM), the phase lasted for 4–19 days (Figure 1a,b). However, T₅ pile (2:2:1 BPS:MMW:CM) took 13–19 days to reach the same phase (52.7 °C to 55.0 °C). Elsewhere, the temperature ranged from 45.4 °C to 48.8 °C in T₄ pile (2:1:1 BPS:MMW:CM) and it consistently remained below the thermophilic stage (<50 °C) throughout the composting period. After a longer mesophilic phase (40–50 °C), the temperature in all the piles (except T₄ pile) started falling and reached cooling stage (<40 °C) after 58, 49, 52, 58, and 55 days, respectively.

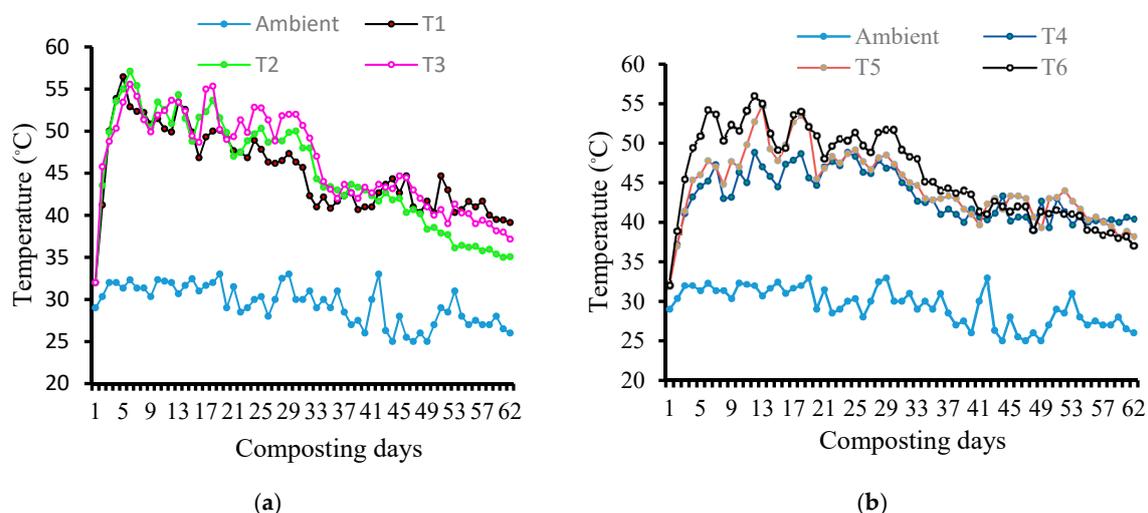


Figure 1. Temperature during the composting as affected by T₁–T₃ treatments (a); Temperature during the composting as affected by T₄–T₆ treatments (b).

3.2. Changes in pH and EC during the Co-Composting

During the composting period, the pH levels in the piles were consistently varied. An increase in the pH and EC levels was observed in each co-compost pile (treatment) (Figures 2 and 3). In the primary stage of composting, pH values revealed a slight decline or remained unchanged up to 7 days in the T₂ pile having increased the amount of MMW followed by the T₃ pile, where the T₄ pile, with a larger amount of BPS, showed a sharp increase in pH value. In the secondary stage, the pH increased gradually up to the final compost. Generally, pH varied from 7.69–8.74 in the initial stage and from 10.0–10.6 in the final stage. However, in the final compost, the lowest pH level (10.0) was recorded in the T₂ pile having an increased amount of MMW (1:2:1 of banana pseudostem, mushroom media waste, and chicken manure) followed by the T₃ (1:3:1 BPS:MMW:CM) pile, while the highest pH (10.6) was recorded in the T₄ (2:1:1) pile where BPS was used in an increased ratio. The EC increase was accompanied by the rising temperature in the co-compost under process (Figure 1a,b). In the final compost, EC ranged from 2.38 to 3.71 dS m⁻¹ in the compost piles, while the T₂ pile mixed with the increased amount of MMW displayed the lowest EC value (2.38 dS m⁻¹), followed by T₃ (2.68 dS m⁻¹) treatment. In the last stage of the co-composting process, the highest EC (3.71 dS m⁻¹) was recorded in the T₄ pile, which was mixed with increased BPS substrate.

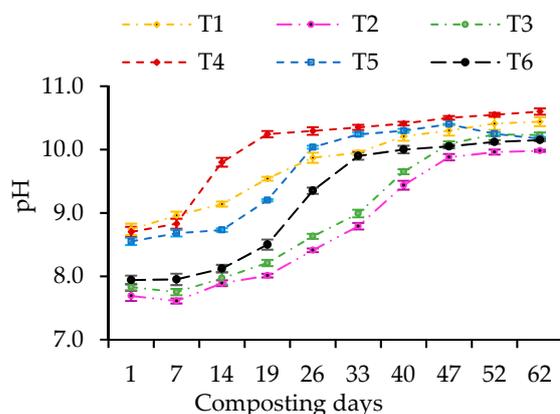


Figure 2. Changes of pH during the composting. Each marker point represents mean ($n = 3$), and the vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively.

