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Nutrient enrichment of food waste compost using agricultural residues

Jutarut Iewkittiyakorn[1*], Trithep Savisai[1], Piyaporn Khunthongkaew[1] and Juntima Chungsiriporn[2]

[1]Division of Biological Science, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand
[2]Division of Chemical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand
[*]Corresponding author: jutarut.p@psu.ac.th

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Abstract

Food waste (FW) management is a critical global challenge due to its environmental and economic impacts. Composting provides a sustainable recycling pathway but FW alone often requires supplementation with carbon-rich residues to balance moisture and enhance compost quality. This study investigated the effects of co-composting FW with dried coffee grounds, soybean meal (SM), banana peel, and light rubber wood ash (LA) in different proportions (0–20% w/w) for 14 days in foam box systems. The objective was to identify the additive and concentration that most effectively improved the nutrient composition of the obtained compost. Results showed that agricultural residues significantly increased macronutrient levels. In particular, 20% SM yielded the compost with the highest nutrient concentrations, with total N, P_2O_5, and K_2O reaching 3.39%, 1.77%, and 2.89% (w/w), respectively, compared with 1.51%, 0.93%, and 0.61% (w/w) in the control. LA enhanced compost alkalinity and K_2O content. These findings demonstrate that SM and LA are promising additives for producing a nutrient-rich compost from FW that could contribute to sustainable waste management and the development of high-quality organic fertilizers.

Keywords: Agricultural waste, Coffee grounds, Compost, Compost nutrient, Food waste, Soybean meal

1. Introduction

Food waste (FW) is a growing environmental concern worldwide. Approximately one-third of all food produced is discarded, causing greenhouse gas emissions, landfill overloading, and loss of resources [1]. In Thailand, FW represents the largest fraction of municipal solid waste, and despite initiatives such as redistribution or reuse as animal feed, significant amounts remain improperly disposed of, posing health and environmental risks [2]. Composting FW offers a simple and sustainable solution that produces nutrient-rich organic soil amendments while reducing dependency on chemical fertilizers [3-5]. However, FW alone is not an ideal substrate for composting because of its high moisture content, high acidity, and poor structural balance. These limitations can reduce microbial activity and result in unstable compost products [6]. Therefore, agricultural residues are often added as bulking agents to adjust moisture, improve aeration, and enhance the final nutrient composition [7]. Several studies have reported that the addition of lignocellulosic and nutrient-rich residues can accelerate organic matter stabilization, improve compost maturity, and reduce greenhouse gas emissions [5,8,9].

Thailand generates large amounts of agricultural residues, many of which have potential as compost additives. Dried coffee grounds (CG), a by-product of coffee processing, account for 45–50% of fresh coffee cherry weight. Thailand produces over 10,000 tonnes of coffee annually, creating substantial amounts of CG waste [10]. CG contain about 2.0% N (total N), 0.3% P (total P_2O_5), and 0.6% K (total K_2O), with a C:N ratio of ~20:1, making them suitable as a compost feedstock. Panusa et al. [11] emphasized the importance of bioactive compound and nutrient contents to the potential of CG as an organic amendment, although their acidic nature may affect soil pH [12]. Soybean meal (SM), a protein-rich by-product of soybean oil extraction, is another promising additive. It contains 6.5–7.5% total N, 0.9–1.2% total P_2O_5, and 2.0–2.5% total K_2O, providing an excellent nitrogen source to support microbial activity [13]. The high organic matter content and good biodegradability of SM [13,14] contribute to the decomposition and stabilization of compost. Zhang and Sun [13] demonstrated that adding SM to FW compost enhanced nitrogen availability and shortened composting time. Banana peel (BP), which accounts for 30–40% of fresh banana weight, is widely available as household and market waste. As Thailand produces over 1.1 million tonnes of bananas annually, significant peel waste is generated. BP contains ~1.9% total N, 0.3% total P_2O_5, and 3.2% total K_2O, with a C:N ratio between 20:1 and 30:1—close to the ideal composting range of 25:1–30:1 [15,16]. The high K content and fermentable sugars in BP promote microbial activity and effectively enrich compost. Light ash (LA) from rubber wood is also available in large quantities in southern Thailand. It is rich in K (7.0–10.0%) and P (1.0–2.0%), with trace amounts of N, Ca, and other micronutrients [16,17]. LA serves as a pH buffer and mineral additive in composting [18], neutralizing acidity and enhancing nutrient balance. Jala and Goyal [19] further confirmed the role of ash in improving soil fertility and crop production.

