

Potential of household food waste for compost production: A laboratory-scale evaluation of mixing formulations

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ABSTRACT

Household food waste (FW) is a major biodegradable fraction of municipal solid waste and represents a potential feedstock for decentralized compost production. This study evaluated the feasibility of converting household FW into compost through laboratory-scale composting and compared six mixing formulations to identify a promising formulation among the tested treatments for further development of decentralized household FW composting systems. Food waste was collected directly from 60 households in Binh Duong Ward, Ho Chi Minh City, over seven consecutive days to characterize its generation rate and composition and to obtain representative feedstock for subsequent composting experiments. Six composting formulations were evaluated under controlled laboratory conditions, with three replicates per treatment. Food waste accounted for 66% of household municipal solid waste, with average generation rates of 0.861 kg/household/day and 0.203 kg/person/day. Plant-based materials represented 61% of the collected FW, indicating a substantial biodegradable fraction suitable for composting. The composting process was conducted for 28 days under aerobic conditions, with periodic monitoring of temperature, moisture content, and pH. The quality of the final compost was evaluated based on total nitrogen, available P₂O₅, available K₂O, organic matter, humic acid, Mg, Pb, *Escherichia coli* (*E. coli*), and *Salmonella*. Among the six formulations, T5, consisting of 80% FW, 10% loam soil, and 10% cow manure, showed the most favorable overall performance in terms of compost quality, particularly for nitrogen, organic matter, humic acid, and magnesium contents, while meeting the assessed microbiological safety criteria. The results demonstrate the feasibility of converting household FW into compost under the tested laboratory-scale conditions and identify T5 as the most favorable formulation among those evaluated, providing a basis for further development and validation of decentralized household FW composting systems.

Keywords: food waste, municipal solid waste, composting, organic fertilizer.

INTRODUCTION

In the context of rapid urbanization and global population growth, MSW has become one of the greatest challenges for urban environmental management, with FW consistently accounting for a significant share of it. According to the United Nations Environment Program's Food Waste Index Report 2024, approximately 1.05 billion tonnes of food are wasted globally each year, equivalent to nearly 19% of the total food available to consumers, with households responsible for 60% of this total (Forbes et al., 2024). This highlights that households are the primary source of food waste

and play a pivotal role in waste sorting, recycling, and reduction efforts (Forbes et al., 2024).

In Vietnam, particularly Ho Chi Minh City, the country's largest socio-economic hub, the daily volume of MSW reaches approximately 14,000 tons, placing significant pressure on waste collection and treatment operations. Although collection rates are high, the utilization of advanced treatment technologies such as waste-to-energy incineration, recycling, and composting remains limited; meanwhile, the majority of organic waste, including FW, continues to be disposed of via landfilling (Russell et al., 2017). Within the composition of MSW, FW is a highly

biodegradable component that generates odors, leachate, and greenhouse gases, yet it holds substantial potential for biological treatment if managed appropriately (Hang et al., 2022).

From a sustainable development perspective, the shift from a “linear economy” model to a “circular economy” model has become an urgent objective (Sanaullah, 2023). Managing FW at the source particularly at the household level is considered a strategic solution to alleviate the burden on urban waste collection and treatment systems (Sinisa et al., 2022). FW is inherently a nutrient-rich, biodegradable resource with significant potential for conversion into high-quality compost (Velvizhi, 2020). Implementing this solution not only enables households to manage waste on-site and reduce the cost of chemical fertilizers for urban agriculture but also contributes to achieving environmental protection and net emission reduction goals (Waqas et al., 2023).

Although household food-waste composting has been widely investigated, the use of a particular mixing ratio does not constitute a fundamentally new composting concept. Accordingly, the contribution of this study lies not in proposing a novel composting principle or a novel formulation ratio, but in integrating field-derived characterization of household FW with comparative screening of six formulations containing locally available amendment materials under a compact, passively aerated laboratory configuration. Unlike studies based solely on predefined or synthetic feedstocks, the present study used FW collected directly from 60 households, thereby linking locally observed FW characteristics with experimental formulation performance. The study should therefore be regarded as a site-specific formulation-screening and feasibility assessment, providing experimental evidence for selecting a promising formulation and a preliminary basis for subsequent validation of decentralized household-scale composting, rather than validation of a fundamentally new composting technology.

METHODS

Study area and food waste sampling

This study was conducted using food waste (FW) generated from households in Binh Duong Ward, Ho Chi Minh City, Vietnam. The household survey and FW sampling were conducted

during the period of administrative reorganization in 2025, when the local administrative units were being reorganized to form the current Binh Duong Ward, Ho Chi Minh City. Therefore, the name “Binh Duong Ward” is used throughout this manuscript to refer to the current administrative unit encompassing the study area. Binh Duong Ward is located in the northern part of Ho Chi Minh City and serves as the central ward of Zone 2. The study area is located at approximately 11°04'12"N and 106°40'15"E and comprises 20 residential quarters, with a total population of 107,576 as reported in Resolution No. 76/2025/UBTVQH15 of the Standing Committee of the National Assembly of Vietnam.

Sixty households were selected from the 20 residential quarters in the study area, with three households included from each quarter. Households were eligible for inclusion if they were occupied during the study period and agreed to participate in the seven-day waste collection program. The number of household members was recorded for each participating household and was used in the calculation of per-capita FW generation. Municipal solid waste (MSW) generated by the selected households was collected for seven consecutive days, from Monday to Sunday, at a fixed collection time of 17:00 each day. A seven-day collection period was adopted to characterize household waste generation and composition over a complete weekly cycle.

The collected MSW was manually sorted into organic and inorganic fractions. The organic fraction was considered FW for the purpose of this study and was further separated into different material groups according to their physical characteristics. Each fraction was weighed using a calibrated balance, and the corresponding mass was recorded. The proportion of FW and the FW generation rates on household and per-capita bases were calculated using Equations 1–3, respectively. The inorganic waste generation rate was calculated using the same approach. Because the survey was based on 60 participating households from the study area and was not designed as a city-wide representative household survey, the resulting FW generation rates were interpreted as estimates for the surveyed households rather than as representative values for the entire population of Ho Chi Minh City. Source separation and characterization of household food waste are commonly applied approaches for determining household FW generation and composition (Liu and Nguyen, 2020).

$$FW \text{ weight per quarter} = \text{Average of FW total in 3 households (kg)} \quad (1)$$

$$FW \text{ weight per household} = \frac{\text{Total of food waste weight (kg)}}{\text{Total households}} \quad (2)$$

$$FW \text{ weight per person} = \frac{\text{Total of food waste weight (kg)}}{\text{Total people}} \quad (3)$$

Food waste characterization and composting feedstock preparation

Prior to the composting experiments, the initial characteristics of the FW and blending materials used in the experiment were determined and are summarized in Table 1. The measured properties included moisture content, pH, total C, total N, C/N ratio, Pb, *E. coli*, and *Salmonella*. Organic matter content and bulk density were not measured for the initial materials and are therefore reported as “Not measured” rather than estimated.