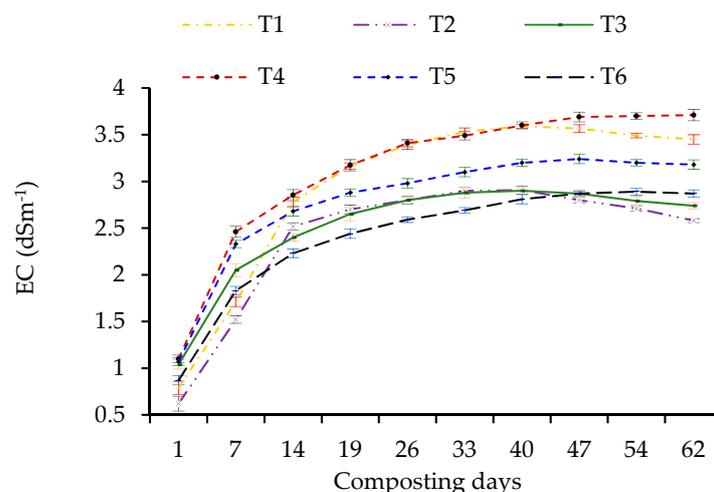


Figure 3. Changes of EC during the composting. Each marker point represents mean ($n = 3$), and the vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively.

3.3. Organic Matter Degradation

The mixing of BPS, MMW, and CM in different ratios significantly influenced the OM degradation in the process (Figure 4). Throughout the composting period, the rapid reduction of OM was recorded in the T₂ pile with 1:2:1 BPS:MMW:CM (79.4% to 36.13%), which was followed by the T₃ pile, while the slowest decomposition was recorded in the T₄ pile having a larger amount of BPS used (2:1:1 BPS:MMW:CM). The decomposition of the initial substrate biomass fell from 66.8% to 49.29% in the T₄ pile. However, the highest (54.5%) relative loss of OM was calculated from the initial to the final stage of the T₂ pile of co-compost with double the MMW used compared to the T₄ pile.

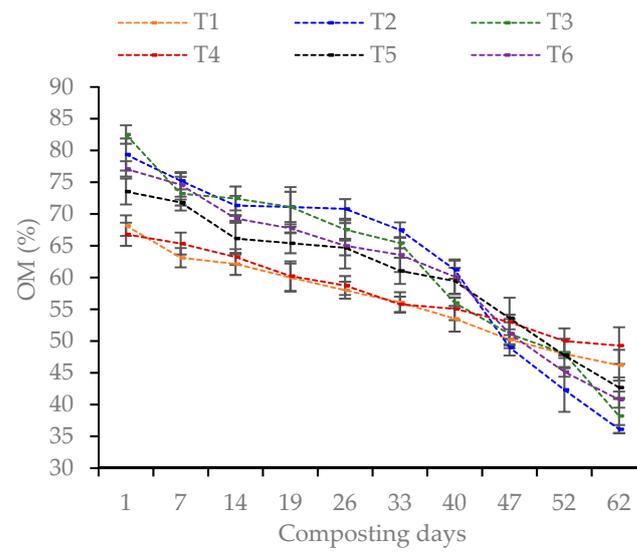


Figure 4. Degradation of organic matter during the composting period. The vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively.

3.4. Changes of Total N, NH₄-N, and NO₃-N

Changes of N were influenced by different ratios of feedstocks used in co-composting. The highest total N was recorded in T₂ having 1:2:1 of BPS, MMW, and CM (1.53%) along with T₅ having 2:2:1 of BPS, MMW, and CM (1.48%) piles, while the lowest N (1.10%) was recorded in the T₄ pile (2:2:1 BPS:MMW:CM) (Table 2). In all piles, the total N loss varied from 11.1% to 23.6% from the initial to the end of the composting, which was recorded in the T₂ and T₁ piles with an equal amount of feedstocks, respectively. NH₄-N ranged from 452–738 mg kg⁻¹ in the first two weeks and decreased gradually to 120–179 mg kg⁻¹ at the end of composting (Figure 5). However, T₂, having a higher amount of MMW, had the largest amount of NH₄-N (179 mg kg⁻¹) while the pile having higher BPS (T₄ pile) had the lowest (120 mg kg⁻¹) at the final stage (Figure 5). The trend of NO₃-N increased with the decline of NH₄-N in all compost piles, and finally, significantly higher values of NO₃-N were recorded in the T₂ (51.9 mg kg⁻¹) pile, followed by the T₃ pile (48.5 mg kg⁻¹), and the lowest (35.55 mg kg⁻¹) in the T₄ pile (Figure 6).

Table 2. Changes of moisture, C:N ratio, total N, and cation exchange capacity of different compost by co-composting.