Therefore, the aim of this study was to investigate the effects of CG, SM, BP and LA on the nutrient composition of FW compost. Co-composting was carried out with different proportions of additives (0–20% w/w) over a period of 14 days in foam boxes. The final compost products were evaluated against the Thai Agricultural Standard for Compost (TAS 9503-2014) [20] and the European Quality Guidelines for Compost [21] to determine the type and proportion of additives that most effectively improved compost quality.

2. Materials and methods

2.1 Composting materials

FW was collected from the canteen of the 10^{th}–11^{th} dormitory on the Hat Yai Campus of Prince of Songkla University, Thailand in January and February 2024. The collected FW was filtered to separate water, and the remaining solids were shredded until they became a homogeneous material. CG, SM and BP were sourced from a coffee shop, a tofu store and a fried banana store, respectively, in Hat Yai, Songkhla, Thailand. LA was sourced from the Chana Power Plant, Chana, Songkhla, Thailand. All compost materials were analyzed for compost quality according to the Thai Agricultural Standards for compost [20] before further composting. The physicochemical characteristics of the materials are shown in Table 1.

2.2 Composting procedure

Two composting procedures were carried out. The aim of the first procedure was to determine the agricultural residue that most improved the quality of FW compost. In this procedure, 1000 g of FW were composted with 500 g of Superbact (SB) in rice bran form, a commercial microbial inoculant (BIOAXEL Co., Ltd., Koh Samui, Surat Thani, Thailand [4]) containing active *Bacillus* spp. One of CG, SM, BP or LA was added at 10 wt.% of the combined FW and SB. As a carbon source, 10 wt% of molasses (mL) diluted in dechlorinated water at a ratio of 1:100 (v/v) was then added. SB was used to accelerate composting within the short 14-day composting period. The formulations of these treatments are shown in Table 2. Each treatment was carried out in triplicate, resulting in a total of 15 composting units (5 mixing ratios × 3 replicates).

Foam boxes were used as composting vessels, following the method recommended by Kalemelawa et al [22] to simulate aerobic composting conditions in a controlled laboratory environment. Each foam box had a volume of 5 L and dimensions of 215 mm (width) × 300 mm (length) × 235 mm (height). For ventilation, a rectangle measuring 100 mm × 150 mm was cut out of the lid and covered with a mesh to allow adequate aeration (Figure 1). The initial moisture content of the compost material was adjusted to 50–60% (wet basis) by adding dechlorinated water, according to the recommendation of Gurusamy et al [23].

The compost was turned and mixed by hand with a spatula twice a day for 15 min to promote aeration and uniform decomposition [24]. Three thermometers were placed in the center of each compost pile to monitor the internal temperature. The treatment with the highest total nutrient content (total N, total P_2O_5 and total K_2O) was selected for further investigation in the second experiment to determine the optimal ratio. In the second procedure, FW was composted with the most effective agricultural residue identified in the first experiment, using the mixing ratios shown in Table 5. All other composting conditions were kept the same as in the first experiment.

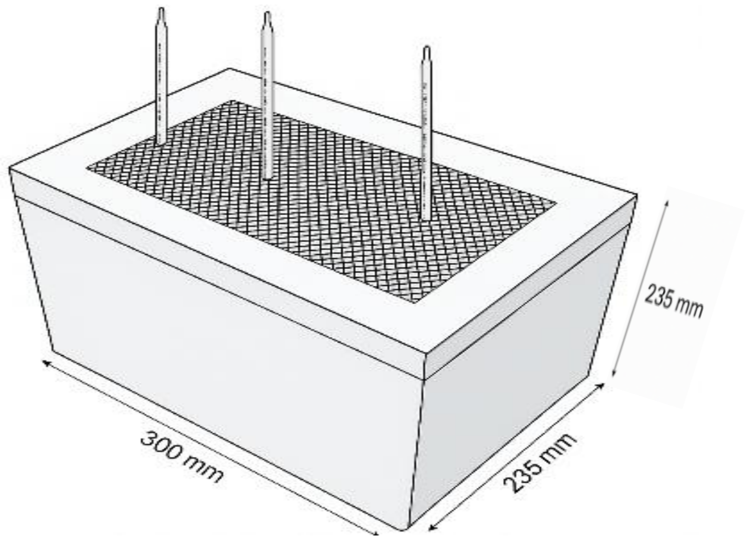

Figure 1 Composting foam box with a volume of 5 L.

