Pertanika J. Sci. & Technol. 34 (4): 2421 - 2440 (2026)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Valorisation of Food Waste and Leftovers into Functional Bio-Compost: Optimisation of Maturation Period and Growth Performance of *Ipomoea aquatica*

Sarah Dini Muhamad Din[1], Muhammad Heikal Ismail[1]*, Tharsini Amma Puspadaran[2], Anie Yulistyorini[3], Muhammad Hazwan Hamzah[4], and Chuah Teong Guan[2]

[1]*Department of Environmental Science and Technology, Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*
[2]*Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*
[3]*Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Malang, 65145 Malang, East Java, Indonesia*
[4]*Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

ABSTRACT

Repurposing Food waste (FW) and leftovers (LF) involves using organic materials that are discarded at different stages of production, retail and consumption. Food waste is food that has decreased nutritional value and is not suitable for human consumption. Leftovers are defined as uneaten edible remains of a meal. In this research, both these wastes are used to produce functional bio-compost using the Bokashi method, an anaerobic food waste treatment technique that utilises a Bokashi bin and Bokashi bran to ferment organic waste before its application as a soil amendment. The duration of the maturation stage of both bio-composts was manipulated to 30 days, 40 days and 50 days. Leftover food bio-compost shows a greater reduction in bulk density, higher moisture content and water-holding capacity as compared to food waste bio-composts. As the maturation period increases, the bulk density decreases, and the moisture content and water-holding capacity of the bio-compost increases. The pH value of all 6 bio-composts produced was within the range of finished compost. The total volatile solids (TVS) decrease as the maturation period of bio-compost increases for both food waste and leftovers. Leftover at day 50 (LF-50) shows the best-optimised result as it has the lowest C: N ratio and highest nitrogen and potassium concentrations.

ARTICLE INFO

Article history:
Received: 12 June 2025
Accepted: 25 June 2026
Published: 20 August 2026

DOI: https://doi.org/10.47836/pjst.34.4.23

E-mail addresses:
sarahdini077@gmail.com (Sarah Dini Muhamad Din)
heikal@upm.edu.my (Muhammad Heikal Ismail)
tharsiniamma@gmail.com (Tharsini Amma Puspadaran)
anie.yulistyorini.ft@um.ac.id (Anie Yulistyorini)
hazwanhamzah@upm.edu.my(Muhammad Hazwan Hamzah)
chuah@upm.edu.my (Luqman Chuah Abdullah)
* Corresponding author

e-ISSN: 2231-8526

The growth quality of *Ipomoea aquatica*, known as water spinach, has been used to compare bio-compost quality. From this aspect as well, LF-50 proves to be the optimum result. This shows that leftover foods produce a finer quality of bio-compost as opposed to food waste. As the maturation period increases, the bio-compost quality improves both physically and chemically.

Keywords: Bokashi, chemical properties, compost, food waste, growth quality, *Ipomoea aquatica*, leftover, physical properties

INTRODUCTION

Statistics reported by the Food and Agriculture Organisation of the United Nations, almost one third of the food produced globally for human consumption, which is approximately 1.3 billion tonnes, gets wasted every year (Blakeney, 2019). The two types of food that have been discarded are food waste and leftovers. First, food waste, often referred to as pre-consumer food, is the category of food that is taken from homes and restaurants' kitchens. Food remnants left on plates that customers discard is typically included in the category of leftovers. Another name for these wastes is post-consumer food (Arumugam et al., 2021). SWCorp Technology Research Division stated that Malaysians generated 38,000 tonnes of solid waste daily in the year 2016, in which food waste contributes to an amount of 15,000 tonnes. Based on constructs of leftover food waste generation behaviour, motivation in leftover food management, and opportunity and ability in leftover food management, are contributing to food leftover generation. Some of the factors include perception toward food leftovers, lifestyle, infrastructure, skill and knowledge (Aloysius et al., 2023).

Bio-compost is a medium formed from organic matter that has undergone decomposition and is widely used in the agriculture sector. Bio-compost can act as a single solution that can manage both food waste issues simultaneously. Composting is a biological method commonly conducted under anaerobic conditions in the absence of free oxygen (Mu et. al, 2016). This process is environmentally favoured compared to incineration, gasification and landfilling (Yin et al., 2016). Bio-compost usually consists of organic matter such as food waste and leftovers that is being decomposed and recycled as fertiliser or manure. Biodegradation of these components contributes to many macronutrients, nitrogen, phosphorus and potassium, in the compost, which makes it a suitable growing condition for plants. As for the aerobic process in the presence of oxygen, microorganisms digest organic compounds and release carbon dioxide, nitrate, and nitrite (Xiao et al., 2009). Anaerobic composting is composting that proceeds without oxygen entanglement (Meena et al., 2021).

Compared to thermophilic compost and vermicompost, the EM for Bokashi treatments offer a nitrogen nutrient that is longer-lasting and plant-available. This technique increases the biomass and aboveground height of plants. This resulted from the compost's capacity to deliver a sustained supply of nitrogen along with an appropriate level of potassium and phosphorus for plant growth. Ultimately, this study found that the Bokashi treatment was an appropriate substitute fertility supplement for the system of organic vegetable production (Arumugam et al., 2021). Home composting of food waste could significantly benefit the environment. Research comparing organic and chemical fertilisers on watermelon growth showed organic fertilisers had the highest results in consistency parameters. Composting was also simpler to incorporate and less expensive than other technical approaches (Arumugam et al., 2021).

The objective of the study is to evaluate the differences in physical properties of bio-compost between food waste and leftovers at 30, 40 and 50 days of maturation. Regulating the maturation phase can enhance understanding of the ideal timing for producing high-quality bio-compost. Additionally, this study also aims to assess the quality of bio-compost by the growth of *Ipomoea aquatica.* The growth of *Ipomoea aquatica* can deepen insight regarding the quality of bio-compost and discover the effect of the bio-compost in practical use in agriculture. The acquired knowledge can encourage the production of functional bio-compost from food waste and leftovers using the Bokashi method. The findings of the study can contribute to knowledge of the optimal duration of the maturation stage of food waste and leftovers. Composting food waste and leftovers can contribute to sustainable agriculture practices where organic matter from waste is converted into valuable products that can enhance nutrients in soil for agriculture

MATERIALS AND METHODS

Materials

Materials used in the research are food waste and leftover foods obtained from the cafeteria of the Faculty of Engineering, Universiti Putra Malaysia (UPM) and household food waste and leftovers as the feedstock for the composting process. The food wastes are all the food material that is wasted and not used during the cooking process and expired manufactured food that cannot be consumed. For the leftovers, these are foods collected from plate waste produced by the consumers of the cafeteria and household waste (Nakagiri et al., 2024).