The initial C/N ratio is an important factor affecting microbial activity and nitrogen availability during aerobic composting. An appropriate C/N ratio is required to support microbial growth and efficient organic matter decomposition, whereas an excessively high C/N ratio may result in nitrogen limitation and prolong the composting process (Lin et al., 2022; Shen et al.,

2024). Therefore, different blending materials were evaluated to adjust the initial characteristics of the composting mixtures.

Loam soil, a mixture of rice husk ash and coconut coir at a ratio of 1:1, and cow manure were selected as blending materials. The addition of suitable bulking or complementary materials can improve the physical structure, aeration, moisture balance, and decomposition conditions of food waste composting systems (Adhikari et al., 2009; Waqas et al., 2023).

The proportions of FW and amendment materials used in the six treatments were calculated on a wet-mass basis. The total initial wet mass was 1.300 g per experimental unit for T1 and 1.600 g per experimental unit for T2–T6. The actual wet mass of each component is presented in Table 2. Before loading, the materials were mixed according to the actual procedure and the initial moisture content was adjusted to approximately 60% (Bernal et al., 2009; Waqas et al., 2023).

Experimental composting design

A laboratory-scale composting system was designed using four polyethylene (PE) composting bins. Each bin consisted of five vertically

Table 1. Characteristics of raw materials

Parameter	Unit	Food waste	Loam soil	Rice husk ash + coconut coir (1:1)	Cow manure
Moisture content	%	80.7	25.5	18.2	12.3
pH	–	6.3	6.5	7.5	7.6
Organic matter	%	Not measured	Not measured	Not measured	Not measured
Total C	%	32.6	1.4	29.8	40.2
Total N	%	0.98	0.13	0.34	1.34
C/N ratio	–	33.3:1	10.8:1	87.6:1	30:1
Pb	mg/kg	ND	ND	ND	ND
<i>Salmonella</i>	(CFU/25g)	ND	ND	ND	ND
<i>Escherichia coli</i>	(MPN/g)	3	9	ND	3
Bulk density	kg m ⁻³	Not measured	Not measured	Not measured	Not measured

Table 2. Composition of composting mixtures used in the experimental treatments

Treatment	FW (g)	Loam soil (g)	Rice husk ash + coconut coir (g)	Cow manure (g)	Total wet mass (g)
T1	1300	–	–	–	1300
T2	1280	320	–	–	1600
T3	1280	–	–	320	1600
T4	1280	–	320	–	1600
T5	1280	160	–	160	1600
T6	1280	–	160	160	1600

arranged compartments, with each compartment serving as an individual composting unit. Each compartment contained a separately prepared composting mixture and was treated as a distinct experimental unit throughout the experiment. Materials were not mixed or transferred between compartments during the 28-day experimental period, and sampling was conducted separately for each compartment. Thus, the three replicates assigned to each treatment represented three physically separate composting units rather than subsamples taken from a common composting mixture. The compartment design included ventilation openings to facilitate passive air exchange and promote conditions favorable for aerobic microbial activity. Adequate aeration is a critical factor in maintaining aerobic microbial activity and promoting organic matter decomposition during composting (Kalamdhad et al., 2009; Waqas et al., 2023).

The experiment was conducted as a single-factor completely randomized design (CRD), with composting formulation as the experimental factor. Six treatments (T1–T6) were evaluated, and each treatment was independently established in three separate composting compartments, resulting in a total of 18 experimental units. The 18 experimental units were randomly allocated among the available compartment positions without a predetermined spatial sequence. Consequently, the three experimental units of each treatment were distributed across the experimental system rather than arranged consecutively within a single supporting bin. Of the 20 available compartments in the four PE bins, 18 were used for the experiment and two remained unused.

Each compartment had dimensions of $15 \times 15 \times 12$ cm, corresponding to an internal volume of approximately 2.700 cm^3 . The compartment volume was selected based on the average daily household FW generation rate determined during the sampling phase. The configuration of the composting system and the randomized allocation of the 18 experimental units are illustrated in Figure 1.

Six composting formulations (T1–T6) were evaluated, as shown in Table 2. T1 consisted of 100% FW and served as the control treatment. In T2–T6, 80% FW was combined with different proportions of loam soil, rice husk ash + coconut coir (1:1), and cow manure. The experimental formulations were designed to evaluate the effects of different blending materials on the composting process and the characteristics of the resulting composted materials. For each treatment, three separate mixtures were prepared and loaded into three randomly assigned experimental compartments, corresponding to three experimental units per treatment.

Composting operation and process monitoring

The prepared composting mixtures were placed in the experimental bins and operated under passive-aeration conditions intended to promote aerobic decomposition for 28 days. The composting units were located in a shaded area under ambient conditions and were not manually turned during the experimental period. Ventilation openings in the compartments provided passive aeration throughout the process. Passive



Figure 1. Laboratory-scale composting system and randomized allocation of the 18 experimental units according to the completely randomized design (CRD)

aeration is an effective approach for small-scale composting when adequate porosity and oxygen transfer within the composting matrix are maintained (Adhikari et al., 2009; Waqas et al., 2023).

Temperature, moisture content, and pH were monitored at seven-day intervals throughout the composting period. These parameters were selected because temperature and pH are important indicators of microbial activity and composting process development, while moisture content directly affects microbial activity and oxygen diffusion within the compost matrix (Bernal et al., 2009; Lin et al., 2022).

At each monitoring event, subsamples were collected from the upper, middle, and lower portions of each composting unit and combined to form one composite sample representative of that experimental unit. Samples used for moisture content and pH determination were analyzed immediately. At the end of the 28-day experimental period, representative composite samples were collected from each unit for chemical characterization. The samples were homogenized and prepared according to the requirements of the analytical methods listed in Table 3. The mass of the resulting composted material and the mass of remaining undecomposed material were also recorded.

Analysis of compost quality

The quality of the final composted materials was evaluated using physicochemical, nutritional, and microbiological indicators. The analyzed parameters included total nitrogen (N), available P_2O_5 , available K_2O , organic matter, humic acid, Mg, Pb, *Escherichia coli* (*E. coli*), and *Salmonella*. These parameters were selected to evaluate the nutrient characteristics, organic matter properties, and potential chemical and microbiological risks

of the composted materials (Bernal et al., 2009; Kupper et al., 2014; Peng et al., 2024).

All analyses were conducted at the Environmental Analysis Laboratory of Thu Dau Mot University, Ho Chi Minh City, Vietnam. Sample preparation and analytical determinations were performed according to the corresponding Vietnamese National Standards (TCVN) listed in Table 3.