Parameters	Time	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
Moisture content (%)	Initial	72.12 ± 2.35 ab	68.52 ± 1.96 b	70.6 ± 1.73 ab	79.32 ± 2.91 a	75.1 ± 1.53 ab	73.39 ± 1.19 ab
	Final	45.24 ± 1.10 b	38.55 ± 0.94 d	36.25 ± 0.74 d	50.10 ± 1.43 a	43.41 ± 0.71 bc	40.21 ± 0.70 cd
Total Organic C (%)	Initial	35.25 ± 1.00 ab	40.96 ± 1.01 a	42.56 ± 0.97 a	34.55 ± 1.13 c	37.98 ± 0.93 abc	39.80 ± 1.13 ab
	Final	24.08 ± 0.59 ab	18.90 ± 0.55 d	20.09 ± 0.57 cd	25.61 ± 0.52 a	22.25 ± 0.40 bc	21.28 ± 0.69 cd
Total N (%)	Initial	1.91 ± 0.04 a	1.70 ± 0.03 b	1.68 ± 0.04 b	1.42 ± 0.03 c	1.76 ± 0.04 ab	1.70 ± 0.03 b
	Final	1.46 ± 0.03 a	1.53 ± 0.04 a	1.45 ± 0.04 a	1.10 ± 0.02 b	1.48 ± 0.03 a	1.42 ± 0.02 a
C:N	Initial	18.44 ± 0.60 c	24.09 ± 0.58 ab	25.33 ± 0.82 a	24.33 ± 0.39 ab	21.57 ± 0.70 b	23.14 ± 0.42 ab
	Final	16.49 ± 0.40 b	12.35 ± 0.25 d	13.76 ± 0.22 cd	23.28 ± 0.52 a	15.03 ± 0.42 bc	14.98 ± 0.30 bc
CEC (cmol kg ⁻¹)	Initial	24.85 ± 0.81 ab	27.48 ± 0.63 ab	27.77 ± 0.56 a	24.00 ± 0.81 b	25.42 ± 0.71 ab	25.21 ± 0.90 ab
	Final	38.00 ± 0.50 bc	41.28 ± 0.98 a	40.14 ± 0.90 a	32.14 ± 0.55 c	38.50 ± 0.68 abc	40.07 ± 0.88 ab

Here, compost piles, viz. T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, indicates mixture ratio of banana pseudostem (BPS), mushroom media waste (MMW), and chicken manure (CM) respectively. Mean ± standard error within the row followed by the same letter are not statistically significant at $p \geq 0.05$ by LSD Test.

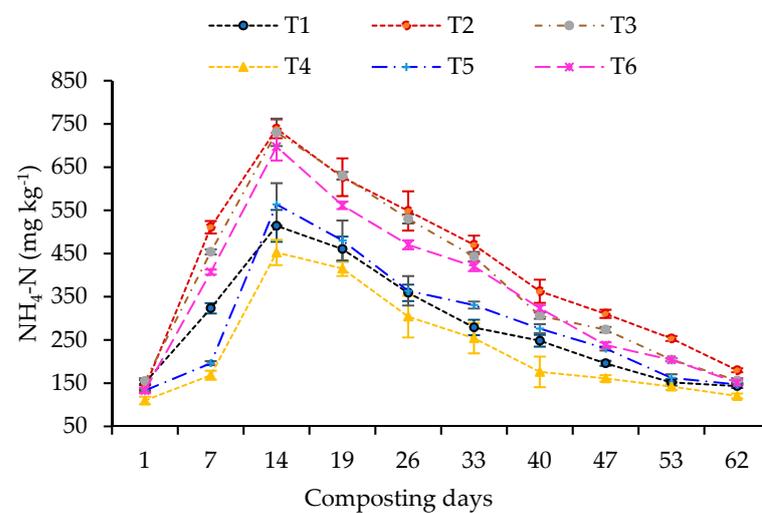


Figure 5. Changes of NH₄-N during the composting. Each marker point represents mean ($n = 3$), and the vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively.

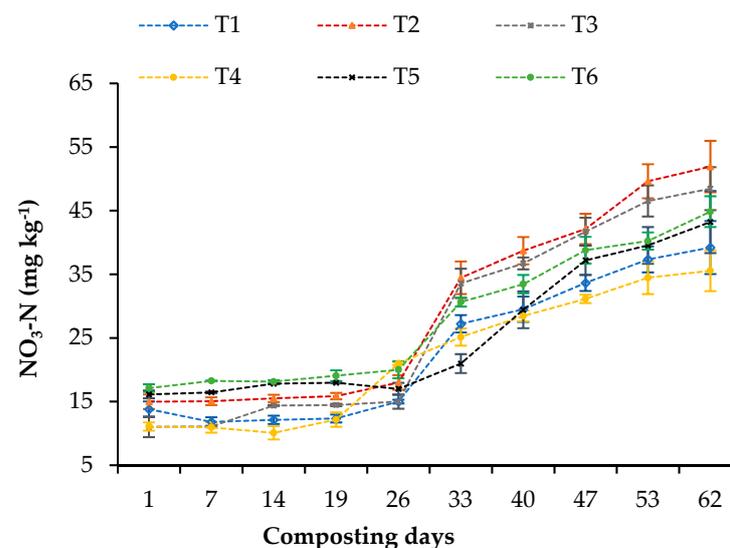


Figure 6. Changes of NO₃-N during the composting. Each marker point represents mean ($n = 3$), and the vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, respectively.