Experimental Procedure

The experimental procedure of this research firstly begins with the preliminary study of drying kinetics of the food materials. In this section, hot air-drying pre-treatment was conducted on the feedstocks at 50°C for 6 hours. Then, the pre-treated food wastes and leftover foods were filled into two Bokashi Kit Bit Coins, respectively. Upon filling to a thickness of 5 cm, Bokashi Bran was added to each layer of food waste, and leftover food was added to the bins. Bokashi Bran was added to introduce Effective Microorganisms (EM) in the compost kit. The compost kits were left to ferment the waste for 14 days; then the waste was removed and added to a soil bed for maturation (Melini & Melini, 2024).

The duration of the fermented food wastes and leftover foods left to compost under the soil beds is divided into three different periods, which are 30 days, 40 days and 50 days, respectively. Hence, from this part, 6 different composts were produced in the process. The physical properties of the bio-compost were compared by assessing the moisture content, bulk density and water-holding capacity of all 6 bio-composts. Then, samples of the bio-composts produced were collected and pre-treated to be analysed for the nutrient concentrations in the bio-compost. The nutrient contents of Carbon (C), Hydrogen (H), Nitrogen (N) and Sulphur (S) were analysed using a CHNS Analyser machine at the Faculty of Engineering, UPM and Potassium (K) concentration was analysed using an Auto Analyser at the Faculty of Agriculture, UPM.

Then, the pH of the composts was measured using a pH meter, and the total volatile solids (TVS) were determined by *ashing* the compost at 550°C for 4 hours. To compare the bio-compost performance, Water Spinach *(Ipomoea aquatica)* were planted, and the growth quality of the plant was assessed. For this, water spinach was grown in 6 different types of bio-compost prepared for this experiment. As a control, the water spinach w*as* also grown using soil fertilised with commercial organic fertiliser as well as an unfertilised soil environment. The growth aspects of plant height and number of leaves were observed daily. The size of the leaves and crop growth rate were measured and calculated after harvesting the plants. From the value of dry weight obtained at two different periods, the crop growth rate of water spinach was calculated.

The feedstocks for this experiment were collected from the Cafeteria of the Faculty of Engineering, UPM and household waste. These feedstocks comprised both food waste and leftover food. The materials obtained were kitchen waste used for cooking and uneaten food that was collected during lunchtime, which is between 1000 am to 1400 pm. The feedstock composition comprises rice, noodles, bones (fish), fruits and vegetables. Then, other components such as eggshell and fish meat are also present in the feedstock but only in small proportions. The total food waste and leftover foods collected were 4 kg each. The method used to decompose the food waste into compost is by using the Bokashi method. This method of composting is established in Japan and uses microbes to decompose food and, at the same time, masks the foul smell produced in the decomposing process. In this part of the methodology, the equipment that will be used is the Bokashi Kit Bit Coin.

To begin with, spread one small handful of Bokashi Bran, approximately ¼ cup, at the bottom of the buckets, with one labelled as a leftover food compost kit and another food waste compost kit. Then, add the food waste and leftover foods respectively to the bins within the range of 2 to 3 inches. Add a teaspoon of Bokashi bran to cover the layer of the waste materials. Subsequently, repeat the steps by layering the food waste and adding the bokashi bran until the compost bin is full. Later, close the compost kit and ensure the lid is covered tightly. This is to facilitate an anaerobic environment in the bin that will aid in the composting process. After completing these processes, the compost bins were closed for 14 days. The treated wastes were poured into 6 different planters filled with soil after completing 14 days of fermentation in the bin, three for fermented food waste and another three for fermented leftover foods. These wastes were covered with a 5-inch depth of soil and left to compost for different lengths of time, as shown in Table 1.

This step was carried out to compare the quality of the bio-compost when the duration of the curing period is extended. Finally, after completing the curing period at 30 days, 40 days and 50 days, the samples of the compost were collected to undergo characterisation and analysis of the nutrient content.

Table 1
Bio-compost labelling (soil bed)

Labelling	Description
Planter 1 (FW30)	Fermented food waste left to compost under the soil bed for 30 days.
Planter 2 (FW40)	Fermented food waste left to compost under the soil bed for 40 days.
Planter 3 (FW50)	Fermented food waste left to compost under the soil bed for 50 days.
Planter 4 (LF30)	Fermented leftover food left to compost under the soil bed for 30 days.
Planter 5 (LF40)	Fermented leftover food left to compost under the soil bed for 40 days.
Planter 6 (LF50)	Fermented leftover food left to compost under the soil bed for 50 days.

Physical Properties, pH and Total Volatile Solids (TVS)

The physical properties that were measured and compared are the moisture content, bulk density and water-holding capacity (WHC). As for the moisture content, the compost sample of 100 g will be dried in an oven at 105°C for 24 hours (Kumar et. al., 2010). The final mass of the compost was measured after the 24-hour duration. The difference in mass determines the amount of moisture available in the compost. The bulk density of the composts was measured by filling 150 g of bio-compost into a 10 L container. The compost was then compressed until there was no large void space; the volume occupied was measured. The bulk density was calculated by dividing the weight of the bio-compost by the volume occupied (kg/m^3). Then, for the water-holding capacity, a wet sample of bio-compost weighing (Wi) with a known initial moisture content was left to soak in water for 1-2 days. Excess water was drained using Whatman 32 filter paper; the saturated sample was weighed once again (Ws). The amount of water that was retained by the bio-compost was calculated using Equation 1.

$$WHC = \frac{(WS - WI) + MC \times WI}{(1 - MC) \times WI} \qquad [1]$$

where,
WHC = Water Holding Capacity (g water/g dry compost)
WI = Initial Weight of Bio-Compost
Ws = Final Weight of Bio-Compost (After Filtration)
MC = Moisture Content of Bio-Compost

To determine the pH of the 6 different bio-composts produced from both food waste and leftover food, a solution of composts was made. The solution of composts was produced by diluting the sample composts into distilled water at a ratio of 1:5 (compost: distilled water). Then, the pH meter was dipped into the solution to measure the pH of the solution (Kumar et. al., 2010). Then, the Total Volatile Solid (TVS) content in the compost was determined by using the product from the moisture content test. The sample that has been heated up to 105°C to determine the moisture content will then be formed into ashes in a furnace at a temperature of 550°C for 4 hours (Melini & Melini, 2024). After 4 hours, the product produced will be weighed, and the mass produced is the mass of TVS available in the composts. This step was carried out for all 6 compost*s*.