2.3 Compost sampling and physicochemical analysis

Each compost was sampled on days 1, 4, 7, 10 and 14. To sample the compost, 20 g of material were collected from the top, center and bottom of each foam box. These subsamples were homogenized to obtain a single representative sample for each treatment, which was used to determine temperature, moisture content, pH and electrical conductivity (EC). The temperature of the compost was measured with a thermometer. The ambient temperature was recorded at the same time. Moisture content was determined by oven drying samples at 105 °C for 24 h until a constant weight was reached, using the standard gravimetric method (AOAC, 950.01) [25]. pH and EC were measured using an extract of compost and deionized water mixed at 1:10 (w/v). The mixture was stirred and allowed to settle for 30 min before pH was measured with a calibrated pH meter (model: Model SP-2100, Suntex Instruments Co., Ltd., Taiwan) and EC with a conductivity meter (Model EC700, Apera Instruments, Columbus, OH, USA), according to the AOAC, 973.04 [26] and BS EN 13038 [27] protocols, respectively. On day 14, when the temperature of the compost had stabilized to the ambient condition, indicating the completion of the active composting phase, the samples were analyzed for organic matter (OM), total nutrients (N, P, K), and the carbon-to-nitrogen ratio (C:N). The OM and total N contents were determined according to the AOAC methods 967.05 [28] and 955.04 [29], respectively. The OM content was calculated from the organic C content multiplied by the Van Bemmelen factor (1.724), following AOAC 967.05 [28]. Total C and N contents were analyzed using a Carbon Nitrogen Elemental Analyzer (CN802, VELP Scientifica, Usmate, Italy). Total P (as P_2O_5) and K (as K_2O) were determined by acid digestion followed by atomic absorption spectroscopy (AAS; model AA-7000, Shimadzu, Japan), according to the AOAC methods 958.01 [30] and 983.02 [31], respectively.

2.4 Statistical analysis

All experimental treatments were conducted in triplicate. The data were analyzed using one-way analysis of variance (ANOVA) to evaluate the effects of the different species and proportions of agricultural residues on the quality parameters of the compost. Mean comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level ($p < 0.05$). For data that did not meet the assumptions of normality or homogeneity of variance, a non-parametric analysis was performed using the Kruskal–Wallis test followed by the Dunn post hoc test. All statistical analyses were carried out using R software (version 4.1.0).

3. Results and discussion

3.1 Characteristics of composting materials

The composition of FW was analyzed by physically separating, weighing, and categorizing the waste. The results showed that FW consisted mainly of rice (45% w/w), followed by vegetable and fruit scraps (30% w/w), meat and bone residues (23% w/w), and eggshells (2% w/w). As shown in Table 1, the physicochemical properties of FW, particularly moisture content and the carbon-to-nitrogen (C:N) ratio, did not meet the requirements of the compost quality standard [20]. Therefore, composting FW alone was not possible, and co-composting with other materials was necessary to achieve the required standards. CG, SM, BP, and LA not only had lower moisture contents and C:N ratios than FW, but also contained higher levels of total nutrients, including total N, P and K.

The total nutrient contents of CG, SM, BP, and LA were 3.41% w/w, 12.10% w/w, 5.11% w/w, and 26.44% w/w, respectively. LA had the highest total nutrient content, largely due to its high total K_2O concentration (24.22% w/w), which made it particularly suitable as a K source.

Table 1 Physicochemical characteristics of composting materials.

Parameter	* Criteria of compost standards [17]	Food waste	CG	SM	BP	LA	Testing method
pH	No standard	5.11±0.04	6.81±0.06	6.52±0.04	5.42±0.07	12.45±0.04	AOAC 973.04 [26]
Total nitrogen	≥ 1.0 %w/w	1.67±0.05	2.33±0.14	7.68±0.22	2.83±0.34	0.28±0.16	AOAC 955.04 [29]
Total P_2O_5	≥ 0.5 %w/w	0.88±0.12	0.41±0.04	1.64±0.06	1.80±0.03	1.94±0.04	AOAC 958.01 [30]
Total K_2O	≥ 0.5 %w/w	0.60±0.04	0.67±0.01	2.78±0.09	0.48±0.04	24.22±0.08	AOAC 983.02 [31]
Organic matter	≥ 20 %w/w	74.27±0.01	88.37±0.14	66.20±0.04	78.06±0.44	5.31±0.34	AOAC 967.05 [28]
C:N Ratio	≤ 20:1	26:1	22:1	5:1	16.1	11:1	BS 7755 [32]
Electrical Conductivity	≤ 10 ds/m	4.31±0.04	0.66±0.03	0.56±0.04	0.31±0.02	0.39±0.04	BS EN 13038 [27]
Moisture	≤ 30 %w/w	85±8.07	22±0.49	20±0.44	80±4.04	3±0.94	AOAC 950.01 [25]

Note: * Criteria of compost standards [20]; CG = coffee ground; SM = soybean meal; BP = banana peel and LA = light rubber wood ash.