Additional analytical detection and reporting information was provided for Pb and the microbiological analyses. Pb was determined using a Shimadzu AA-7000 atomic absorption spectrophotometer with flame atomization (Flame-AAS). The retained analytical information indicated an instrumental limit of detection (LOD) of 0.015 mg/L and an instrumental limit of quantification (LOQ) of 0.05–0.07 mg/L in the measurement solution. These instrumental values were not converted to a sample-specific method detection limit expressed on a compost mass basis (mg/kg), because the corresponding validated method-level detection-limit information was not available in the retained laboratory records. *Salmonella* was evaluated qualitatively as a presence/absence test in a 25-g test portion; therefore, a separate numerical LOD/LOQ was not available in the retained laboratory records. *E. coli* was determined using the MPN method, with a lower reporting limit of <3 MPN/g. Serial dilutions from 10^{-1} to 10^{-3} were used during the analysis; this dilution range does not represent an LOQ. A separate numerical LOQ for *E. coli* was not available in the retained laboratory records.

Analytical quality assurance and quality control procedures, including instrument calibration, method blanks, and routine quality-control checks, were performed in accordance with the requirements of the respective TCVN methods and the laboratory's standard operating procedures.

Table 3. Analytical methods used for evaluation of compost quality

Indicator	Unit	Method of determination
Total N	%	TCVN 8557:2010
P_2O_5 content	%	TCVN 8559:2010
K_2O content	%	TCVN 8560:2018
Pb content	mg/Kg	TCVN 9290:2018
<i>Salmonella</i>	CFU/25 g	TCVN 10780-1:2017
<i>E.coli</i>	MPN/g	TCVN 6846:2007
Organic matter content	%	TCVN 9294: 2012
Humic acid content	%	TCVN 8561:2010
Mg content	%	TCVN 9285:2018

Statistical analysis

The experiment was conducted as a single-factor CRD, with six composting formulations and three independent experimental units per treatment ($n = 3$). Data are presented as mean $\pm$ standard deviation (SD). Statistical analyses were performed using Statgraphics 19-X64. Prior to one-way analysis of variance (ANOVA), the assumptions of normality and homogeneity of variances were assessed using the Shapiro-Wilk test and Levene's test, respectively. One-way ANOVA was then used to determine differences among the six composting formulations. When a significant treatment effect was detected, Tukey's multiple-comparison test was applied for pairwise comparisons at a significance level of $\alpha = 0.05$. ANOVA results are reported using the F-statistic, corresponding degrees of freedom, and exact p-values. Graphs were prepared using Microsoft Excel.

RESULTS AND DISCUSSION

Generation rate of food waste

Figures 2 and 3 present the FW generation rates observed among the 60 surveyed households in the study area. The household-based FW generation rates ranged from 0.387 to 1.286 kg/household/day (Figure 2), while the per-capita generation rates ranged from 0.141 to 0.257 kg/person/day (Figure 3). Across the surveyed households, the average FW generation rates were 0.861 kg/household/day and 0.203 kg/person/day, respectively. These values characterize FW generation within the surveyed households and should not be interpreted as representative estimates for the entire population of Ho Chi Minh City.

FW constitutes the largest proportion of total household MSW, averaging 66%, whereas inorganic waste accounts for only about 34% (Figure 3). This finding is consistent with previous studies reporting that FW constitutes a major fraction of

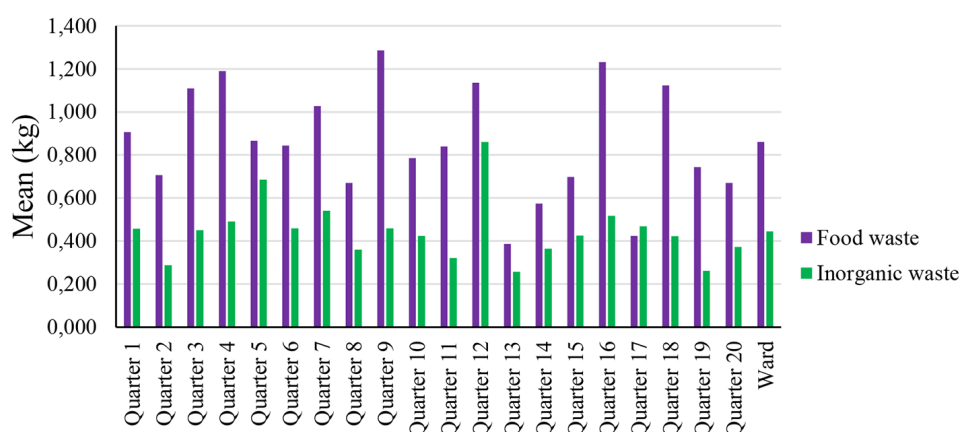


Figure 2. Generation rate of FW (per household)

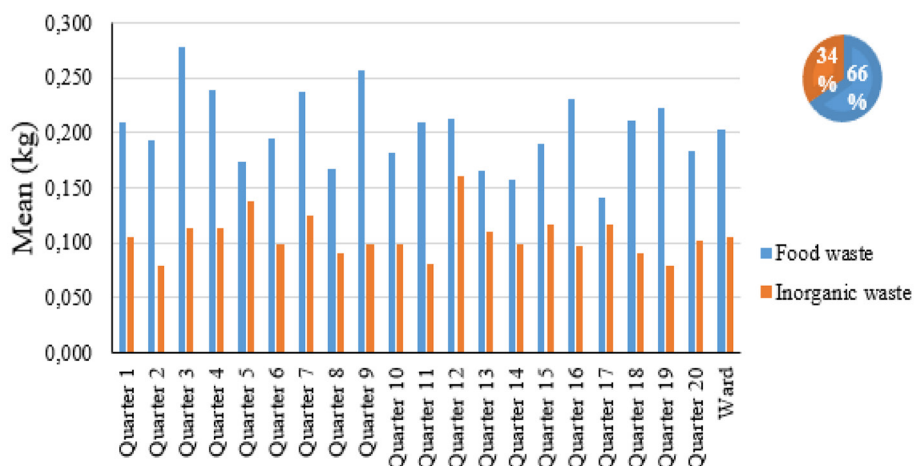


Figure 3. Generation rate of FW (per person)

household MSW (Smith and Landry, 2021). Liu and Nguyen (2020) reported that the daily FW generated by most households in Hanoi is approximately 0.275 kg/person/day. This indicates significant regional variation in the amount of discarded FW, which may be attributed to factors such as income levels, purchasing habits, storage infrastructure, and consumption culture. According to an FAO report (2018), per capita FW in middle-income urban areas can range from 0.3 to 0.6 kg per person per day, depending on living standards and consumption habits.

FW consists of four main categories plant-based, animal-based, seafood, and processed foods with disposal rates of 61%, 20%, 8%, and 11%, respectively. Thus, household FW is primarily composed of plant-based items (vegetables, tubers, and fruits). Fruits and vegetables have been identified as the most frequently discarded food group in household waste across many countries (Ananda et al., 2022). In Thailand and Indonesia, vegetables and fruits account for 55–65% of total household FW (Liu and Nguyen, 2020). This is because fruits and vegetables are highly perishable and prone to spoilage if not stored properly. When discarded, they cause significant environmental impacts due to specific characteristics such as rapid decomposition under anaerobic conditions, which generates methane (CH_4), toxic leachate, and foul odors. The aforementioned figures indicate inadequate portion control within households, as evidenced by the fact that fruit, vegetable, and unprocessed food waste accounts for 61% of the total; this material serves as a valuable feedstock for biogas production through the

decomposition of household waste. Sorting results also demonstrate the potential of household waste for organic fertilizer production (Figure 4).