Nutrient Content in Bio-Compost

The macro-element nutrients in the soil will be analysed and measured using the Auto Analyser machine. The Auto Analyser machine functions to conduct environmental analysis on soil and composts, and the design of this equipment is based on segmenting a continuous flowing stream with air bubbles. The list of micro and macro elements that were measured is Nitrogen (N), Phosphorus (P), Potassium (K), Carbon (C), Hydrogen (H) and Sulphur (S). For the concentration of C, H, N and S, the samples of Bio-Compost were sent to the Material Characterisation Laboratory, Faculty of Engineering, UPM, to be analysed using a CHNS analyser. The concentration of potassium (K) was determined in the Faculty of Agriculture using the Auto Analyser machine. This equipment functions only to analyse organic liquids; hence, a solid-liquid extraction process must be conducted on the compost before the test.

The steps involved in the solid-liquid extraction process began by collecting 20 g of bio-compost from the leftover food compost and food waste compost and placing it into two separate labelled bags. The samples were then placed in a clean Petri dish and dried in an oven at 105°C for 2 days. After drying, the samples were crushed using a mortar and pestle until a refined, smooth granule was formed. Then, the samples were sieved using a 2 mm sieve and the products were stored in a beaker of conical flask at room temperature (Alves et al., 2023; Whittinghill et al., 2024).

Universal Soil Extractant were used to extract the potassium (K) nutrient in the Bio-Compost. The preparation method began with adding 53.12 g of sodium sulphate and 37.80 g of sodium bicarbonate in 800 mL distilled water to a conical flask of 1L. Then, the pH of the solution was maintained at 8.5 using sulfuric acid solution and sodium hydroxide solution. 2.5 g of the dried bio-compost was loaded into a 100 mL conical flask. After that, 50 mL of the universal soil extractant and 0.5 g of phosphate-free activated carbon were added. The solution was then stirred for 10 minutes at 200 rpm. The solution was then filtered with filter paper. The extracted solutions were then sent to the Analytical Laboratory 2, Faculty of Agriculture, UPM. All analyses were replicated three times to ensure data reliability and enable statistical analysis.

Germination of *Ipomoea Aquatica*

For this experiment, the germination of water spinach was conducted in an outdoor environment since this plant needs plenty of sun or partial shade to aid its growth. Then, aside from comparing the growth rate of water spinach for both food waste and leftover food compost, the water spinach will also be grown in unfertilised soil, and another will be fertilised using commercial organic fertiliser. The commercial organic fertiliser that was chosen to be assessed and compared to the bio-composts is BIO LOF Organic Fertiliser. The unfertilised soil and commercial fertiliser were used as a control in this experiment. The procedure that needs to be taken begins with 8 bags of planter bag will be filled with the same amount of soil. About 2/3 of the planter bag will be filled with soil. The plant bags were labelled as shown in Table 2.

Table 2
Water Spinach (WS) planter bag label

Type of Soil/Fertiliser/ Compost	Label
Unfertilised soil	WS-UF
Commercial organic fertiliser	WS-CF
Food waste compost -FW 30	WS-FW 30
Leftover food compost -LF 30	WS-LF 30
Food waste compost -FW 40	WS-FW 40
Leftover food compost- LF 40	WS-LF 40
Food waste compost -FW 50	WS-FW 50
Leftover food compost -LF 50	WS-LF 50

Before planting, the seeds of water spinach were left to soak in a water bath for 24 hours. This step was taken to promote germination of the water spinach. For each plant bag, 3-4 water spinach seeds are planted in the WS-labelled plant bag. Once the water spinach germinates, the seedlings will be relocated to 5 cm × 5 cm. This is to prevent the plants from wilting and to germinate effectively. To get the optimum reading, the two best plant readings were obtained for each planter, and the average was calculated. The watering schedule for water spinach is 1-2 times daily. The water spinach will be left to grow for 30 days (Ibrahim et al., 2019; Ni'am & Yuniati, 2021).

For the growth of water spinach, four aspects will be measured: the height of the plant, number of leaves, size of leaves and dry weight of the leaves. To begin with, the height of the plants will be measured daily until the plant is fully mature. Firstly, the ruler was set at the base of the plant the height was recorded. The value was recorded with both the date and height value. Then, for the number of leaves, the leaves were counted daily and recorded. The leaf area and dry weight were calculated after 30 days of growth; the leaves' surface area and dry weight of the greens were measured. The leaf area was measured using an application named "Petiole". This application runs by calibrating the mobile camera with a Petiole Pad, and once the calibration is completed, the leaf was placed in front of the camera. The leaf area was then measured automatically by the app, and the results obtained were recorded. As for the dry weight of plants is an estimate of the plants' weight once all water has been removed from them.

The steps involved in this part began with the water spinach being weighed and then dried in an oven at 70°C for 1 hour. After 1 hour, the plants were weighed again to obtain the dry weights. This step was conducted for all 8 categories of water spinach. Then, based on dry matter accumulation, the values of the growth parameter of the crop growth rate (CGR) (mg m-3 day-1) were calculated for each treatment of Water Spinach as in Equation 2.

$$CGR = \frac{1}{\mathrm{GA}} \times \frac{(W_2 - W_1)}{(\mathrm{T}^2\text{-}\mathrm{T}^1)} \qquad [2]$$

In which GA is the ground area (m^2) of the crop collected, and W_1 is the dry weight at time T_1. W_2 is the dry weight at time T_2.

Statistical Analysis

The published results are expressed as mean ± standard deviation (SD) of triplicates. Relative change (%) was used in descriptive statistics and One-way ANOVA to analyse the height of Water Spinach against the 6 bio-composts. One-way ANOVA was also performed to determine the crop growth rate. ANOVA test employed Tukey's post hoc analysis. All statistical analyses were conducted with SPSS software (v.12, IBM, SPSS, New York, USA) at a significance level of 0.05. Differences in means are marked with a letter in the figures.