Table 2 Composting experiment using food waste with added organic waste materials.

Treatment	Description
A1 (Control)	FW 1000 g + SB 500 g + ML 100 mL
A2	FW 1000 g + SB 500 g + ML 100 mL + CG 10% (150 g)
A3	FW 1000 g + SB 500 g + ML 100 mL+ SM 10% (150 g)
A4	FW 1000 g + SB 500 g + ML 100 mL+ BP 10% (150 g)
A5	FW 1000 g + SB 500 g + ML 100 mL + LA 10% (150 g)

Note: FW = food waste; SB = Superbact; ML = molasses; CG = coffee ground; SM = soybean meal; BP = banana peel and LA = light rubber wood ash.

3.2 Effect of co-composting FW with agricultural residues

Table 3 presents the physicochemical properties of compost produced from FW and agricultural residues. The finished compost from treatment A1 (FW composted with SB) met all the criteria of the Thai Agricultural Standard for compost [20]. SB in rice bran, which is rich in effective digestive microorganisms and organic matter, promoted decomposition and improved the physical structure of the FW. The total nutrient content of the compost in this treatment was 5.38±0.10% w/w. Co-composting FW with agricultural residues further increased the total nutrient values (Table 4). Treatment A3 (FW with SM) had the highest total nutrient content (6.97±0.12% w/w) on day 14, followed by treatment A2 (FW with CG) (6.19±0.15% w/w) and treatment A4 (FW with BP) (6.06±0.07% w/w). In treatment A5 (FW with LA), the total nutrient content reached 8.59% w/w on day 30. The inclusion of SM and CG was particularly beneficial, as these nitrogen-rich materials accelerated decomposition, resulting in faster composting and higher N accumulation. Composting FW with LA increased K_2O due to the K content of LA, and also raised compost pH [33]. Compost temperatures decreased to ambient levels (28.5 °C) by day 14 in all treatments except A5. In treatment A5, the temperature did not rise to the thermophilic phase because excessive LA addition (pH > 8.0) inhibited microbial activity. Since microbial metabolism and organic acid accumulation are regulated by pH, an optimal range of 6–8 is generally required during composting [34]. Therefore, LA should only be applied in small proportions to regulate pH and enhance K_2O enrichment. These results indicated that the addition of CG, SM, and BP increased the nutrient enrichment of FW compost. Based on these findings, further experiments were conducted in which the ratios of SM and BP were increased, while LA was added at 10% w/w (Table 5). Because the composition of FW at source varies daily, representative samples were analyzed prior to the experiments.

The second composting experiment showed that the largest proportion of FW collected in February 2024 was rice (49% w/w), followed by vegetable and fruit waste (30% w/w), meat and bone waste (19% w/w), and eggshells (2% w/w). The total N, total P_2O_5, and total K_2O contents were 1.64, 0.90, and 0.56% w/w, respectively, which were similar to the nutrient values in the first experiment. The changes in temperature, moisture content, pH, and EC during composting are shown in Table 6. Composting temperatures in treatments B3, B5, and B6 reached 45–55 °C, indicating a thermophilic phase (45–70 °C). In this phase, mesophilic microorganisms were replaced by thermophiles, which sustained high temperatures with their extensive metabolic activity. The thermophiles degraded complex C sources such as cellulose and lignin and converted N into ammonia, thereby increasing compost pH [35]. The pH of the compost tended to rise, increasing from 7.37 to 8.20. This tendency can be attributed to higher bio-oxidative activity. The final compost pH was consistent with the recommended range (6.0–8.0) for organic waste reported by Barreira et al. [36]. The increase in EC during composting may be explained by the conversion of organic matter into water-soluble inorganic salts [37]. The elevated EC values observed in all treatments were consistent with the findings of Yadav and Garg [38], who reported that soluble salts released during decomposition increase EC. Similar findings were also reported by Kumar et al [39], who noted that EC increases as complex organic bonds break down into simpler compounds. Moisture content was maintained within the acceptable range but gradually decreased, as microbial activity requires water for metabolism. The final compost was brown to dark brown and had developed a soil-like texture, consistent with typical organic compost [24].