Barriers of recycling food waste in households

Figure 5a provides detailed results about Food waste disposal routes in households. The results show that most of the respondents threw food waste into the domestic waste bin for landfill (56%). However, 33% of respondents still choose to reuse and recycle the food waste they generate, with 17% using it as animal feed and 16% recycling it into organic fertilizer through aerobic composting. A small percentage choose to burn food waste (6%) or other solutions, such as burying it in the soil or applying it directly to plants (4%). A small proportion of households (1%) reported disposing of FW directly into the surrounding environment. These results indicate that recycling and reuse solutions are limited and require policy and technological support to improve the efficiency of food waste management. This is consistent with Kaza's (2018) survey, which found that over 70% of organic waste in Vietnam is disposed of via landfilling, while household-level recycling and reuse activities are negligible. In Japan, the rate of utilization of food waste for fertilizer and animal feed production is approximately 42%, significantly higher than in Vietnam. This suggests that circular solutions such as recycling, reuse, and household-level organic fertilizer production in Vietnam still have significant untapped potential (Kaza et al., 2018).

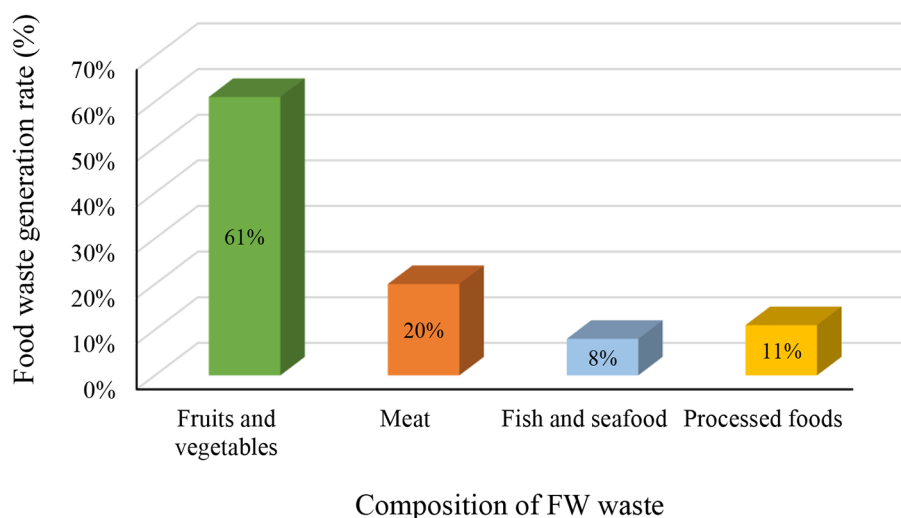


Figure 4. Discarded food components

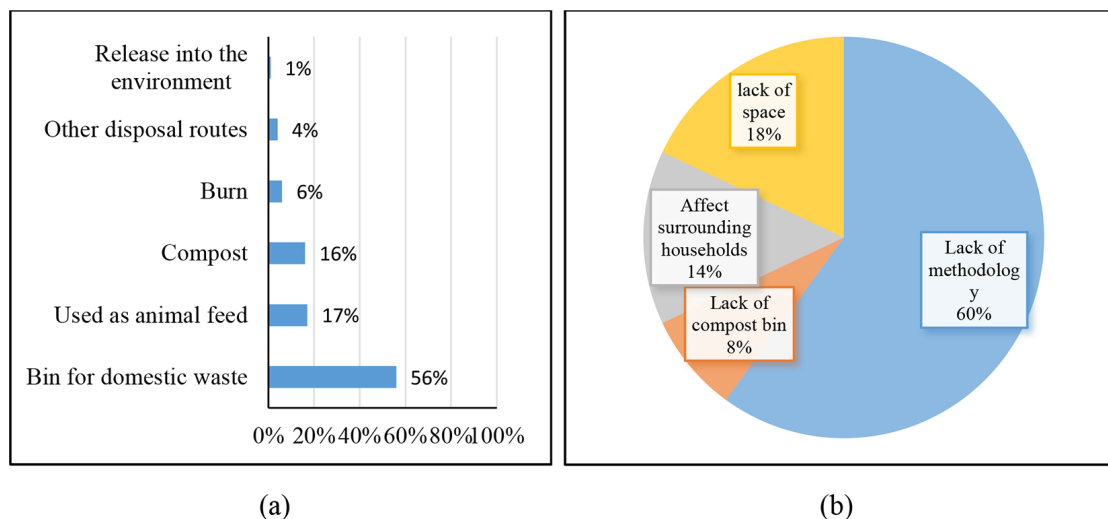


Figure 5. (a) Disposal routes and (b) barriers to food waste recycling

Figure 5b showed that the lack of an implementation method was identified as the primary obstacle (60%). Those participants showed that recycling FW to compost requires a clear protocol, too much effort, and hassle. Empirical evidence suggests that a lack of methods and knowledge about FW recycling influences awareness and behavior regarding food waste reduction (Bernstad, 2014). When identifying factors influencing UK citizens' household FW recycling, Ayşe et al. (2022) also identified that lack of knowledge, facilities, the collection of food waste, inconvenience, and infrastructure are the main barriers to FW recycling (Ayşe et al., 2022). These barriers may be the reason for low participation rates in reuse and recycling. Besides, 18% participants mentioned that the lack of space for bins and compost cans (8%) was also a barrier to recycling and reusing FW. Participants also mentioned that there is not enough space in or outside their homes to fit an extra FW bin on top of the existing recycling and landfill bins, due to living in a small flat or having a small kitchen. Participants in the study by Robin et al. (2021) in Mauritius also highlighted that the lack of space is a barrier to food recycling, especially for those living in apartment buildings. They are worried that the recycling process will generate unpleasant odors that will affect neighboring households (14%) (Figure 5b). These barriers may be the reason for low participation rates in reuse and recycling. Therefore, households need easy access to recycling to improve their behavior and encourage them to manage FW sustainably.