3.5. Changes in Moisture

Among the treatments, the moisture content, total C, total N, and the C:N ratio fell from the initial to final stage whereas the CEC was increased significantly ($p \leq 0.05$) (Table 2). The moisture content varied from 68.5% to 79.3% in the initial stage and 36.3% to 50.1% in the final stage. The minimum moisture (36.3%) was observed in the final compost at T₃ pile, which was statistically similar to the T₂ (38.6%) pile, while the maximum moisture of 50.1% was recorded from T₄ compost (50% banana pseudostem, 25% mushroom media waste, and 25% chicken manure).

3.6. Changes in Total C

A remarkable decrease in TOC was found from the beginning to the final compost and it ranged from 25.9–53.9% in the piles where 31.7%, 53.9%, 52.8%, 25.9%, 41.4%, and 46.5% were recorded in the T₁, T₂, T₃, T₄, T₅, and T₆ piles, respectively. The highest reduction of 53.9% appeared in the T₂ (1:2:1 ratio) pile and 25.9% in the T₄ (2:1:1 ratio) pile. Of the six compost mixtures, however, the lowest content (18.9%) of organic C was recorded in T₂, and the highest was 25.6% in T₄, followed by the T₁ (24.1%) co-compost pile.

3.7. Changes in C:N Ratio

All the compost samples had a C:N ratio below 20 except for T₄ (23.3), while the lowest C:N ratio (12.4) in T₂ was statistically identical to (1:3:1) the T₃ (13.8) pile at the end of composting (Table 2). Moreover, the C:N ratio of the compost significantly decreased by 10.6%, 48.7%, 45.7%, 4.31%, 30.3%, and 35.3% in the T₁–T₆ treatments, respectively. Among the treatments, the highest C:N ratio decreased (48.7%) in T₂ and the lowest (4.31%) was in T₄ from initial to final compost.

3.8. Changes in CEC

The CEC for all treatments has shown a significant increase in the final compost (Table 2). The piles T₂ (1:2:1 BPS:MMW:CM), T₃ (1:3:1 BPS:MMW:CM), and T₅ (2:2:1 BPS:MMW:CM) showed statistically identical results of CEC where the numerically higher value was obtained from T₂ treatment (41.3 cmol kg⁻¹) and a lower value was found in the T₄ treatment (32.1 cmol kg⁻¹). In the final compost, CEC was higher by 45% than that of the initial condition.

3.9. Changes in Macro- and Micro-Nutrients

Co-composting of BPS, MMW, and CM in different ratios had varied nutrient concentrations in the final compost (Table 3). In the final compost, the highest values of P (9.84 g kg⁻¹), Ca (14.8 g kg⁻¹), Zn (456 mg kg⁻¹), Cu (60.7 mg kg⁻¹), and Mn (784 mg kg⁻¹) were recorded from the T₂ pile having BPS, MMW, and CM at a 1:2:1 ratio but the highest values of K (12.1 g kg⁻¹), Mg (5.94 g kg⁻¹), Na (2.70 g kg⁻¹), and S (300 g kg⁻¹) were recorded in the T₁ pile. This was comparable to the lowest value of all nutrients observed in the T₄ compost, having a higher amount of BPS added (50%). However, the concentrations of P, K, Ca, Na, and Zn were increased by 79.2%, 73.3%, 44.7%, 41.2%, and 86.1%, respectively, in the T₂ pile. In contrast, the amounts of K, Mg, and Na in the T₄ pile, having more BPS (50%), fell by 7.08%, 8.56%, and 1.87%, respectively, compared to their corresponding initial value.

Table 3. Changes of total macro- and micronutrients of different treatments (T₁–T₆) during the composting period.

Treatments	P (g kg ⁻¹)			K (g kg ⁻¹)			Ca (g kg ⁻¹)		
	Initial	Final	% Increase	Initial	Final	% Increase	Initial	Final	% Increase
T ₁	4.14 ± 0.13 bc	6.76 ± 0.27 b	63.29	7.47 ± 0.18 b	12.1 ± 0.47 a	61.98	6.64 ± 0.26 b	8.97 ± 0.19 c	35.09
T ₂	5.49 ± 0.20 a	9.84 ± 0.35 a	79.23	5.28 ± 0.11 c	9.15 ± 0.46 b	73.30	10.23 ± 0.23 a	14.8 ± 0.17 a	44.67
T ₃	6.20 ± 0.15 a	10.4 ± 0.16 a	67.74	4.84 ± 0.22 c	8.04 ± 0.42 b	66.12	9.88 ± 0.09 a	14.2 ± 0.26 ab	43.72
T ₄	3.45 ± 0.10 c	4.39 ± 0.12 c	27.25	10.6 ± 0.12 a	9.85 ± 0.35 ab	-7.08	5.97 ± 0.14 c	5.08 ± 0.17 d	-14.90
T ₅	3.69 ± 0.13 bc	6.64 ± 0.26 b	79.95	6.04 ± 0.14 c	9.26 ± 0.25 b	53.31	6.43 ± 0.17 b	8.46 ± 0.20 c	31.57

Table 3. Cont.