RESULTS AND DISCUSSION

Pre-treatment of Food Waste and Leftovers

The food waste and leftovers were subjected to pre-treatment at a temperature of 55°C using an Air-Drying Incubator. This bio-drying method functions to remove water from organic waste through microbial activities. The biomass product with lower water content restricts odour emission and has a higher potential to produce high-value-added products such as bio-compost (Han et al., 2024). The suitable range for proper growth of microorganisms for this process is between 40°C and 70°C; hence, 55°C was chosen to carry out the drying (Tun & Juchelková, 2019). The Hot-Air Drying Incubator that has been used is a

Binder BOD Incubator, and the operating limit of this incubator is -5 to 100°C. The type of drying equipment used is a sealed type and operates in forced-air circulation mode. The raw materials of food waste and leftover foods were dried in the incubator until a constant reading was obtained. The results of the moisture ratio against time for both the food waste and leftovers are displayed in Figure 1.

The moisture ratio determines the unaccomplished moisture change, the ratio of the free water still to be removed at time t, over the initial total free water. From Figure 1, the drying of the food waste took an estimated time of 420 minutes to reach a stable reading. The moisture ratio of the food waste material has dropped by about 21.3%. As for leftover foods, the time taken to complete the drying process was 540 minutes. The moisture ratio for the leftover food materials has dropped by approximately 43.9%. From this part of the pre-treatment, it can be deduced that the drying time for food waste is shorter compared to leftover food (Lai et al., 2023).

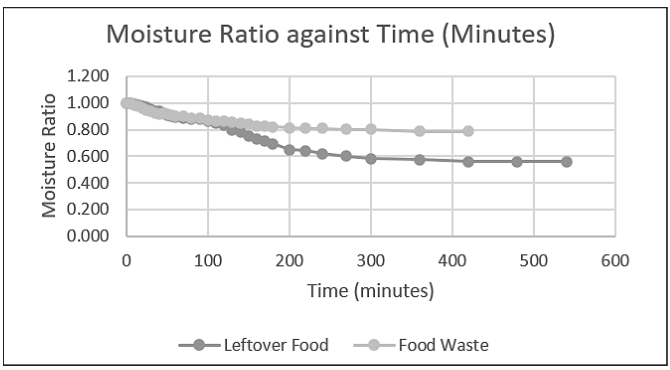

Figure 1. Moisture ratio against time of food waste and leftover foods

Properties of Food Waste and Leftovers

The properties that were analysed in the food waste and leftover compost are the pH value, moisture content and total volatile solids. The results obtained were as tabulated in Table 3. The readings obtained for moisture content and total volatile solids are statistically significant ($p \leq 0.05$), whereas bulk density and pH value are not statistically significant ($p \leq 0.05$). P are stand for p-value (probability value) is a statistical measure that helps determine the significance of results in a hypothesis test. From the results obtained, there are some differences in the parameters measured for the properties of the raw materials selected for this research. Firstly, the bulk density of Food Waste seems to be slightly higher compared to leftover foods. The variation between both materials in this aspect might be due to the state of the raw material. Leftover food is subjected to more moisture; hence, it is easily compressed (Lee et al., 2024).

Table 3
Properties of raw material

Properties	Leftover	Food Waste
Bulk density (kg/m^3)	781.29	813.06
pH	6.11	6.16
Moisture content (%)	82.15*	72.65*
Total volatile solids (%)	76.67*	71.33*

Note. *Indicates the mean difference is significant at $p \leq 0.05$

The moisture content and Total Volatile Solids (TVS) in leftover food were higher values compared to food waste. The TVS results obtained for both food waste and leftover is within the range which are within 73% to 98% (Selvam et al., 2021). For moisture content, both materials recorded a difference of 9.5%, whereas for total volatile solids, it is 5.34 %. The pH of food waste and leftover foods had a mean of 6.16 and 6.11, respectively, with a minimal difference of 0.82% between both.

Physical Properties of Bio-Compost

The physical properties that were analysed are the moisture content (%), bulk density (kg/m3) and water-holding capacity (g water/g dry sample) of the bio-compost. All the physical parameters measured for the bio-compost are statistically significant ($p \leq 0.05$). The desired and typical moisture content of a completed compost is within the range of 40 – 60 %. Based on the results from Table 4, it can be observed that all the 4 bio-compost not including LF-30 and FW-30, have moisture compositions that fit within that range. The moisture content in bio-compost has a physical impact on permeability and significant biological implications for the soil (Ameen et al., 2016). The moisture content has a great influence on microbial activity. The LF-30 and FW-30 bio-composts have moisture content slightly below 40%, at 39.03% and 35.98%, respectively. In the leftover food compost aspect, LF-50 recorded the highest, which is 46.18%, and the lowest is LF-30, which is 39.03%.

Table 4
Physical properties of bio-compost

Type of Bio-compost	Moisture Content (%)	Bulk Density (kg/m^3)	Water Holding Capacity (g water / g dry sample)
LF-30	39.03*	574.73*	3.28*
LF-40	40.10*	549.59*	3.61*
LF-50	46.18*	530.54*	3.98*
FW-30	35.98*	600.65*	3.17*
FW-40	40.06*	588.32*	3.49*
FW-50	42.60*	581.43*	3.79*

Note. *Indicates the mean difference is significant at $p \leq 0.05$

As for the food waste bio-compost, FW-50 recorded the highest moisture content at 42.60% and FW-30 the lowest at 35.98%. For bulk density, it is a function of the local pressure that is being exerted on the material. This property is influenced by the effects of subsidence, loss of organic matter due to biological degradation processes, and changes in moisture distribution. The overall bulk density for food waste and leftover decreased gradually from the 30-, 40- and 50-day periods. The biological decomposition is still active and present during the 40- and 50-day periods of composting; hence, the bulk density declined slightly for both the food waste and leftover compost. It can be observed that as the period of composting increases, the bulk density of the bio-compost decreases. The bio-compost produced from leftover food is within the range of 530.54 kg/m3 to 574.73 kg/m3, whereas for food waste it is 581.43 kg/m3 to 600.65 kg/m3.

The leftover food seems to have reduced in bulk density even more as compared to the food waste, which might be due to the rate of organic matter decomposition. Organic matter has a lower density than the mineral fraction in compost, and it can increase the void spaces in the compost heap, which leads to a decrease in overall bulk density.