Study on the potential for recycling FW to organic fertilizer

Monitoring parameters

Temperature is a key parameter reflecting the level of microbial activity during the composting process (Jamaludin et al., 2017). The results in Figure 6a show that the temperature of the composting mixtures increased rapidly during the early experimental period and reached maximum values on day 14, ranging from 60.47 ± 3.44 °C in treatment T1 to 68.70 ± 1.17 °C in treatment T6. This temperature increase indicates substantial microbial metabolic activity during the early stage of decomposition. However, because O_2 concentration, redox potential, and CO_2 evolution were not measured, the temperature response alone cannot confirm that fully aerobic conditions prevailed throughout the composting matrix, and the occurrence of localized anaerobic zones cannot be excluded. After this stage, the temperature decreased markedly to approximately 33.43 ± 0.23 °C– 35.63 ± 0.35 °C, indicating a reduction in microbial metabolic activity as readily degradable substrates became progressively depleted. The temperature of the composting mixtures subsequently approached ambient temperature. Statistical analysis results showed that the composting mixture temperatures on day 14 in treatments T2, T3, T4, T5, and T6 were significantly higher than those in the control treatment (T1). These differences suggest that the composition of the composting mixtures influenced microbial activity and heat generation during the composting process. Previous studies

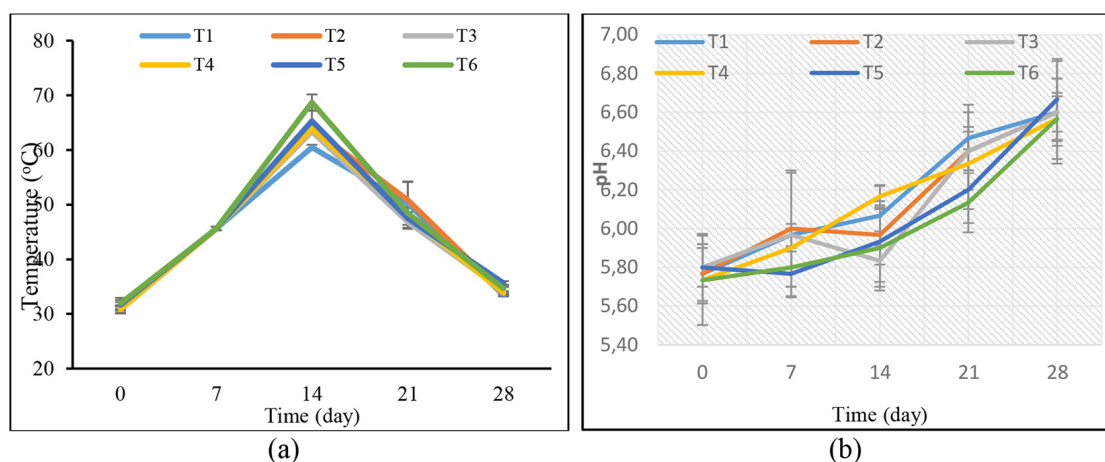


Figure 6. Temperature and pH evolution during composting: a) temperature; b) pH

have reported that thermophilic temperatures may contribute to accelerated organic matter degradation and pathogen reduction under appropriate composting conditions (Arokiyaraj et al., 2024). However, because temperature was measured at a single monitoring location within each experimental unit, the present study cannot confirm uniform heating or thermal sanitization throughout the entire composting mass.

pH is an important parameter influencing microbial activity and organic matter transformation during composting (Arokiyaraj et al., 2024). Strongly acidic conditions may inhibit the activity of some decomposing microorganisms, particularly when organic acids accumulate during the degradation of readily biodegradable substrates (Cheung et al., 2010). In the present study, the pH of the composting mixtures generally decreased during the experimental period, reaching approximately 5.73–5.83 on day 28 (Figure 6b). A decrease in pH during composting may be associated with the formation and accumulation of low-molecular-weight organic acids generated during the decomposition of readily biodegradable organic matter (Cheung et al., 2010). However, organic acids and other chemical species potentially responsible for the observed pH changes were not directly measured in the present study. Therefore, the mechanism responsible for the decrease in pH cannot be conclusively established from the available data. Treatments T1, T2, and T3 showed a slight increase in pH on day 21, which may reflect changes in the balance between acid-forming and alkalinizing processes during organic matter decomposition; however, the compounds responsible for this variation were not specifically determined. The relatively acidic final pH

values observed after 28 days suggest that stabilization of the composted materials may have been incomplete. Therefore, the pH results should be interpreted as evidence of continuing transformation of the organic materials rather than confirmation of compost maturity, and further curing and maturity assessment are recommended.

Compost quality

Nitrogen is an important compound for plant growth and development and is absorbed primarily as ammonia and nitrate (Kiba and Krapp, 2016). In addition, nitrogen has a significant impact on biochemical processes during composting and can help maintain the pH balance of the compost pile. Nitrogen can be lost through various pathways during composting, primarily via evaporation. Among these, NH_3 is the primary compound responsible for nitrogen loss (Hoang et al., 2022). By measuring the residual nitrogen content in the compost of different treatments, the rate of nitrogen loss can be assessed, thereby selecting a suitable material blend for the composting process. The results in Figure 7a show that the total nitrogen content in the compost samples of the treatments varied, with the highest content in treatment T5, averaging $0.86 \pm 0.10\%$. A significant treatment effect was observed for total N [one-way ANOVA: $F(5,12) = 45.44$, $p = 2.19 \times 10^{-7}$]. The control treatment (T1) showed significant nitrogen loss, with the nitrogen content in the resulting compost being only about $0.31 \pm 0.03\%$. This indicates that the aerobic decomposition process in this treatment resulted in a large loss of nitrogen. Meanwhile, treatments T2, T3, T4, and T6 showed no statistically significant differences.