Treatments	P (g kg ⁻¹)			K (g kg ⁻¹)			Ca (g kg ⁻¹)		
	Initial	Final	% Increase	Initial	Final	% Increase	Initial	Final	% Increase
T ₆	4.39 ± 0.17 b	7.50 ± 0.20 b	70.84	5.81 ± 0.17 c	7.55 ± 0.22 b	29.95	9.18 ± 0.19 a	12.8 ± 0.26 b	39.43
LSD (0.05)	0.84	1.19	-	1.32	2.41	-	1.28	1.65	-
Treatments	Mg (g kg ⁻¹)			Na (g kg ⁻¹)			S (mg kg ⁻¹)		
	Initial	Final	% Increase	Initial	Final	% Increase	Initial	Final	% Increase
T ₁	3.77 ± 0.11 bc	5.94 ± 0.03 a	57.56	2.05 ± 0.02 b	2.70 ± 0.04 a	31.71	270 ± 8.15 a	300 ± 6.12 a	11.11
T ₂	3.45 ± 0.02 c	4.81 ± 0.04 b	39.42	1.70 ± 0.02 d	2.40 ± 0.02 b	41.18	200 ± 4.89 d	250 ± 4.08 c	25.00
T ₃	3.38 ± 0.07 c	4.62 ± 0.03 c	36.69	1.81 ± 0.01 c	2.31 ± 0.03 c	27.62	190 ± 3.67 d	270 ± 8.16 bc	42.11
T ₄	4.51 ± 0.16 a	4.12 ± 0.04 d	-8.65	2.14 ± 0.02 a	2.10 ± 0.02 d	-1.87	230 ± 5.30 bc	290 ± 3.26 ab	26.09
T ₅	3.91 ± 0.04 b	4.86 ± 0.03 b	24.30	1.81 ± 0.03 c	2.30 ± 0.03 c	27.07	250 ± 4.89 ab	260 ± 4.48 c	4.00
T ₆	3.40 ± 0.08 c	4.59 ± 0.03 c	35.00	1.59 ± 0.02 e	2.14 ± 0.05 d	34.59	210 ± 4.08 cd	250 ± 2.85 c	19.05
LSD (0.05)	0.44	0.13	-	0.04	0.08	-	23.73	21.19	-
Treatments	Zn (mg kg ⁻¹)			Cu (mg kg ⁻¹)			Mn (mg kg ⁻¹)		
	Initial	Final	% Increase	Initial	Final	% Increase	Initial	Final	% Increase
T ₁	170 ± 3.26 d	230 ± 6.12 d	35.3	31.3 ± 1.02 ab	49.0 ± 1.33 b	56.5	270 ± 11.02 cd	470 ± 8.16 d	74.1
T ₂	245 ± 4.08 a	456 ± 6.53 a	86.1	28.7 ± 0.81 b	60.7 ± 1.17 a	111	319 ± 11.71 ab	784 ± 13.88 a	145.8
T ₃	241 ± 4.10 ab	426 ± 6.53 ab	76.8	21.4 ± 0.57 c	59.6 ± 1.06 a	178	255 ± 6.12 d	670 ± 12.24 b	162.7
T ₄	150 ± 4.08 e	170 ± 2.04 e	13.3	33.4 ± 0.73 a	34.0 ± 0.74 c	1.8	342 ± 8.97 a	370 ± 6.12 e	8.2
T ₅	193 ± 2.86 c	310 ± 8.16 c	60.6	29.3 ± 0.53 b	51.3 ± 0.69 b	75.1	292 ± 4.89 bc	583 ± 8.87 c	99.7
T ₆	224 ± 4.49 b	419 ± 7.75 b	87.1	22.3 ± 0.93 c	47.7 ± 0.37 b	113.9	244 ± 5.71 d	602 ± 12.23 c	146.7
LSD (0.05)	18.82	31.11	-	3.53	6.61	-	35.50	50.09	-

Here, piles, viz., T₁ = 1:1:1, T₂ = 1:2:1, T₃ = 1:3:1, T₄ = 2:1:1, T₅ = 2:2:1, and T₆ = 2:3:1, indicate mixture ratio of BPS, MMW, and CM respectively. Mean ± standard error within the column followed by the same letter are not statistically significant at $p \geq 0.05$ by LSD Test.

3.10. Germination Index (%) under the Compost

The germination index showed a parallel or straight trend up to the 14th day in all piles except the T₄ pile (with a higher amount of BPS), which experienced a slight decline up to the 19th day. In the study, the GI (%) started to increase from 14–19 days in all piles (T₁–T₆) towards the end of composting (Figure 7). The order of the GI values was 129, 125, 115, 93.4, 87.5, and 72.4% in T₂, T₃, T₆, T₅, T₁, and T₄ piles, respectively. The maximum germination index (129%) was recorded in T₂ pile having a higher amount of MMW used, which was statistically similar to T₃ (125%), while the T₄ pile showed the lowest 72.4% from the final compost.