Table 3 Physiochemical characteristics of food waste compost with added materials for nutrient enrichment.

Treatment	Composting time (days)	Parameter			
		T (°C)	M (%wet basis)	pH	EC (dS/m)
A1	0	29.0±0.1	55.30±1.50	6.21±0.17	0.30±0.55
	1	45.1±0.1	32.36±1.69	6.91±0.08	0.32±0.27
	4	49.3±0.1	29.10±0.97	6.42±0.05	0.35±0.52
	7	40.1±0.1	27.02±1.24	6.55±0.11	0.40±0.52
	10	34.1±0.1	24.55±1.99	6.35±0.02	0.42±0.79
	14	28.5±0.1	20.50±0.97	6.25±0.05	0.40±0.29
A2	0	29.0±0.1	54.30±1.52	5.98±0.02	0.37±0.01
	1	43.5±0.1	30.50±1.64	7.88±0.02	0.31±0.08
	4	52.5±0.1	26.26±1.90	6.14±0.03	0.40±0.12
	7	45.4±0.1	21.42±0.13	6.03±0.04	0.34±0.09
	10	33.7±0.1	20.89±0.67	5.99±0.02	0.30±0.02
	14	28.5±0.1	20.09±1.72	5.89±0.06	0.30±0.08
A3	0	29.0±0.1	55.60±1.00	6.48±0.17	0.30±0.03
	1	42.4±0.1	27.20±1.47	7.45±0.14	0.37±0.05
	4	53.1±0.1	32.18±1.38	6.36±0.04	0.42±0.01
	7	45.5±0.1	31.28±0.49	6.77±0.08	0.44±0.08
	10	36.5±0.1	26.56±0.13	6.55±0.06	0.40±0.02
	14	28.5±0.1	20.12±0.21	6.46±0.02	0.39±0.04
A4	0	29.0±0.1	55.80±0.95	4.99±0.13	0.29±0.08
	1	33.5±0.1	21.90±0.84	6.39±0.03	0.33±0.03
	4	49.3±0.1	31.54±0.65	6.84±0.06	0.44±0.03
	7	43.5±0.1	29.98±0.09	7.15±0.03	0.46±0.09

Treatment	Composting time (days)	Parameter			
		T (°C)	M (%wet basis)	pH	EC (dS/m)
	10	34.5±0.1	23.56±0.81	6.89±0.12	0.41±0.01
	14	28.5±0.1	20.44±0.23	6.67±0.08	0.35±0.02
A5	0	29.0±0.1	55.50±0.27	9.79±0.75	0.25±0.02
	1	31.5±0.1	53.00±0.28	9.69±0.28	0.28±0.12
	4	32.5±0.1	51.50±0.21	9.55±0.21	0.30±0.05
	7	32.5±0.1	46.50±0.58	8.89±0.08	0.32±0.07
	10	31.5±0.1	43.50±0.93	8.77±0.93	0.39±0.10
	14	30.5±0.1	40.50±0.74	8.80±0.76	0.40±0.04
	21	30.0±0.1	30.50±0.45	8.70±0.24	0.38±0.01
	30	29.0±0.1	20.10±0.56	8.50±0.06	0.37±0.04

Note: Treatment A1 = FW + SB + ML, A2 = A1 + CG 10%, A3 = A1 + SM 10%, A4 = A1 + BP 10%, A5 = A1 + LA 10%, A6 = A1 + SM 20%, A7 = A6 + LA 10%, A8 = A1 + SM 10% + BP 10% + LA 10%: FW = food waste, SB = Superbact, ML = molasses, SM = soybean meal, BP = banana peel, LA = light rubber wood ash: M = moisture, EC = electrical conductivity

Table 4 Total N, P (P_2O_5), and K (K_2O) contents of food waste compost after 14 days of composting.

Treatment	Composting time (days)	C:N ratio	Compost nutrients (% w/w)			
			N	P_2O_5	K_2O	NPK
A1	14	14:1	3.22±0.03	1.37±0.04	0.79±0.03	5.38±0.10
A2	14	11:1	3.80±0.09	1.24±0.03	1.15±0.03	6.19±0.15
A3	14	12:1	3.56±0.01	1.98±0.09	1.43±0.02	6.97±0.12
A4	14	13:1	3.47±0.02	1.55±0.01	1.04±0.04	6.06±0.07
A5	30	20:1	1.91±0.06	1.84±0.01	4.84±0.04	8.59±0.11

Note**:** N = total nitrogen, P_2O_5 = total phosphorus, K_2O = total potassium, NPK = the sum of total nitrogen, total phosphorus and total potassium.