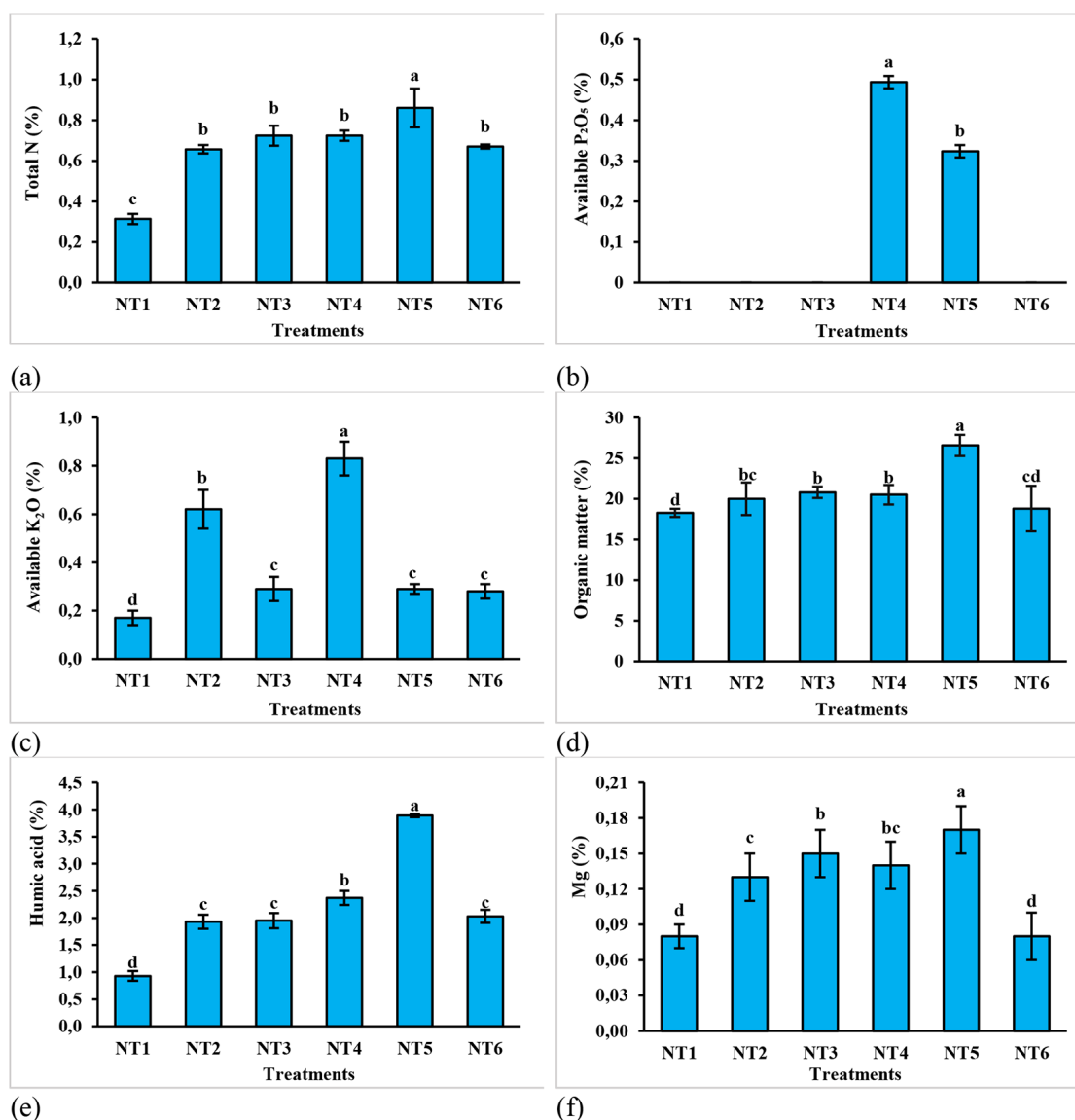


Figure 7. Quality assessment criteria for compost production: a) total N; b) available P_2O_5 content; c) available K_2O content; d) organic matter content; e) humic acid content; f) Mg content

This suggests that mixing with other materials during composting limited nitrogen loss, with treatment T5 performing best with 80% FW, 10% loam, and 10% cow manure. This result is higher than the report by Mangera et al. (2022), which reported only 0.08% total nitrogen in liquid compost from household waste after 2 months (Mangera et al., 2022). However, it is lower than that of composted fertilizer produced within one week, which has a relatively high total nitrogen content of 2.6% when plant waste is used as the composting material (Kalamdhad et al., 2009). Therefore, to increase the nitrogen content in compost products, factors ranging from raw materials and processing conditions to the microorganisms involved in the decomposition process need to be considered. Adding compost materials such as

loam and cow manure significantly increases nitrogen retention efficiency in the finished fertilizer. This may be due to ammonifying bacteria in the composting materials promoting ammonification and nitrogen sequestration (Xu et al., 2023).

Phosphorus is also an important compound affecting plant growth and development, primarily derived from animal and other organic waste (Wei et al., 2015). Phosphorus absorption plays a crucial role in crop yield. However, plants have a relatively low capacity for P absorption due to their slow diffusion and high fixation in the soil (Shen et al., 2011). Therefore, applying compost is a solution to improve plant P absorption. The aerobic composting process helps regulate microbial activity, thereby increasing the content of readily available P (Richardson and Simpson,

2011). By determining the P_2O_5 content in compost produced from the treatments, the quality of the compost in each treatment can be assessed. Figure 7b shows that P_2O_5 was detected only in treatments T4 and T5, at concentrations of $0.49 \pm 0.02\%$ and $0.32 \pm 0.02\%$, respectively. Because numerical P_2O_5 values were available only for T4 and T5, the statistical comparison was restricted to these two treatments. Available P_2O_5 differed significantly between T4 and T5 [one-way ANOVA: $F(1,4) = 185.79$, $p = 1.68 \times 10^{-4}$]. Treatments T1, T2, T3, and T6 were reported as not detected (ND) and were not assigned numerical zero values for statistical analysis. The absence of P_2O_5 in the remaining treatments may be due to reasons such as low initial available P_2O_5 content in the raw material or insufficient organic decomposition to convert phosphorus into a form readily absorbable by plants (Wei et al., 2015). This result is lower than reported by Kilo et al. (2023) with available P_2O_5 content in 6 formulations ranging from 1.47 to 2.29% (Kilo et al., 2023). However, the P_2O_5 content in the two current experimental treatments was higher than the available P_2O_5 content in manure composted after 56 days from organic components of municipal solid waste, with different mixing formulations and fillers (0.24 to 0.41%) (Adhikari et al., 2009).

Potassium is an essential nutrient that affects the biochemical and physiological processes of plants (Wang et al., 2013). It helps plants withstand environmental stress, activate enzymes, synthesize proteins, photosynthesize, regulate osmosis and stomata, transport phloem, and balance cation-anion balance (Wang et al., 2013). Determining the effective K_2O content in compost in these different treatments aims to assess the available K_2O content, reflecting the ability to supply potassium to plants. Although plants absorb potassium as K^+ ions, K_2O content is commonly used as an indicator of the potassium nutritional value of fertilizers. The results in Figure 7c show that the effective K_2O content in the treatments ranged from $0.17 \pm 0.02\%$ to $0.83 \pm 0.04\%$. Available K_2O differed significantly among the six treatments [one-way ANOVA: $F(5,12) = 273.65$, $p = 6.26 \times 10^{-12}$]. The highest K_2O content was observed in treatment T4 at $0.83 \pm 0.04\%$, which was significantly higher than that of the other treatments in the experiment. Further investigation of the addition of 20% of each component - loam soil, cow manure, and ornamental plant soil in treatments T2, T3, and T4 revealed that the

potassium supply efficiency in treatments T2 and T4 was significantly higher than in the treatment with the addition of 20% cow manure (T3). This could be due to the soil used in the compost mixture having a higher potassium content than the cow manure, thereby increasing the compost's potassium supply efficiency. Sharma's report noted the effective K_2O content in the finished compost after composting different materials. The results showed that the K_2O content of compost from urban household waste ranged from 0.64% to 0.82%, exceeding the minimum threshold ($>0.40\%$) (Sharma et al., 1997). However, the finished compost produced from 100% organic waste collected in the survey area of the current study had a fairly low K_2O content, exceeding the standard threshold ($>0.40\%$) only when additional composting materials were added. This reflects that the living habits of each area will differ, causing the quality of the compost after composting to also vary. Zorzi et al. (1992) also showed that the K_2O content in manure and poultry waste after composting was significantly higher, at 1.78% and 3.11%, respectively (Sharma et al., 1997). The addition of mixing materials significantly increased the K_2O content of the compost produced by the treatments. Therefore, the initial composting material composition needs to be selected to retain the K_2O content in the finished compost. In addition, the mixing ratio and composting conditions also need to be evaluated to optimize composting efficiency. In the current study, mixing composting materials consisting of 80% FW and 20% potting soil had a significant potassium-conservation effect during the composting process.