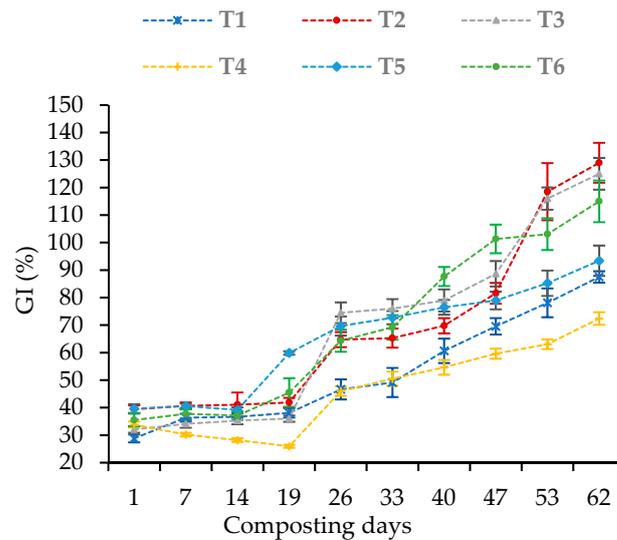


Figure 7. Changes of germination index in different treatments over the composting period. Each marker point represents mean ($n = 3$), and the vertical bars indicate Standard Error of Means (S.E.M). Legends: BPS, MMW, and CM mixed at $T_1 = 1:1:1$, $T_2 = 1:2:1$, $T_3 = 1:3:1$, $T_4 = 2:1:1$, $T_5 = 2:2:1$, and $T_6 = 2:3:1$, respectively.

4. Discussion

The final composts, which had banana pseudostem (BPS), mushroom media waste (MMW), and chicken manure (CM) at the ratios of 1:2:1 and 1:3:1, did better in compost production and germination of sweet corn seeds. Based on the physical and chemical changes recorded during the co-composting, it emerged that the compost piles having more MMW was transformed into a compost of good quality. These composts showed better maturity and stability based on the temperature, C:N ratio, CEC, weight loss (CO_2 evolution), nutrient concentration, and seed germination. These features are discussed in more detail below.

4.1. Monitoring Temperature during the Composting

Temperature during composting is an important indicator of its maturity and quality [42]. An ideal composting process consists of three phases of temperature, namely, the thermophilic ($>50\text{ }^\circ\text{C}$), mesophilic ($40\text{--}50\text{ }^\circ\text{C}$), and cooling phases ($<40\text{ }^\circ\text{C}$), where the thermophilic stage represents the rapid decomposition of organic matter through microbial activity and the mesophilic and cooling phases may cause increased nitrous oxide emission [43]. The decline of the temperature below $40\text{ }^\circ\text{C}$ expressed the maturity of compost [44]. In our study, the T_2 pile showed a faster rise in temperature and longer thermophilic phase lasting up to 30 days followed by T_3 due to the incorporation of 50% mushroom media waste (MMW) as a C source. The microbial degradation of added OM materials that released CO_2 led to an increase in the compost temperature [45]. Some researchers even showed that two stage co-composting has double thermophilic stages indicating even faster decomposition and maturity of compost [44]. Throughout the whole process, T_4 treatment did not reach the thermophilic stage due to the addition of a higher amount (50%) of BPS while excess moisture was evident in BPS. However, the early drop in temperature by the 49th day to cooling phase ($<40\text{ }^\circ\text{C}$) indicated 13 days earlier maturity of the T_2 compost compared to T_4 . The declining temperature also meant that the small portion of the easily degradable composting materials remained in the cooling phase [46].

4.2. Changes in pH and EC during the Co-Composting

The pH and EC are important parameters in composting, and they indicate the rate of decomposition of compost as well as the suitability of its application in soil. Overall, the compost piles resulted in an alkaline pH (≥ 10) and a higher EC value from

2.38–3.71 dS m⁻¹ due to the use of alkaline materials rich in K and Ca (Table 1, Figure 3). During the initial stage (1–21 days), the pH showed an unchanged or slightly increasing trend. After 21 days of co-composting, the pH significantly increased with the decrease in the temperature, the mineralization of organic N, and the release of NH₄ ions. A similar trend was detected by Jolanun and Towprayoon [47]. In the present study, T₂ (1:2:1) had the lowest value of pH (10.0) followed by the T₃ (1:3:1) pile, which received 25% BPS, 50% MMW, and 25% CM in the process (Figure 2). This outcome was consistent with the pH (9.3–9.7) of banana peel compost as studied by Kalemelawa et al. [15], who reported that high K concentrations in banana waste forms a strong base (KOH) that increases the pH value. However, the T₂ compost with moderately alkaline pH could be effective in diminishing the acidity of acidic soil. In addition, T₁ (33.33% BPS) and T₄ (50% BPS) piles were BPS-dominated composts which recorded higher EC values. The added BPS and/or CM contained a higher amount of K and Ca salts (Table 1), which increased the EC of the composts. The release of mineral salts due to volume loss via decomposition, increased the EC values studied by Silva and Brás [13]. Considering the individual EC of the piles, T₂ resulted in the most suitable value of 2.38 dS m⁻¹, followed by the acceptable limit of EC < 3 dS m⁻¹ [48]. Thus, the T₂ compost having 25% BPS, 50% MMW, and 25% CM is suitable as an organic fertilizer.