Water Holding Capacity (WHC) of bio-compost is the amount of water held between field capacity and wilting point. The WHC is affected by the number of pores and pore-size distribution. The main component that determines the WHC of compost is the compost texture and organic matter content (Beesley et al., 2010; Cervera-Mata et al., 2021). High organic matter in compost increases the WHC and the moisture content in the bio-compost. The result of WHC for the leftover foods are in the range of 3.28 to 3.98 g of water/g of dry sample. For food waste compost, the WHC is within the range of 3.17 to 3.79 g of water/g of dry sample. The WHC for leftover food is slightly higher compared to the food waste compost. The WHC plays a very important role in plant growth quality. For both the food waste and leftover food, the WHC increases as the period of the composting process increases. The level of WHC quality can affect the overall water spinach growth. Low WHC causes vegetation to undergo stress, which will affect the transpiration rate of the plant. The decrease in transpiration rate, in turn, closes stomata and inhibits plant growth. The result obtained on the WHC of the bio-compost might influence the growth quality of the water spinach produced.

Chemical Properties of Bio-Compost

The chemical properties that have been analysed in the bio-composts produced, as in Table 5, are the pH, total volatile solids (TVS), carbon to nitrogen ratio (C: N), total Carbon content (C%), and hydrogen content (H%). Nitrogen (%), Sulphur content (S%) and Potassium concentration (mg/L).

Table 5
Chemical properties of bio-compost

Properties	LF-30	LF-40	LF-50	FW-30	FW-40	FW-50
pH	6.64	6.65	7.01	6.3	5.07	6.69
TVS (%)	63.5*	50*	47.5*	58.5*	50*	45*
C: N	22.06:1	14.37:1	12.46:1	21.51:1	15.44:1	13.48:1
C (%)	42.14	39.94	37.73	41.95	39.86	38.01
H (%)	5.12	4.96	4.77	5.69	5.74	5.72
N (%)	1.91	2.78	3.03	1.95	2.58	2.82
S (%)	0.25	0.25	0.25	0.26	0.25	0.26
K (mg/L)	104.8	138.1	265.8	89.42	170.8	130.4

Note. *Indicates the mean difference is significant at $p \leq 0.05$

The results recorded for pH value and the total volatile solids (TVS) of the bio-composts are statistically significant ($p \leq 0.05$). The pH value is obtained from different sections of the compost pile, and the average value is tabulated. Based on the results tabulated in Table 5, the pH value obtained from the leftover food compost is in the range of 6.64 to 7.01, whereas for the food waste compost the pH value obtained is at 5.07 to 6.69. Generally, mature compost has a pH value of between 6 and 8 (Wang et al., 2022). The H levels measured are between highest 5.74% and lowest at 4.77%. The increase in pH to a base condition is beneficial to the composting process because alkaline conditions can limit the growth of diseases such as fungi that thrive in acidic environments (Irvan et al., 2018). The higher hydrogen generation in compost can be attributed to its elevated mineralisation (Barneto et al., 2009).

Before the maturation stage, the compost will be quite acidic. As the temperature of the pile increases when the mesophilic stage takes over, the composting material eventually neutralises. The increase in pH value of leftover compost can also be explained by the ammonification process undergone by the compost. The ammonification of compost-derived nitrogen and the presence of Ca and Mg in the compost may release hydrogen ions (H^+) from the subsequent site. For the food waste compost, the pH reading at FW-30 is 6.3, then it dropped to 5.07 at FW-40 and stabilised at 6.69 for FW-50. The dip in the pH value might be due to the anaerobic digestion that is still occurring in the compost. Anaerobic digestion occurs if the turning of compost and improved air circulation are not completely fulfilled in the compost heap. However, the increase in acidity level at 40 days is just slightly below the mature compost pH requirement. Once it is used for planting in soil, the compost will neutralise accordingly and might not significantly affect the crop growth rate of the Water Spinach.

For the FW-50, the pH value is 6.69, which is mature and suitable to be used for fertilising application. Total volatile solids in compost are the elements that can easily transform from the solid phase to its vapor phase, without a liquid phase interval. These solids are the organic matter content in the compost, which is the food waste and leftover material. The total organic matter during the composting process will decrease during the composting process. A significant reduction in volatile solids indicates the decomposition, mineralisation and maturity of the composting process, in which both leftover foods and food waste show a clear sign of reduction.

The reduction of volatile solids can be compared for the food waste and leftover food compost. The initial value of LF feedstock has a reading of 76.67%, and it reduced to 63.5%, 50% and 47.5% for LF-30, LF-40 and LF-50, respectively. As for the food waste compost, the FW feedstock recorded 71.33% initial volatile solids, and it decreased to 41.95%, 39.86% and 38.01% for FW-30, FW-40 and FW-50, respectively. The quantity of trend reduction for leftover food compost shows a higher reduction reading of reduction which is 33.32%, whereas for food waste it is 29.17% for the overall reading. The degradation of volatile solids can be influenced by the proper availability of substrate to the microbes. Total Carbon in a compost is the direct measurement of the organic and inorganic carbon in the bio-compost sample. The carbon in bio-compost is mainly in organic form. Based on Table 5, the total organic carbon decreased gradually in the three maturation periods of food waste and leftover food. The total carbon for leftover food is within the range of 37.73% to 42.14%, and 38% to 41% for food waste. The leftover food recorded lower total carbon, which can be a result of a higher rate of degradation of organic matter in the compost pile.

For both food waste and leftovers, the total carbon experiences a decreasing trend. Carbon content will naturally drop during the composting process as microbes consume it as a source of energy, and some is released in the form of Carbon Dioxide (CO^2). Nitrogen is a vital source of nutrients for plant growth, and it's the major component of chlorophyll. The total nitrogen concentration can be observed to be increasing when the composting maturation period increases.

This might be due to net loss of dry mass of Carbon Dioxide and water loss by evaporation during oxidation of organic carbon (Oliveira et al., 2022; Ugak et al., 2022). For compost, nitrate -nitrogen may increase as the compost matures, and most of the N will be in the organic form. The concentration of nitrogen from all 6 composts is marginally different. From Table 5, LF-50 shows the highest reading of nitrogen concentration, which is 3.03%, and the lowest recorded is LF-30 at 1.91%. From 1.91 % at 30 days, the concentration leapt to 2.78 % at LF-40, which is a 45% increase and finally, for LF-50, the N% increased by about 8.9%. As for FW-30 to FW-40, the changes recorded surged by 32.3% and at FW-50 the concentration increased to 9.3%. From the results, it can be observed that the concentration of nitrogen increases as the maturation period increases. From the 30-day and 40-day gap of maturation period for both leftover food and food waste experience a notable increase in N% compared to 40 and 50 days, which is <10%. C/N, or carbon-to-nitrogen ratio, is the ratio of the mass of carbon to nitrogen in soil. The essential C: N ratio is < 20-25:1. C: N ratio higher than 20:1 indicates that the compost or soil amendment is poor in nitrogen and rich in organic carbon, which leads to Nitrogen immobilisation (Wei et al., 2022).