The organic matter (OM) content in compost is an important indicator for evaluating the agronomic value of finished fertilizers (Bernal et al., 2009). However, the OM content can decrease during composting due to microbial decomposition of OM. At the end of this stage, humification occurs, producing a slow-release fertilizer. Therefore, evaluating the OM content will reflect the compost's agronomic value. The results shown in Figure 7d indicate that the highest OM content was observed in treatment T5 at $26.57 \pm 0.65\%$, and it differed significantly from the other treatments. Organic matter content differed significantly among treatments [one-way ANOVA: $F(5,12) = 35.95$, $p = 8.11 \times 10^{-7}$]. The lowest OM content was recorded in the control treatment (T1) at $18.27 \pm 0.25\%$, which was not significantly different from treatment T6 ($18.80 \pm 1.56\%$). This

indicates that the mixing formula used in treatment T6 did not significantly reduce the loss of OM from microbial decomposition. The remaining treatments had OM content of $20.00 \pm 1.00\%$, $20.80 \pm 0.36\%$, and $20.50 \pm 0.62\%$, corresponding to treatments T2, T3, and T4. These results show that the selection of filler is crucial for increasing composting efficiency and the quality of the finished fertilizer. In the current study, a filler consisting of 10% loam soil and 10% cow manure effectively limited OM loss, thereby ensuring the quality of the finished compost.

Humic acid is a complex compound formed through the decomposition of organic matter. It plays an important role in ion exchange and metal-ion complexation, thereby improving soil fertility and crop yields (Wandansari et al., 2023). Therefore, determining the humic acid content also assessed compost quality. The results in Figure 7e show that the highest humic acid content was achieved in treatment T5 at $3.89 \pm 0.02\%$, and the lowest in the control treatment (T1) at $0.93 \pm 0.05\%$. Humic acid content differed significantly among treatments [one-way ANOVA: $F(5,12) = 746.12$, $p = 1.59 \times 10^{-14}$]. Most treatments with added composting materials showed an increase in humic acid content in the compost, indicating greater efficiency of organic matter decomposition.

Mg was an important element for the growth and development of plants. Magnesium deficiency in plants may affect plant productivity and product quality by influencing photosynthesis and physiological activities (Hauer-Jákli and Tränkner, 2019). However, current intensive farming practices that rely solely on N, P, and K fertilizers, along with soil acidification and severe weathering, are leading to increasingly widespread magnesium deficiency (Hauer-Jákli and Tränkner, 2019; Chaudhry et al., 2021). Therefore, ensuring sufficient magnesium for crops is crucial, especially supplementing Mg into the soil through fertilizers to maintain stable crop yields and quality. In this experiment, the Mg content in compost was also recorded after composting. The results in Figure 7f showed that the Mg content increased across treatments from T2 to T5 compared to the control (T1). The content significance was highest in treatment T5 (80% FW, 10% loam soil, and 10% cow manure), at $0.17 \pm 0.01\%$. Mg content differed significantly among treatments [one-way ANOVA: $F(5,12) = 38.89$, $p = 5.24 \times 10^{-7}$]. Mg content in treatment T6 shows a marked decrease relative to the other treatments, remaining at approximately $0.08 \pm 0.01\%$. This

result is quite similar to the Mg content recorded in the study by Sawaya et al. (2024) in 2006 (0.176%). However, the Mg content was significantly lower than that recorded in the remaining years from 2005 to 2016, ranging from 0.196% to 0.316%. Nevertheless, the Mg content recorded in the current study was significantly lower than that of the compost reported by De Sá et al. (2025), which ranged from 1.68% to 2.05% depending on the composting method. This may be due to the significantly different Mg content of the input materials used in the current study compared with those in the previous study. Therefore, additional compostable materials need to be added to increase the compost's Mg content.

Overall, T5 was identified as the most favorable formulation based on its balanced performance across the physicochemical parameters evaluated rather than on the maximum value of any single nutrient. Although T4 showed higher available P_2O_5 and available K_2O contents than T5, T5 exhibited the highest total N, organic matter, humic acid, and Mg contents among the tested formulations. Therefore, the selection of T5 reflects its overall performance across multiple measured indicators rather than superiority for every individual parameter.

The concentration of potentially toxic elements in compost is an important consideration when assessing its suitability for agricultural application. Pb is of particular concern because its accumulation in soils and subsequent uptake by plants may contribute to environmental and human health risks (Kupper et al., 2014; Kumar et al., 2019). In the present study, Pb was reported as not detected by the analytical laboratory in the composted materials from all six treatments under the applied analytical method. The Flame-AAS measurement had an instrumental LOD of 0.015 mg/L and an instrumental LOQ of 0.05–0.07 mg/L in the measurement solution. However, a validated sample-specific method detection limit expressed on a compost mass basis (mg/kg) was not available in the retained laboratory records. Therefore, the ND results should not be interpreted as indicating zero Pb concentration or complete absence of Pb from the composted materials. Furthermore, Pb was the only potentially toxic element evaluated in this study; therefore, this result cannot establish the overall chemical safety of the composted materials. Previous studies have reported detectable Pb concentrations in compost derived from different waste materials. For example, Jimoh et al. (2013)

reported Pb concentrations ranging from 13.80 to 62.07 mg/kg in compost produced from municipal waste, while Saffari et al. (2020), Shen et al. (2025), and Su et al. (2025) also reported the occurrence of Pb in compost samples. These findings indicate that the characteristics and contamination of input materials can influence the concentrations of potentially toxic elements in the resulting compost. Therefore, source separation of organic waste before composting may help reduce the introduction of contaminated materials. Nevertheless, broader screening of potentially toxic elements and comparison with applicable regulatory requirements are required before the overall chemical safety and suitability of the composted materials for agricultural application can be established.

Microbiological quality is another important consideration in the assessment of composted materials because pathogenic microorganisms may pose risks to human and environmental health. The survival and inactivation of microorganisms during composting can be influenced by process conditions, particularly temperature and moisture. In the present study, *E. coli* and *Salmonella* were reported as not detected by the analytical laboratory in the day-28 composted materials from all six treatments under the respective analytical methods applied. These results are favorable with respect to the two microbiological parameters evaluated; however, their absence should not be interpreted as evidence of the elimination of all potentially harmful microorganisms or as confirmation of comprehensive microbiological safety. Previous studies have reported the occurrence or persistence of *Salmonella* and *E.*

coli in composted materials under certain conditions (Peng et al., 2024), indicating that pathogen reduction may depend on the composting conditions and feedstock characteristics. Therefore, the present findings should be interpreted specifically with respect to *E. coli* and *Salmonella*, while broader microbiological assessment and comparison with applicable regulatory requirements would be required before the overall microbiological safety and suitability of the composted materials for agricultural application can be established.