4.3. Changes in OM, TOC, C:N, and CEC during the Co-Composting

Due to the long-term persistence of thermophilic temperatures, more organic matter is lost in the T₂ pile (1:2:1 BPS:MMW:CM), resulting in a lower OM (36.1%) content in the final compost (Figure 4). In this study, the T₂ pile having a higher proportion (50%) of MMW contained the various type of enzymes (results are included in another manuscript under review), and fungus mycelium [9], thereby resulting in 54.5% of OM loss. This amount of reduction in OM in the present study is consistent with the reduction of OM (47–52%) in the study conducted by Kulcu et al. [49]. A more than 42% reduction in OM was considered able to stabilize the process [16]. Fang et al. [9] also recorded the reduction of OM in the mushroom substrate composting material. Moreover, the addition of a higher proportion of MMW with lower BPS may create a favorable microbial environment through better aeration in the composting and facilitate the faster degradation of OM [42]. On the other hand, the T₁ (33.3% BPS, 33.3% MMW, and 33.3% CM) and T₄ (50% BPS, 25% MMW, and 25% CM) piles were recorded with the higher OM content in the final compost than the T₂ pile. It strongly suggests that those piles were partially decomposed due to a limitation in microbial activity or higher moisture content (72 to 79%). In addition, the existing lignin and cellulose in banana pseudostem [32] were slowly degraded and persisted for a longer period of time, thus confirming higher OM contents in the T₁ and T₄ piles.

In the composting process, the C content promotes the degradation of OM. A low C concentration can restrict biomass formation and compromise degradation [16]. The greater reduction of total organic carbon (TOC) content in T₂ (53.8%) and T₃ (52.8%) piles (Table 2) indicated the higher bio-oxidation of OM maintained by the thermophilic temperature (Figure 1a). In this study, the reduction of the C:N ratio is mainly due to the decomposition of organic matter (loss of C as CO₂ via transformation). In the course of decomposition during composting, the increase of the total N% was associated with the volume reduction. The increase in inorganic N in the T₂ co-compost pile (having higher MMW) may contribute to the total N increase as well as the low C:N ratio. The strong sorption capacity of the added MMW bulk material may also help adsorb N on its large surface area. The highest reduction of C (53.8%) through OM decomposition was also associated with the low C:N ratio (12.4) (Table 2). These outcomes reflect the result of composting of wood chips with green waste as documented elsewhere [18]. The compost with a < 20 C:N ratio is more acceptable as noted by Gaiind [35].

On the other hand, as the BPS had lower C content, even under high moisture (79.3%) content in it, the OM decomposition and loss of C did slow down (Figure 4 and Table 2).

The higher C:N ratio (23.3) in the T₄ compost (2:1:1 BPS:MMW:CM) is associated with these. The N loss through volatilization might also affect the low C:N ratio obtained in the final compost. The results are consistent with Mohee et al. [48] who discovered that microbial consumption of C decreased the C:N ratio of the compost. In the present study, the CEC was increased in all treatments from the initial to final compost (Table 2), and it varied from treatment to treatment and with the amount of added banana pseudostem and mushroom media waste. The CEC was greater of those treatments due to higher decomposition of added banana pseudostem and mushroom media waste, particularly in the T₂ compost. This may explain the high content of exchangeable cations in BPS and MMW (Table 1).

Zhang and Sun [18] obtained a 45% increase in CEC from the co-composting of wood chips and green waste compared to green waste that was similar to the T₂ compost. Bahtiar et al. [7] studied banana waste as a vital source of Na, K, Ca, and Mg as possibly increasing the CEC in compost. Moreover, the carboxyl and phenolic functional groups may emerge from the humification of organic materials which can increase the CEC in T₂ compost. This finding appeared to agree with what Steiner et al. [50] found. The greater CEC value also represents the higher decomposition rate and nutrient retention capacity of compost [50]. Although the T₄ (2:1:1 of BPS, MMW, and CM) compost contained BPS in greater amounts, the CEC was comparatively lower than that of T₁ (1:1:1) and T₂ (1:2:1) compost. However, at the initial stage, the addition of 50% BPS in the T₄ treatment may lead to having excess moisture that ultimately leached down some cations and lowered the CEC value (Table 3).

4.4. Changes in TN and Inorganic N during the Co-Composting

The stimulated microbial activity under high temperature and alkaline pH degrades the organic compounds and might induce ammonia volatilization and reduced TN in the pile having an increased amount of MMW (T₂ pile). The loss of TN 11.1% was much lower than that of TN loss 21–40% from the co-composting of biowaste and sugarcane filter cake [16]. Composts with 1–2% N have minimal effect on N fertilizer requirements for crop production [51]. However, TN in T₂ (1.53%) compost remained within this range for agricultural use. In addition, the T₂ pile receiving a higher proportion of MMW, which could assimilate NH₃ on its large surface and in turn contribute NO₃-N [18] as well as TN. A similar finding was noted by Guo et al. [39]. Most of the inorganic N remained in the form of NH₄-N and low levels of NO₃-N were detected in the compost.