Table 5 Formulations for composting food waste with the addition of soybean meal, banana peel and light ash.

Treatment	Description
B1	control (FW 1 kg + SB 500 g+ ML 100 ml)
B2	FW 1 kg + SB 500 g + ML 100 ml + SM 10% (300 g)
B3	FW 1 kg + SB 500 g + ML 100 ml + SM 20% (300 g)
B4	FW 1 kg + SB 500 g + ML 100 ml + SM 20% (300 g) + LA 10% (150 g)
B5	FW 1 kg + SB 500 g + ML 100 ml + BP 10% (300 g)
B6	FW 1 kg + SB 500 g + ML 100 ml + BP 20% (300 g)
B7	FW 1 kg + SB 500 g + ML 100 ml + BP 20% (300 g) + LA 10% (150 g)
B8	FW 1 kg + SB 500 g + ML 100 ml + SM 10% (150 g) + BP 10% (150 g) + LA 10% (150 g)

Note**:** FW = food waste, SB = Superbact, ML = molasses, SM = soybean meal, BP = banana peel, LA = light rubber wood ash

Table 6 Physiochemical characteristics of food waste compost with added materials for nutrient enrichment.

Treatment	Composting time (days)	Parameter				
		T (°C)	M (% wet basis)	pH	EC (dS/m)	C:N ratio
B1	0	29.0±0.1	55.30±1.50	6.21±0.17	0.30±0.55	
	1	45.1±0.1	32.36±1.69	6.91±0.08	0.32±0.27	
	4	49.3±0.1	19.10±0.97	6.42±0.05	0.35±0.52	
	7	40.1±0.1	27.02±1.24	6.55±0.11	0.40±0.52	18±0.2:1
	10	34.1±0.1	24.55±1.99	6.35±0.02	0.42±0.79	
	14	28.5±0.1	20.50±0.97	6.25±0.05	0.40±0.29	20:1
B2	0	29.0±0.1	54.30±1.52	5.98±0.02	0.37±0.01	
	1	43.5±0.1	30.50±1.64	7.88±0.02	0.31±0.08	
	4	52.5±0.1	26.26±1.90	6.14±0.03	0.40±0.12	
	7	45.4±0.1	21.42±0.13	6.03±0.04	0.34±0.09	11±0.2:1
	10	33.7±0.1	20.89±0.67	5.99±0.02	0.30±0.02	
	14	28.5±0.1	20.09±1.72	5.89±0.06	0.30±0.08	13±0.2:1
B3	0	29.0±0.1	55.60±1.00	6.48±0.17	0.30±0.03	
	1	42.4±0.1	27.20±1.47	7.45±0.14	0.37±0.05	
	4	53.1±0.1	32.18±1.38	6.36±0.04	0.42±0.01	
	7	45.5±0.1	31.28±0.49	6.77±0.08	0.44±0.08	15±1.2:1
	10	36.5±0.1	26.56±0.13	6.55±0.06	0.40±0.02	
	14	28.5±0.1	20.12±0.21	6.46±0.02	0.39±0.04	12±0.4:1
B4	0	29.0±0.1	55.80±0.95	4.99±0.13	0.29±0.08	
	1	33.5±0.1	21.90±0.84	6.39±0.03	0.33±0.03	
	4	49.3±0.1	31.54±0.65	6.84±0.06	0.44±0.03	
	7	43.5±0.1	29.98±0.09	7.15±0.03	0.46±0.09	13±2.2:1
	10	34.5±0.1	23.56±0.81	6.89±0.12	0.41±0.01	
	14	28.5±0.1	20.44±0.23	6.67±0.08	0.35±0.02	10±3.2:1
B5	0	29.0±0.1	56.30±0.68	5.79±0.05	0.29±0.01	
	1	43.5±0.1	33.00±0.53	7.79±0.07	0.39±0.03	
	4	56.5±0.1	28.63±0.35	6.45±0.03	0.52±0.06	
	7	45.2±0.1	26.55±0.95	6.82±0.11	0.46±0.04	20±0.2:1
	10	34.5±0.1	23.55±0.86	6.76±0.04	0.45±0.02	
	14	28.5±0.1	21.06±0.42	6.78±0.03	0.46±0.01	14±1.2:1
B6	0	29.0±0.1	55.50±0.27	9.79±0.75	0.25±0.02	
	1	36.5±0.1	53.00±0.28	9.69±0.28	0.28±0.12	
	4	49.5±0.1	51.50±0.21	9.55±0.21	0.30±0.05	
	7	52.5±0.1	46.50±0.58	8.89±0.08	0.32±0.07	22±0.6:1
	10	41.5±0.1	43.50±0.93	8.77±0.93	0.39±0.10	
	14	29.5±0.1	40.50±0.74	8.80±0.76	0.40±0.04	15±0.2:1
B7	0	29.0±0.1	56.30±0.68	9.79±0.05	5.29±0.01	
	1	32.5±0.1	40.76±2.12	8.87±0.87	4.77±0.98	
	4	36.0±0.1	36.99±3.71	8.97±0.33	6.00±1.85	
	7	37.0±0.1	40.79±1.94	8.78±0.35	7.58±3.54	19±0.2:1
	10	39.0±0.1	41.12±0.33	8.68±0.40	7.25±4.18	
	14	39.0±0.1	38.92±0.29	8.87±0.56	6.29±2.83	17±0.5:1
B8	0	29.0±0.1	56.30±0.58	10.79±0.05	5.09±0.01	
	1	33.5±0.1	54.76±1.12	9.87±0.87	5.77±0.18	
	4	37.0±0.1	50.99±1.71	9.98±0.33	5.50±1.05	
	7	39.0±0.1	45.79±1.94	9.78±0.35	6.58±3.04	13±0.9:1
	10	40.0±0.1	41.12±0.43	9.68±0.40	8.05±4.08	
	14	41.0±0.1	37.92±1.89	9.07±0.56	8.29±2.63	18±1.3:1