These types of compost undergo microbial decomposition before nutrients become accessible to the plants. From the results, LF-30 and FW-30 displayed a C: N reading above 20:1. This might affect the growth potential of Water Spinach (Aylaj & Adani, 2023; Nair et al., 2024; Noor et al., 2024). This is because of poor nitrogen concentration, as microbes might immobilise soil nitrogen into their body to maintain their own C: N ratio and the water spinach crop might suffer from nitrogen deficiency. As for the other 4 bio-composts, the C: N ratio is within the range of 12 to 15:1 ratio which is below 20:1 (Al-Tawarah et al., 2023; Gelsomino et al., 2023; Kumar et al., 2024).

This feature allows faster N mineralisation and eases the release of nutrients to support plant growth. For the Potassium concentration analysis, the equipment used to carry out it is by using the Auto Analyser machine. This concentration analysis was conducted separately from the other element analysis, and the concentration recorded is in the unit (mg/L). The highest reading recorded for K is LF-50, which is 265.8 mg/L, and the lowest is FW-30 at 89.42 mg/L. Based on studies, the potassium concentration will increase as the composting period increases. The result obtained from the leftover food shows the same trend. The increase in potassium concentration from LF-40 to LF-50 is almost a 92% increment. However, there were fluctuations in the concentration of potassium in food waste compost (Jahan et al., 2022; Kabir, 2022; Sarminingsih et al., 2023).

The K (mg/L) concentration increased by about 91% from FW-30 to FW-40 and slumped by 30.9% (130.4 mg/L) at FW-50. This decrease in K concentration might be caused by the activity of microorganism which consumes nutrients during the curing period (Almulla et al., 2024). The absence of a similar decline in the leftover treatment may be due to differences in their original composition. Leftover food contains cooked rice, meat, sauces, oils, and other processed materials, which have a different potassium concentration and decomposition pattern from food waste. In addition, differences in moisture content, salt concentration, particle size, and the amount of liquid released during decomposition could have affected potassium concentration. The Sulphur content in the bio-compost is an essential mineral that helps to produce important enzymes and contributes to the formation of plant proteins. As for all the 6 bio-compost, the sulphur concentration obtained is not significantly different from one another, with a concentration of 0.25 to 0.26 % (Jahan et al., 2022; Noor et al., 2024).

Growth Analysis of Water Spinach

There are four parameters that have been measured in the growth analysis of Water Spinach. The parameters that were evaluated are the height of the plant (cm), number of leaves, size of leaves (cm^2), and crop growth rate ($g/m^2/day$) of Water Spinach.

The ANOVA conducted on the data collected for the crop growth rate was statistically significant ($p \leq 0.05$). The crop growth rate, as shown in Table 6, is influenced by the area of plant growth, duration of plant growth and the dry weight of the plant (Safdar et al., 2022).

Table 6
Crop growth rate of water spinach

Type of Compost	Crop Growth Rate ($g/m^2/day$)
Commercial Organic Fertiliser	14.11*
Unfertilised Soil	1.35*
LF-30	5.22*
LF-40	8.50*
LF-50	12.85*
FW-30	4.93*
FW-40	8.50*
FW-50	10.43*

Note. * Indicates the mean difference is significant at $p \leq 0.05$

The highest crop growth rate recorded is 12.85 $g/m^2/day$ for LF-50, whereas the lowest is 4.93 $g/m^2/day$ for FW-30. In addition, the crop growth rate of LF-50 is approaching the quality of growth rate of a commercial organic fertiliser, with a marginal difference of 9.8%. The crop growth rate difference between FW-30 and LF-50 is stimulated due to the considerable gap in nitrogen concentration, potassium concentration, as well as the C: N ratio of both bio-composts (Wahi et al., 2019).

CONCLUSION

Based on the physical and chemical properties assessed, there were comparatively different result obtained. The height of the Water Spinach for each bio-compost varies significantly. LF-50 recorded the tallest, followed by FW-50, LF-40, FW-40, LF-30 and FW-30. The height of Water Spinach using bio-compost LF-30 and FW-30 is quite shorter compared to the other four bio-composts. The size of leaves (11.80 cm^2) and number of leaves of LF-50 (11 leaves) were the highest as well. The crop growth rate of the Water Spinach using LF-50 showed the highest rate and difference of 8.93% compared to a commercial organic fertiliser. These findings suggest that the leftover food bio-compost produces a better quality of bio-compost as compared to food waste, and the increase in maturation period of bio-compost improves the final product quality.

Various recommendations can be made to improve the research. To begin, food waste and leftover foods can be pre-treated at various temperatures before being composted. This approach allows us to investigate the effect of raw material drying kinetics on the quality of bio-compost produced. Furthermore, the bio-composts created could be used to evaluate various vegetation and plant growth. This process is done to better understand the influence and limitations of bio-compost quality on various types of plants. Furthermore, future research can examine the N:P:K ratio of each bio-compost to determine the optimal nutrient balance and which plant best meets these requirements. Lastly, different types of composting can also be applied to the same type of waste; thus, the quality of bio-compost produced by other methods under the same variables can be explored.

According to the research, organic waste has significant potential to be utilised in plant growth, instead of ending up in the landfill. The energy produced from the degradation process is instead used as a nutrient provider to the soil, rather than producing emissions that contribute to the greenhouse effect. The composting process using a bokashi kit utilises minimal space and low maintenance. Since both food waste and leftovers are commonly sourced from households, this method is very suitable for being adapted to households. This research identifies the most effective durations for the compost and reveals physical and chemical properties in each phase. Through effectively exposing the findings of this research to the public, we can promote increased engagement in home-based composting.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Putra Malaysia for supporting this study under the MyTiger Matching Grant (MATCHING GRANT/2023/9300493) and Universiti Negeri Malang through the Postgraduate Scheme. The authors also gratefully acknowledge the financial support provided by Universiti Putra Malaysia for publication under the Dana Penerbitan Jurnal (9001103). In addition, the authors extend their sincere appreciation to the staff of Universiti Putra Malaysia, particularly the laboratory team of the Department of Environmental Science and Technology and the Department of Chemical and Environmental Engineering, Faculty of Engineering, for their collaboration, excellent facilities, and invaluable guidance throughout this study.