Proposed process for household food waste using a compost bin

Based on the experimental results, treatment T5, consisting of 80% FW, 10% cow manure, and 10% loam soil, showed the most favorable overall performance among the six tested formulations based on the measured physicochemical indicators. The laboratory-scale experiment provided preliminary evidence for the feasibility of processing household FW under the tested conditions using a compact, passively aerated composting configuration without manual turning. Based on these findings, a conceptual sequential-compartment configuration was proposed for future household-scale application and validation (Figure 8). However, the proposed configuration should not be interpreted as a ready-to-use household composting technology. The laboratory experiment was conducted using pre-prepared mixtures with defined blending ratios and an adjusted initial moisture content, whereas FW generated under actual household conditions

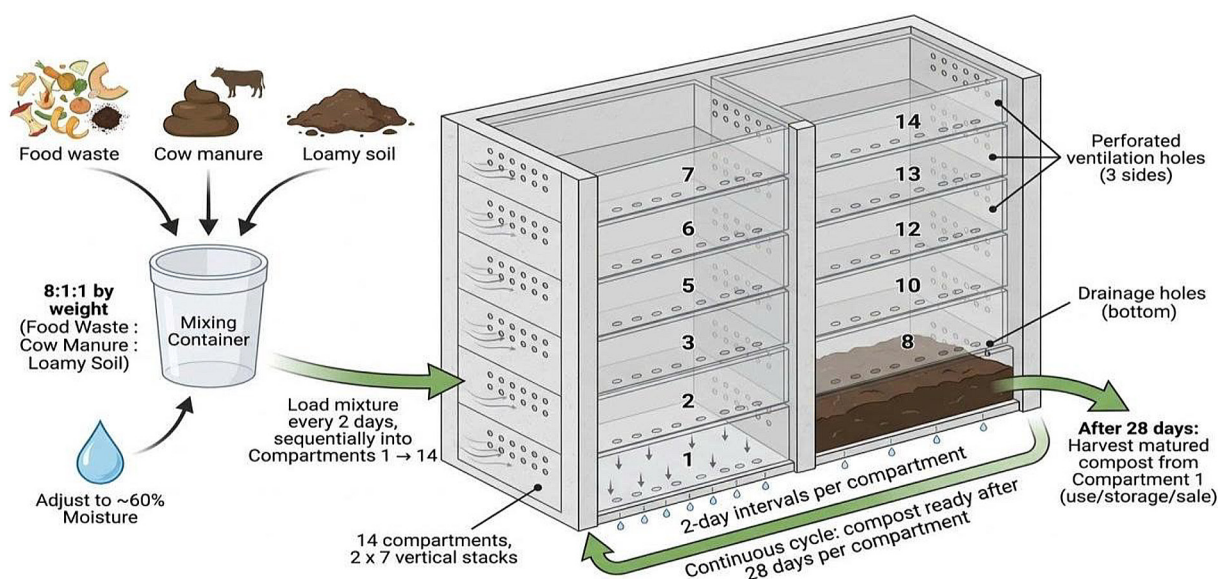


Figure 8. Conceptual sequential-compartment configuration proposed for future household-scale validation

may vary considerably over time in composition, moisture content, and generation rate. Therefore, the operational performance of the proposed configuration requires pilot-scale validation under actual household conditions before practical implementation can be recommended.

It should be emphasized that the 14-compartment configuration proposed for household application differs from the experimental configuration shown in Figure 1. The laboratory experiment used 18 active experimental units because six treatments were evaluated with three experimental units per treatment (6 treatments $\times$ 3 experimental units = 18). In contrast, the proposed 14-compartment configuration represents a conceptual household-scale operating sequence based on a two-day FW loading interval over a nominal 28-day residence period (28 days/2 days = 14 compartments). Thus, the difference in the number of compartments reflects the different purposes of the experimental design and the proposed household-scale configuration. The 14-compartment configuration was not experimentally evaluated in the present study and therefore requires further validation under actual household operating conditions.

The proposed household-scale process consists of three main stages. Mixing stage: After source separation, FW is mixed with cow manure and loam soil at a wet-mass ratio of 80:10:10, corresponding to the T5 formulation evaluated in the laboratory experiment. The initial moisture content of the mixture is adjusted to approximately 60% before loading. Sequential composting stage: FW collected over a two-day period is mixed with the amendment materials and loaded into the first compartment. After the next two-day collection period, a newly prepared mixture is loaded into the second compartment, and this sequence is continued until the 14th compartment is loaded on day 28. This conceptual arrangement is designed to provide a nominal 28-day residence period for each batch and to enable sequential household FW processing; however, its operational performance has not yet been validated under actual household conditions. Post-composting stage: After the nominal 28-day period, the composted material is removed from the corresponding compartment for further curing and stabilization. Because compost maturity and stability were not directly evaluated in the present study using specific indicators such as respiration activity, germination index, $\text{NH}_4^+/\text{NO}_3^-$ ratio, temporal C/N evolution, or phytotoxicity, the material obtained after 28 days should not be

considered fully mature compost solely on the basis of the present results. Therefore, an additional curing/stabilization period followed by appropriate maturity and stability assessment is recommended before agricultural application.

CONCLUSIONS

This study characterized household FW generation and composition in the surveyed households and evaluated six FW-based composting formulations under laboratory-scale conditions. The average FW generation rates among the surveyed households were 0.861 kg/household/day and 0.203 kg/person/day, while vegetable- and fruit-derived materials accounted for 61% of the FW, indicating its potential as a feedstock for composting. Among the six tested formulations, T5 (80% FW, 10% cow manure, and 10% loam soil) showed the most favorable overall performance based on the measured physicochemical indicators, with total N, available P_2O_5 , available K_2O , organic matter, humic acid, and Mg contents of $0.86 \pm 0.10\%$, $0.32 \pm 0.02\%$, $0.29 \pm 0.01\%$, $26.57 \pm 0.65\%$, $3.89 \pm 0.02\%$, and $0.17 \pm 0.01\%$, respectively. Pb, *E. coli*, and *Salmonella* were reported as not detected by the analytical laboratory under the respective methods applied in this study; however, these results should not be interpreted as demonstrating comprehensive chemical or microbiological safety. Furthermore, because direct oxygen measurements and established maturity and stability indicators were not included, the material obtained after 28 days cannot be conclusively classified as fully mature compost. The results therefore identify T5 as a promising formulation for further investigation and provide a preliminary basis for the proposed household-scale sequential-compartment configuration rather than validation of a ready-to-use household composting technology. Because household FW may vary over time in composition, moisture content, and generation rate, pilot-scale validation under actual household conditions is required before practical implementation can be recommended.

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