Note: M = moisture, EC = electrical conductivity, C/N ratio = ratio of carbon to nitrogen. Treatments: B1 = FW + SB + ML; B2 = B1 + SM 10%; B3 = B1 + SM 20%; B4 = B3 + LA 10%; B5 = B1 + BP 10%; B6 = B1 + BP 20%; B7 = B6 + LA 10%; B8 = B1 + SM 10% + BP 10% + LA 10%. FW = food waste, SB = Superbact, ML = molasses, SM = soybean meal, BP = banana peel, LA = light rubber wood ash
Error bars represent SD (n=3).

When considering compost nutrient contents (Figure 2), treatment B3 yielded the highest total nutrients (8.76% w/w on day 7 and 8.05% w/w on day 14). This result was attributed to the addition of SM, which is rich in N and P_2O_5. The compost produced in this study contained relatively high levels of N and K compared with the findings of previous studies. For instance, co-composting rice straw with SM yielded total N, P_2O_5, and K_2O values of 2.40%, 0.70%, and 1.20% (w/w), respectively [40], while co-composting FW with tofu residue yielded 2.10%, 0.60%, and 1.10% (w/w), respectively [41].

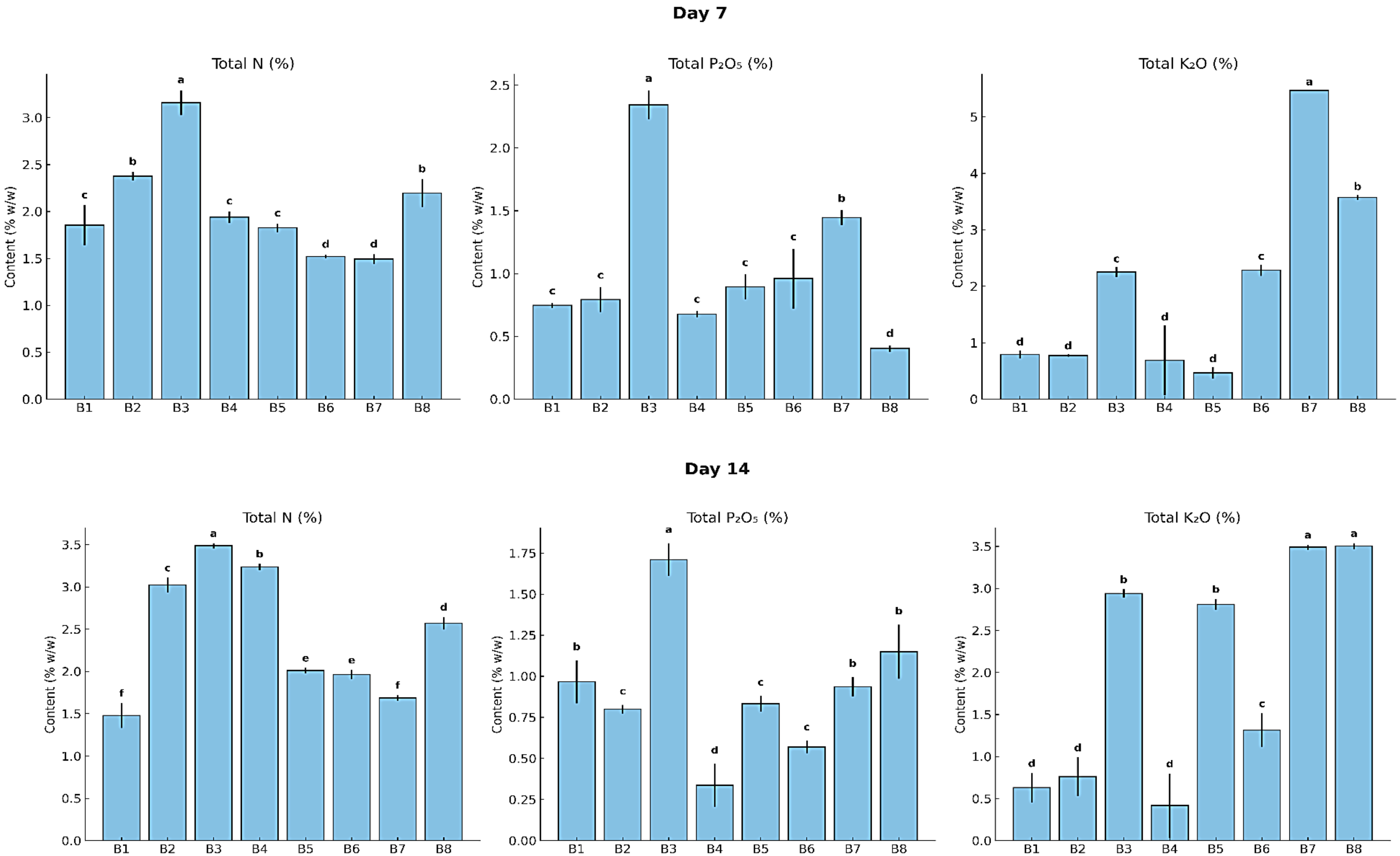

Figure 2 Total nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) contents of food waste compost after 7 and 14 days of composting. Values represent means ± standard deviation (n = 3). Different letters above the bars indicate significant differences among treatments according to Tukey's HSD test ($p < 0.05$). Treatments: B1 = FW + SB + ML; B2 = B1 + SM (10%); B3 = B1 + SM (20%); B4 = B3 + LA (10%); B5 = B1 + BP (10%); B6 = B1 + BP (20%); B7 = B6 + LA (10%); B8 = B1 + SM (10%) + BP (10%) + LA (10%). FW = food waste, SB = Superbact, ML = molasses, SM = soybean meal, BP = banana peel, LA = light rubber wood ash.