DATA AVAILABILITY

The authors declare that the data supporting the findings of this study are available within the paper.

DECLARATIONS

The authors have no conflicts of interest to declare that are relevant to the content of this article.

CONTRIBUTION

Sarah Dini Muhamad Din and Tharsini Amma Puspadaran are preparing the conceptualisation, visualisation, writing, methodology, data curation and investigation of the original draft preparation. Annie Yulistyorini, Muhammad Hazwan Hamzah and Chuah Teong Guan oversee the review of the whole article. Muhammad Heikal Ismail is supervising the publication.

LIST OF ABBREVIATIONS

C	:	Carbon
Ca	:	Calcium
CGR	:	Crop growth rate
cm	:	Centimeter
EM	:	Effective microorganisms
FW	:	Food waste
g	:	Gram
H	:	Hydrogen
K	:	Potassium
Kg	:	Kilogram
L	:	Liter
LF	:	Leftover
m	:	Meter
Mg	:	Magnesium
mg/L	:	Milligram pr liter
mm	:	Millimetre
N	:	Nitrogen
P	:	Phosphorus
S	:	Sulphur
TVS	:	Total volatile solids
WHC	:	Water holding capacity
WS	:	Water spinach
°C	:	Celsius
%	:	Percentage

REFERENCES

Ameen, A., Ahmad, J., & Raza, S. (2016). Effect of pH and moisture content on composting of municipal solid waste. *International Journal of Scientific and Research Publications, 6*(5), 35-37.

Al-Tawarah, B., Alasasfa, M. A., & Mahadeen, A. Y. (2023). Efficacy of compost and vermicompost on growth, yield and nutrients content of common beans crop (*Phaseolus vulgaris* L.). *Journal of Ecological Engineering, 25*(2), 215-226. https://doi.org/10.12911/22998993/176862

Aloysius, N., Ananda, J., Mitsis, A., & Pearson, D. (2023). Why people are bad at leftover food management? A systematic literature review and a framework to analyse household leftover food waste generation behaviour. *Appetite, 186*, Article 106577. https://doi.org/10.1016/j.appet.2023.106577

Almulla, L., Thomas, B. M., Jallow, M. F. A., Al-Roumi, A., Devi, Y., & Jacob, J. (2024). Rotary drum composting of organic school wastes and compost valorisation. *Sustainability, 16*(6), Article 2428. https://doi.org/10.3390/su16062428

Alves, D., Villar, I., & Mato, S. (2023). Community composting strategies for biowaste treatment: Methodology, bulking agent and compost quality. *Environmental Science and Pollution Research, 31*(7), 9873-9885. https://doi.org/10.1007/s11356-023-25564-x

Arumugam, V., Ismail, M. H., Puspadaran, T. A., Routray, W., Ngadisih, Karyadi, J. N. W., Suwignyo, B., & Suryatmojo, H. (2021). Food waste treatment methods and its effects on the growth quality of plants: A review. *Pertanika Journal of Tropical Agricultural Science, 45*(1), 75-101. https://doi.org/10.47836/pjtas.45.105

Aylaj, M., & Adani, F. (2023). The effect of compost type, application rate, and maturity on nutrient leaching and soil nutrient levels. *Communications in Soil Science and Plant Analysis, 55*(6), 759-781. https://doi.org/10.1080/00103624.2023.2276860

Barneto, A. G., Carmona, J. A., Ferrer, J. A. C., & Blanco, M. J. D. (2009). Kinetic study on the thermal degradation of a biomass and its compost: Composting effect on hydrogen production. *Fuel, 89*(2), 462-473. https://doi.org/10.1016/j.fuel.2009.09.024

Beesley, L., Moreno-Jiménez, E., & Gomez-Eyles, J. L. (2010). Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution, 158*(6), 2282-2287. https://doi.org/10.1016/j.envpol.2010.02.003

Blakeney, M. (2019). Food loss and food waste. In *Food loss and food waste* (pp. 8-11). Edward Elgar Publishing. https://doi.org/10.4337/9781788975391

Cervera-Mata, A., Delgado, G., Fernández-Arteaga, A., Fornasier, F., & Mondini, C. (2021). Spent coffee grounds by-products and their influence on soil C-N dynamics. *Journal of Environmental Management, 302*, Article 114075. https://doi.org/10.1016/j.jenvman.2021.114075

Gelsomino, A., Petrovičová, B., & Panuccio, M. R. (2023). Exhausted fire-extinguishing powders: A potential source of mineral nutrients for reuse and valorisation in compost enrichment for soilless cultivation. *Science of the Total Environment, 906*, Article 167633. https://doi.org/10.1016/j.scitotenv.2023.167633

Ibrahim, M. H., Abas, N. A., & Zahra, S. M. (2019). Impact of salinity stress on germination of water spinach (*Ipomoea aquatica*). *Annual Research & Review in Biology, 31*(5), 1-12. https://doi.org/10.9734/arrb/2019/v31i530060

Irvan, N., Husaini, T., Trisakti, B., Batubara, F., & Daimon, H. (2018). Composting of empty fruit bunches in the tower composter: Effect of air intake holes. *IOP Conference Series: Materials Science and Engineering, 309*(1), Article 012066. https://doi.org/10.1088/1757-899X/309/1/012066

Jahan, S., Ujjaman, S., Rahman, S., Sarker, B. C., Hossain, Z., & Kamal, M. (2022). Physicochemical properties and nutrient contents of compost as influenced by organic wastes and methods of composting. *Journal of the Indian Society of Soil Science, 70*(1), 106-112. https://doi.org/10.5958/0974-0228.2022.00006.8

Kabir, M. Y. (2022). Evaluation of nutrient content of composts made from water hyacinth, kitchen waste and manures. *Journal of Wastes and Biomass Management, 4*(2), 96-101. https://doi.org/10.26480/jwbm.02.2022.96.101

Kumar, V., Pathania, N., Sharma, S., & Sharma, R. (2024). Dynamics of plant nutrient signalling through compost. *The Microbe, 2*, Article 100047. https://doi.org/10.1016/j.microb.2024.100047