During the composting, a reverse trend of NH₄-N and NO₃-N production was evident in all the piles followed by a typical composting process [52]. A similar trend was observed by Kalemelawa et al. [15] from banana peel compost. In the final stage, T₂ showed a significantly ($p < 0.05$) higher value (179 mg kg⁻¹) of NH₄-N over the other piles, which increased NH₄-N by 28.5% from the initial value (140 mg kg⁻¹) due to the decomposition of organic compounds (Figure 5). This increase in NH₄-N was due to the degradation of protein and amino acid by NH₄⁺ ions [53]. After 14 days, NH₄-N decreased with the volatilization of NH₃ due to high temperature (>40 °C) and high alkaline pH (10) as mentioned by Meng et al. [46]. Furthermore, the fall in temperature may have activated the nitrifying bacteria for nitrification [54], which might be attributed to the highest NO₃-N (51.9 mg kg⁻¹) in the T₂ compost at the final stage. On the other hand, excess moisture from BPS may inactivate nitrifying bacteria that can affect the NO₃-N production in the T₄ pile where increasing use of BPS was evident.

4.5. Changes in Nutrients Density during the Co-Composting

The content of macronutrients is a very important variable of compost [51]. Macro and micronutrients in the final compost were significantly ($p < 0.05$) influenced by the amount of BPS and MMW in the composting process (Table 3). Results indicated that the T₂ (25% BPS with 50% MMW) compost increased the highest percentages of nutrient concentrations (P 79.23%, K 73.30%, Ca 44.67%, Na 41.18%, and Zn 86.10%) followed by T₃ from the initial to final compost (Table 3) compared to other piles. It was due to the complete decomposition

of OM through a longer thermophilic phase [55] (Figure 1a,b). These results agreed with the findings of Kalemelawa et al. [15], who observed the increase in P (86%) and K (34%) in banana peel with cow dung compost. Ultra et al. [56] detected extremely large amounts of K, Ca Mg, and Na in banana waste compost. Moreover, the T₂ and T₃ composts resulted in extremely large amounts of Zn, Cu, and Mn through the humification of the added BPS and MMW. These outcomes were similar to Chimuka and Manungufala [57], who suggested that Cu and Zn have a strong affinity to adsorb with organic and carbonate fractions in compost. In another study, Hsu and Lo [58] indicated that decomposition of OM increased the amount of Cu, Mn, Zn in compost by almost two- to threefold, which resulted in a greatly improved compost product. On the other hand, the T₄ pile, which received 50% BPS, showed the incomplete decomposition of OM due to the limitation of C (34.55%) and excess moisture (Table 2). The excess moisture (79%) from BPS created a poor window system and microbial inactivity for OM degradation [39]. Moreover, excess moisture in T₄ (50% BPS) compost influenced leaching loss of K (7.08%), Ca (14.90%), Mg (8.56%), and Na (1.87%), so the value of the final content was lower than that of the initial one. This is despite the banana pseudostem being rich in cations [59]. Thus, the T₁ and T₅ piles showed a higher increment of K, Mg, and Na in the final product. However, all the nutrients in the T₂ compost (1:2:1 i.e., 25% BPS, 50% MMW, and 25% CM) can be potential sources of organic fertilizer for crop production and especially for low pH soil.

4.6. Changes in Germination Index during the Co-Composting

The seed germination test is the most sensitive indicator for evaluating the phytotoxicity and maturity of compost [60]. This study showed that the GI declined or remained unchanged in the initial stage, and it may have been due to the formation of organic acids or salts at a high temperature, prevailing up to 19 days in the compost pile. This result is consistent with the findings of Guo et al. [39]. After 19 days, GI started to increase in all piles mainly due to the degradation of toxic substances [61] throughout the study period. In the final stage of composting, all the compost piles with varied feedstock ratios (T₁–T₃) and (T₅–T₆) showed a GI value above 80%, except T₄, which documented higher BPS. T₂ and T₃ resulted in higher GI values of 129% and 125%, respectively, with the addition of 20–25% of BPS in the composting. The higher GI might be attributed to their maturity and being free of toxic substances or less toxic to germination of seedlings, as found by Zorpas and Loizidou [62]. The GI value showed <80% in the T₄ pile, which means that the BPS might not have been decomposed properly, excessive salts were present in it, and/or toxic substances were added from the higher amount of BPS (2:1:1 of BPS:MMW:CM) to the process. In short, 20–25% of BPS with 50–60% MMW had higher seed germination that can be safe for application in agricultural soil.

5. Conclusions

The present study examined the optimal ratio of banana pseudostem, mushroom media waste, and chicken manure for the composting process, which was monitored in connections with temperature, pH, EC, OM, TOC, C:N ratio, CEC, TN, and other nutrients as a function of time. Around half the proportion of BPS to MMW enhanced composting process by extending the duration of thermophilic phase; improved the pH, EC, CEC values; and increased the macro- and micronutrient concentrations. Of the six combinations of feedstocks, the addition of BPS, MMW, and CM at a 1:2:1 ratio (25% BPS, 50% MMW, 25% CM) decomposed earlier and performed better in terms of acceptable pH value (10), suitable C:N ratio (<15), nutrients content and showed no toxicity to crops. That is why the optimal seed germination was associated with the improved compost properties. The highly alkaline pH of the compost samples suggests that it could be employed for the upgradation of acidic soils. However, the effectiveness of these alkaline composts has yet not been tested in the field level. Thus, the next research would be forwarded to using this compost in a soil–plant system in acidic soil, especially Ultisols and Oxisols.

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