These comparisons highlight the potential of SM not only to improve nutrient contents but also to produce compost that can meet or exceed national standards for organic fertilizers. Such comparisons reinforce the significance of the current findings and support recommendations for optimized compost formulations. Overall, the results demonstrated that compost produced with supplementary agricultural residues had higher nutrient values than compost produced from FW alone. These findings underscore the potential of agricultural residues to improve compost quality and highlight opportunities for the sustainable utilization of biowaste in agriculture.

4. Conclusions

This study has shown that co-composting food waste with dried coffee grounds, banana peel, rubber wood ash and soybean meal effectively increases the nutrient content of the obtained compost. Soybean meal was the most beneficial additive. The addition of 20% soybean meal significantly increased the total nitrogen, total P_2O_5 and total K_2O from 1.51%, 0.93% and 0.61% (w/w) to 3.39%, 1.77% and 2.89% (w/w), respectively, by day 14 of composting. These results indicate that soybean meal is a suitable material for the nutrient enrichment of food waste compost. However, as soybean meal is a commercially valuable resource, further trials are recommended to assess the agronomic benefits of the resulting compost.

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6. Conflicts of interest

The authors declare no conflict of interest.

7. Author contributions

JI: Conceptualization, Data curation, Writing – review & editing, Resources, Funding acquisition, Project administration; TS: Methodology, Investigation, Formal analysis; PS: Writing – original draft, Supervision; JC: Software, Visualization, Writing – review & editing.

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