Kumar, M., Ou, Y., & Lin, J. (2010). Co-composting of green waste and food waste at low C/N ratio. *Waste Management, 30*(4), 602-609. https://doi.org/10.1016/j.wasman.2009.11.023

Lai, J. C., Then, Y. L., Hwang, S. S., & Lee, C. S. (2024). Optimal aeration management strategy for a small-scale food waste composting. *Carbon Resources Conversion, 7*(1), Article 100190. https://doi.org/10.1016/j.crcon.2023.06.002

Lee, D., Wan, C., Leung, T. C. H., Rundle-Thiele, S., & Li, G. (2024). Application of marketing to reduce consumer food waste in restaurants. *European Journal of Marketing, 58*(7), 1776-1792. https://doi.org/10.1108/EJM-06-2023-0447

Meena, A., Karwal, M., Raghavendra, K. J., & Narwal, E. (2021). Aerobic composting versus anaerobic composting: Comparison and differences. *Food and Scientific Reports, 2*(2), 23-26. https://foodandscientificreports.com/assets/uploads/issues/16139950835__aerobic_composting_versus_anaerobic_composting_comparison_and_differences_compressed.pdf

Melini, F., & Melini, V. (2024). Role of microbial fermentation in the bio-production of food aroma compounds from vegetable waste. *Fermentation, 10*(3), Article 132. https://doi.org/10.3390/fermentation10030132

Nakagiri, K., Sato, Y., & Kawakami, T. (2024). Factors associated with the leftover rate of side dishes in Japanese school lunches. *PLOS ONE, 19*(2), Article e0298691. https://doi.org/10.1371/journal.pone.0298691

Nair, H. T., Nath, G. R., & Perumal, S. (2024). Impact of different organic compost on seed germination and seedling growth performance of mungbean (*Vigna radiata*). *The Indian Journal of Agricultural Sciences, 94*(2), 229-232. https://doi.org/10.56093/ijas.v94i2.136493

Ni'am, M. I., & Yuniati, R. (2021). Effect of lead (Pb) on seed germination of water spinach (*Ipomoea aquatica* Forsk). *Journal of Physics: Conference Series, 1725*(1), Article 012041. https://doi.org/10.1088/1742-6596/1725/1/012041

Noor, R. S., Shah, A. N., Tahir, M. B., Umair, M., Nawaz, M., Ali, A., Ercisli, S., Abdelsalam, N. R., Ali, H. M., Yang, S. H., Ullah, S., & Assiri, M. A. (2024). Recent trends and advances in additive-mediated composting technology for agricultural waste resources: A comprehensive review. *ACS Omega, 9*(8), 8632-8653. https://doi.org/10.1021/acsomega.3c06516

Oliveira, L. M., Mendonça, V., Moura, E. A., Irineu, T. H. S., Figueiredo, F. R. A., Melo, M. F., Celedonio, W. F., Rêgo, A. L. B., Mendonça, L. F. M., & Andrade, A. D. M. (2022). Salt stress and organic fertilisation on the growth and biochemical metabolism of *Hylocereus costaricensis* (red pitaya) seedlings. *Brazilian Journal of Biology, 84*, Article e258476. https://doi.org/10.1590/1519-6984.258476

Safdar, H., Jamil, M., Hussain, A., Albalawi, B. F. A., Ditta, A., Dar, A., Aimen, A., Ahmad, H. T., Nazir, Q., & Ahmad, M. (2022). The effect of different carrier materials on the growth and yield of spinach under pot and field experimental conditions. *Sustainability, 14*(19), Article 12255. https://doi.org/10.3390/su141912255

Sarminingsih, A., Sumiyati, S., Syafrudin, N., Andika, A. F., & Balqis, M. (2023). Effect of variation of eco-enzyme addition on macro nutrient content of compost with biopore infiltration holes. *E3S Web of Conferences, 448*, Article 03035. https://doi.org/10.1051/e3sconf/202344803035

Selvam, A., Ilamathi, P. M. K., Udayakumar, M., Murugesan, K., Banu, J. R., Khanna, Y., & Wong, J. W. C. (2021). Food waste properties. In *Current developments in biotechnology and bioengineering* (pp. 11-41). Elsevier. https://doi.org/10.1016/B978-0-12-819148-4.00002-6

Ugak, M. A. M., Yaser, A. Z., Lamaming, J., Subin, E. K., Rajin, M., Saalah, S., Tze, F. W. H., & Abang, S. (2022). Comparative study on passive aerated in-vessel composting of food wastes with the addition of Sabah ragi. *Carbon Resources Conversion, 5*(3), 200–210. https://doi.org/10.1016/j.crcon.2022.05.004

Wahi, R., Bidin, E. R., Asif, N. M. M., Hamizat, N. A. N., Ngaini, Z., Omar, R., & Jamel, J. (2019). Nutrient availability in sago bark and empty fruit bunch composts for the growth of water spinach and green mustard. *Environmental Science and Pollution Research, 26*(22), 22246-22253. https://doi.org/10.1007/s11356-019-05548-6

Wang, Y., Tang, Y., & Yuan, Z. (2022). Improving food waste composting efficiency with mature compost addition. *Bioresource Technology, 349*, Article 126830. https://doi.org/10.1016/j.biortech.2022.126830

Wei, J., Knicker, H., Zhou, Z., Eckhardt, K., Leinweber, P., Wissel, H., Yuan, W., & Brüggemann, N. (2022). Nitrogen immobilisation caused by chemical formation of black- and amide-N in soil. *Geoderma, 429*, Article 116274. https://doi.org/10.1016/j.geoderma.2022.116274

Whittinghill, L., Jackson, C., & Poudel, P. (2024). The effects of annual compost addition to agricultural green roofs on runoff water quality. *HortScience, 59*(3), 307-322. https://doi.org/10.21273/hortsci17556-23

Xiao, Y., Zeng, G., Yang, Z., Shi, W., Huang, C., Fan, C., & Xu, Z. (2009). Continuous thermophilic composting (CTC) for rapid biodegradation and maturation of organic municipal solid waste. *Bioresource Technology, 100*(20), 4807-4813. https://doi.org/10.1016/j.biortech.2009.05.013

Yin, Y., Liu, Y., Meng, S., Kiran, E. U., & Liu, Y. (2016). Enzymatic pretreatment of activated sludge, food waste and their mixture for enhanced bioenergy recovery and waste volume reduction via anaerobic digestion. *Applied Energy, 179*, 1131-1137. https://doi.org/10.1016/j.apenergy.2016.07.083